In this study, we compared the relationships of body mass index (BMI) and body adiposity index (BAI) with body fat percentage (BF%) in a Caucasian, European population. BF% was measured by dual-energy x-ray absorptiometry in a population-based cross-sectional study of 5,193 middle-aged (47–49 years) and elderly (71–74 years) men and women from the Hordaland Health Study in western Norway from 1997 to 1999. In the total population, the correlation between BAI and BF% was stronger ($r = 0.78$) than the correlation between BMI and BF% ($r = 0.56$) with similar results in the middle-aged and elderly groups. However, in men and women separately, BMI was a better correlate of BF% (for men, $r = 0.76$; for women, $r = 0.81$) than was BAI (for men, $r = 0.57$; for women, $r = 0.72$). BMI was also a better correlate of BF% than was BAI assessed by partial correlations adjusted for sex (for BMI-BF%, $r = 0.79$; for BAI-BF%, $r = 0.67$). Bland-Altman plots and BF%-stratified analyses showed that BAI tended to underestimate BF% in lean subjects and to overestimate it in those with higher proportions of body fat, but that it predicted BF% well for those whose BMI was in a normal range. At the individual level and in population studies adjusted for sex, BMI outperforms BAI as a predictor of BF%.

adiposity; Bland-Altman plots; body adiposity index; body mass index; dual-energy x-ray absorptiometry

Abbreviations: BAI, body adiposity index; BF%, body fat percentage; BMI, body mass index; DXA, dual-energy x-ray absorptiometry; HUSK, the Hordaland Health Study.
that the most important advantage of BAI over BMI is that weight measurement is not needed, but they also emphasized that BAI has several limitations. In a recent study, Freedman et al. (4) suggested that the use of BAI is likely to produce biased estimates of BF% with the errors varying by sex and degree of adiposity.

By using data from the Hordaland Health Study (HUSK), we systematically tested exponentiation for fat mass was 1.9%. The mean difference between BAIHUSK and DXA measurements on the y-axes (BAI – DXA) versus the average of the 2 measurements on the x-axes ((BAI + DXA)/2). The limits of agreement between the 2 methods were defined as mean difference (standard deviation, 1.96) (11). Statistical analyses were performed with PASW Statistics for Windows, version 18.0, software (SPSS, Inc., Chicago, Illinois). Tests of significance were 2-tailed and P ≤ 0.05 was considered significant.

RESULTS

The study included men and women in 2 age groups: a middle-aged group (aged 47–49 years; n = 3,084) and an elderly group (aged 71–74 years; n = 2,109) (Table 1).

For the total population, the correlation between BAI and BF% (measured by using DXA) (r = 0.78) was stronger than the correlation between BMI and BF% (r = 0.56) (Table 2). These correlations were similar when the 2 age groups were examined separately; the correlations between BAI and BF% were 0.77 in the middle-aged group and 0.79 in the elderly group, and the correlations between BMI and BF% were 0.52 in the middle-aged group and 0.62 in the elderly group. However, when stratified by sex, the correlation of BAI with BF% was weakened (for men, r = 0.57; for women, r = 0.72), whereas the correlation between BMI and BF% was strengthened (for men, r = 0.76; for women, r = 0.81). Furthermore, BMI was a better correlate of BF% than was BAI in partial correlations adjusted for sex (BMI-BF%, r = 0.79; BAI-BF%, r = 0.67).

In the total population (Table 2) and in the 2 age groups (data not shown), the 2 anthropometric variables that most strongly correlated with BF%, with the exception of BMI, were hip circumference (positive) and height (inverse). Notably, the correlations for height, waist circumference, and waist/hip circumference ratio with BF% were biased by sex in the total population. Thus, when the analyses were stratified by sex, the correlations changed and the variables most strongly correlated with BF%, in addition to BMI, were waist circumference (r = 0.79) and weight (r = 0.64) in men and waist circumference (r = 0.74) and hip circumference (r = 0.73) in women.

The Bland-Altman plots of the overall agreement between BF% as measured by DXA and predicted by the BAI showed a tendency toward overestimation of BF% by the BAI in subjects with lower BF% and underestimation of BF% in subjects with higher BF% (Figure 1). In both age groups, this trend was stronger in women than in men. Estimation of sex-specific deciles according to BF% revealed that the BAI predicted BF% best for deciles in the normal BMI range of 22.7–24.2 (Table 3). Corresponding data separated for each sex are presented in Web Table 1, available at http://aje.oxfordjournals.org/. Confirming the plots in Figure 1, BAI overestimated adiposity in subjects with lower BF% (particularly in men) and underestimated it in overweight and obese subjects. When optimizing the BAI for the study population in HUSK, the new BAIHUSK (1.66 × hip/height1.2 – 56.21) improved the prediction of BF%, especially at higher adiposity levels (Web Table 2). The mean difference between BAIHUSK and DXA measurements was reduced. Furthermore, BAIHUSK slightly overestimated BF% in overweight and obese subjects and underestimated BF% in normal weight subjects. The waist/hip circumference ratio differed significantly (P < 0.001, analysis of variance) across BMI groups, increasing from underweight (BMI <18.5) to obese (BMI ≥30) subjects.

MATERIALS AND METHODS

HUSK was conducted from 1997 to 1999 as a collaboration of the University of Bergen, the National Health Screening Service, local health services in the Bergen area, and the University of Oslo. Details of the study have been described elsewhere (8). The cross-sectional analyses in the current study were confined to 5,193 men and women belonging to 2 different age groups (born in 1925–1927 and 1950–1952) and with data available on body composition as measured by DXA. All participants gave their written, informed consent. The Regional Committee for Medical Research Ethics of Western Norway approved the study protocol, which conformed to the guidelines of the Declaration of Helsinki.

Height (to the nearest 1 cm) and weight (to the nearest 0.5 kg) were measured while participants were wearing light clothing and no shoes, and BMI was calculated as the ratio of weight in kilograms to the square of height in meters. Waist circumference was measured at the umbilicus to the nearest 1 cm with the subject standing and breathing normally. Hip circumference was measured as the maximum circumference around the buttocks. BAI was calculated as hip circumference (cm)/height (m)1.5 – 18. Body composition was assessed by DXA (9) on a stationary fan-beam densitometer by using EXPERT-XL, version 1.72–1.9, software (Lunar Corp., Madison, Wisconsin). The coefficient of variation for fat mass was 1.9%.

To optimize the BAI for the study population in HUSK (termed BAIHUSK), we systematically tested exponent values between 1.0 and 2.0 to find an initial BAI (hip circumference/height1) with maximum correlation with BF%. We arrived at the exponent 1.2, resulting in an initial definition of BAI as hip circumference/height1.2. Next, linear regression between BF% and the initial BAI was used to estimate the best intercept and slope. The resulting BAIHUSK equation was 1.66 × hip circumference/height1.2 – 56.21.

We used Pearson’s product-moment correlation coefficients to assess correlations between BF% (measured by using DXA) and weight, height, waist circumference, hip circumference, BMI, and BAI. We used a Bland-Altman plot to visually compare the BAI and DXA data (10, 11). The plot shows the difference between the 2 methods on the y-axes (BAI – DXA) versus the average of the 2 measurements on the x-axes ((BAI + DXA)/2). The limits of agreement between the 2 methods were defined as mean difference (standard deviation, 1.96) (11). Statistical analyses were performed with PASW Statistics for Windows.
Table 1. Characteristics of Subjects in the Hordaland Health Study, Hordaland, Norway, 1997–1999

<table>
<thead>
<tr>
<th></th>
<th>Total Population (n = 5,193)</th>
<th>Men (n = 2,204)</th>
<th>Women (n = 2,989)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>No.</td>
</tr>
<tr>
<td>Middle-aged group(^a)</td>
<td>3,084</td>
<td>1.36–2.00</td>
<td>5,190</td>
</tr>
<tr>
<td>Elderly group(^b)</td>
<td>2,109</td>
<td>40.6</td>
<td>978</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.77</td>
<td>1.36–2.00</td>
<td>5,190</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>82.1</td>
<td>48.0–145.0</td>
<td>5,187</td>
</tr>
<tr>
<td>Body mass index(^c)</td>
<td>26.1</td>
<td>15.3–43.8</td>
<td>5,187</td>
</tr>
<tr>
<td>&lt;18.5</td>
<td>57</td>
<td>1.1</td>
<td>5,190</td>
</tr>
<tr>
<td>18.5–24.9</td>
<td>2,391</td>
<td>46.1</td>
<td>831</td>
</tr>
<tr>
<td>25–29.9</td>
<td>2,148</td>
<td>41.4</td>
<td>1,135</td>
</tr>
<tr>
<td>≥30</td>
<td>591</td>
<td>11.4</td>
<td>228</td>
</tr>
<tr>
<td>Body adiposity index(^d)</td>
<td>27.9</td>
<td>16.4–55.9</td>
<td>5,186</td>
</tr>
<tr>
<td>BF% as measured by DXA</td>
<td>32.9</td>
<td>4.1–65.0</td>
<td>5,193</td>
</tr>
<tr>
<td>Waist circumference, cm</td>
<td>87</td>
<td>54–143</td>
<td>5,186</td>
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<tr>
<td>Hip circumference, cm</td>
<td>101</td>
<td>79–144</td>
<td>5,186</td>
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<tr>
<td>Waist/hip circumference ratio</td>
<td>0.86</td>
<td>0.59–1.22</td>
<td>5,186</td>
</tr>
</tbody>
</table>

Abbreviations: BF%, body fat percentage; DXA, dual-energy x-ray absorptiometry.
\(^a\) Middle-aged group: 47–49 years of age.
\(^b\) Elderly group: 71–74 years of age.
\(^c\) Body mass index: weight (kg)/height (m)\(^2\).
\(^d\) Body adiposity index: hip (cm)/height (m)\(^{1.5} – 18\).
Obese subjects had a waist/hip circumference ratio that was on average 0.14 (95% CI: 0.16, 0.13) higher than for underweight subjects.

**DISCUSSION**

The discrepancy between BMI and BF% at the individual level was elegantly illustrated in the report by Yajnik and Yudkin (12), in which the authors had a nearly identical BMI but 1 author had twice the BF% of the other. The BAI emerged as a promising tool, addressing the limitations of BMI as a measure of body fatness (13). In our large Caucasian population, BAI correlated well with BF% as measured by DXA, especially for subjects who were within the normal BMI range. However, BAI overestimated adiposity in subjects with lower BF% and underestimated it in overweight and obese subjects. Also, in men and women...
separately, BMI was a better predictor of BF% than was BAI.

As in the studies by Bergman et al. (3) and Schulze et al. (14), we found that hip circumference and height were the anthropometric measures most strongly correlated with BF% in the total population. As a result, BAI was strongly correlated with BF%. Schulze and Stefan (15) suggested that the strong correlation of hip circumference with BF% (3) may have been caused by overrepresentation of women. Indeed, in our population, inclusion of both sexes distorted the correlations among height, waist circumference, and waist/hip circumference ratio versus BF%. In sex-stratified analyses, hip circumference correlated better with BF% in women, whereas waist circumference correlated better with BF% among men; consequently, BAI performed better in women ($r = 0.72$) than in men ($r = 0.57$), in a manner similar to the findings in 2 other European cohorts (14). We further found that, in both women and men and in the total population adjusted for sex, BMI was a better correlate of BF%. These results confirmed the recent observation by Lopez et al. (5), who used bioimpedance measurements. Another potential problem was that, although BAI predicted BF% well for subjects who were within a normal BMI range, it underestimated BF% in overweight and obese subjects, as

![Figure 1. Comparison of body fat percentage as measured by body adiposity index and dual-energy x-ray absorptiometry for the total population and the 4 age and sex groups in the Hordaland Health Study, Hordaland, Norway, 1997–1999. A) Total population; B) men aged 47–49 years; C) men aged 71–74 years; D) women aged 47–49 years; E) women aged 71–74 years. Bland-Altman plots show the difference between BAI and DXA measurements against the mean of BAI and DXA measurements. The solid lines represent the average difference between BAI and DXA measurements. The dotted lines are the 95% limits of agreement (mean (standard deviation, 1.96)). BAI, body adiposity index; DXA, dual-energy x-ray absorptiometry.](https://academic.oup.com/aje/article-abstract/177/6/586/160459)
observed in other populations (3, 7, 16). This underestimation may be explained by the fact that, as weight increases, the truncal adiposity is not captured well by the increase in hip circumference. In support of this concept, waist/hip circumference ratio increased as BMI increased, indicating that hip circumference does not increase in proportion to waist circumference in obese persons. Importantly, there is evidence that visceral fat, as measured by waist circumference or by waist/hip circumference ratio, is positively associated with risk of coronary heart disease (17), whereas hip circumference is inversely associated with risk of coronary heart disease (18). In the study by Schulze et al. (14), BAI was more weakly associated with diabetes risk compared with BMI and waist circumference among men, whereas the associations were similar for BAI and BMI but weaker compared with waist circumference among women. Thus, BAI based on hip circumference may not adequately predict obesity-related morbidity, but this needs to be further evaluated in comparison with performance of other measures of adiposity.

A major strength of this study is the large population-based sample of white men and women with precise measurements of BF% by using DXA. The sample includes a large range of BMI and BF% values, thus enabling evaluation of BAI in sizable samples within lean, overweight, and obese subjects. Although the narrow age ranges (47–49 years and 70–72 years) limit generalization to other age groups, our findings likely reflect the performance of the BAI in middle-aged and elderly populations.

In summary, BAI correlated with BF% better in women than in men and was outperformed by BMI in both sexes separately. In the combined group of men and women, BAI correlated well with BF% only for subjects who were within the normal BMI range, and BAI had a tendency to underestimate adiposity as BMI increased. These results indicate that, where weight and sex data are available, BMI would be a more accurate measure of adiposity. Optimizing the equation for BAI for our population noticeably improved the association with BF%, but the usefulness of the BAI weakens if a new formula needs to be developed for every population. Because much of the interest in body fat arises from its association with health outcomes such as diabetes, heart disease, and cancer (19, 20), it remains to be seen whether BAI is a more useful predictor of obesity-related morbidity compared with BMI or BF%.

ACKNOWLEDGMENTS

Author affiliations: Department of Nutrition, Institute of Basic Medical Sciences, Faculty of Medicine, University of Oslo, Oslo, Norway (Kathrine J. Vinknes, Christian A. Drevon, Helga Refsum); Department of Pharmacology, University of Oxford, Oxford, United Kingdom (Amany K. Elshorbagy, Helga Refsum); Department of Physiology, Faculty of Medicine, University of Alexandria, Alexandria, Egypt (Amany K. Elshorbagy); Department of Medicine, University of Bergen, Bergen, Norway (Clara G. Gjesdal); Department of Rheumatology, Haukeland University Hospital, Bergen, Norway (Clara G. Gjesdal); Department of Public Health and Primary Health Care, University of Bergen, Bergen, Norway (Grethe S. Tell, Stein E. Vollset); Section for Cardiology, Institute of Medicine, University of Bergen, Bergen, Norway (Ottar Nygård); Department of Heart Disease, Haukeland University Hospital, Bergen, Norway (Ottar Nygård); and Division of Epidemiology, Norwegian Institute of Public Health, Oslo, Norway (Stein E. Vollset).

This work was supported by the Advanced Research Programme of Norway; the Research Council of Norway; the Norwegian Rheumatism Association; the Johan Throne
Holst Foundation for Nutrition Research; and the University of Oslo, Norway.
No funding bodies were involved in the study design, collection, analyses, interpretation of the data, or preparation of the manuscript.
Conflict of interest: none declared.

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