CLINICAL STUDY

Superiority of skinfold measurements and waist over waist-to-hip ratio for determination of body fat distribution in a population-based cohort of Caucasian Dutch adults

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Abstract

Objective: To determine which anthropometric measurement is the most reliable alternative for fat distribution as measured by dual-energy X-ray absorptiometry (DXA).

Design: Population-based survey carried out in Amsterdam, The Netherlands.

Subjects and methods: A total of 376 individuals (200 women) with a mean age of 36.5 years and mean body mass index (BMI) of 24.0 (±3.1) kg/m² underwent various anthropometric and DXA measurements of central (CFM) and peripheral fat mass (PFM). Furthermore, for the assessment of apple-shaped body composition, CFM-to-PFM ratio was calculated. Anthropometric measurements were waist and hip circumference, waist-to-hip ratio (WHR), BMI, waist/length and the skinfold thickness of biceps, triceps, suprailiacal (SI), subscapular (SS) and upper leg. We determined whether equations of combined anthropometrics were even more reliable for the assessment of fat mass.

Results: In both women and men, reliable alternatives for CFM are central skinfolds and waist (Pearson’s correlation (r) ≥0.8). Peripheral skinfolds are the best predictors of PFM (r≥0.8). In contrast, WHR correlated only marginally with any of the DXA measurements. Equations based on several anthropometric variables correlate with CFM even better (R²≥0.8). CFM-to-PFM ratio has the highest correlation with the ratio (SS+SI)/BMI in women (r=0.66) and waist/length in men (r=0.71). Equations are reasonable alternatives of CFM-to-PFM ratio (R²≥0.5).

Conclusion: Waist and skinfolds are reliable alternatives for the measurement of body fat mass in a cohort of Caucasian adults. WHR is not appropriate for the measurement of fat distribution.

Introduction

Central fat mass (CFM) is increasingly recognized as an independent risk factor for cardiovascular disease (1–5) and metabolic disease as well as overall mortality. In contrast, peripheral fat mass (PFM) may independently contribute to a lower risk for cardiovascular disease (4–10). Therefore, measuring fat distribution, i.e. CFM/ PFM ratio, is a topic of great interest, especially population-based cohort studies, in which large numbers of subjects are measured, simple anthropometric measurements are needed to determine fat distribution. Dual-energy X-ray absorptiometry (DXA) is a well-accepted method and has a good concordance with computed tomography (CT) for the assessment of body fat (11). However, CT and DXA are costly and time consuming. Moreover, these techniques involve exposing the subject to ionizing radiation. As a consequence, the use of these techniques cannot be extended to studies that involve large numbers of subjects. In these kinds of studies, body mass index (BMI, for overall body fatness) and waist-to-hip ratio (WHR, for body fat distribution) are most often used (12). There is doubt whether WHR, which is partly dependent on pelvic skeletal structure and muscle distribution, is a valid anthropometric measure for the assessment of body composition (13–15). Measurement of skinfold thickness in combination with waist circumference may be reasonable alternatives. However, there are no larger studies so far that correlate both skinfold measurements and waist circumference with DXA for determining body fat. Therefore, the purpose of the present study was to assess the predictive value of various simple anthropometric measures of body fat compared with DXA measurements in a population-based cohort of Dutch Caucasian adults.

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Besides the commonly used anthropometric and DXA measures for the estimation of CFM, we had particular interest in ratios. Since CFM is positively and PFM is negatively correlated with cardiovascular disease, the CFM-to-PFM ratio might be a stronger predictor for the assessment of cardiovascular risk. The CFM-to-PFM ratio is known to be associated with increased risk of mortality (16, 17). Furthermore, we analysed a number of skinfold ratios which have been associated with cardiovascular risk factors in previous studies (18–21). In addition, we aimed to develop easy-to-use regression equations consisting of various combinations of anthropometric measurements that predict body fat distribution as measured with DXA.

Methods

Subjects and design

The Amsterdam Growth and Health Longitudinal Study (AGAHLS), which started in 1976, was designed to investigate the development of indicators of growth and health in a cohort of Dutch adolescents. For that purpose, 615 healthy boys and girls were recruited from two secondary schools in and around Amsterdam. All participants were born between 1961 and 1965, and were residents of the Netherlands. In 2000, at a mean age of 36 years, 376 Caucasian subjects (200 women) visited the Vrije Universiteit for assessment of, amongst others, anthropometrics and DXA. More detailed information about the AGAHLS has been described in previous publications (19, 22, 23). The Medical Ethical Committee of the Vrije Universiteit Medical Centre approved the protocol. All subjects gave informed consent.

Data collection

A whole-body DXA scan was performed using the Hologic QDR-2000 (S/N 2513; Hologic Inc., Waltham, MA, USA). With the use of specific anatomic landmarks, regions of the head, trunk, arms and legs were distinguished as shown in Fig. 1. Total body fat, fat mass of the trunk, legs and arms (kg) were used for analysis. Fat mass of the trunk, further referred to as CFM, includes both the subcutaneous and the visceral fat of this anatomical region. PFM was estimated by the sum of the fat mass of both arms and legs. Furthermore, the CFM-to-PFM ratio was calculated.

Anthropometric measurements of body height, body mass, waist-hip and skinfolds were performed according to standard procedures (19). BMI was calculated by dividing body mass (kg) by body height squared (m²).

Skinfolds were measured with a Harpenden caliper (Holtain, UK) to the nearest 0.1 mm according to the recommendations of the International Biological Programme (24). Measurements were performed according to standard procedures (25, 26) and with the same instruments throughout the study. Over the entire period of study, one trained examiner performed the measurements of the skinfolds. The DXA and skinfold measurements were done on the same day. The correlation coefficients were calculated for every skinfold. For the single skinfolds, these reproducibility coefficients were ≥0.8.

The following skinfolds were measured: subscapular (SS), suprailiacal (SI), biceps (BI), triceps (TRI) and upper leg (LEG). Two measurements were performed and the mean was used for the analyses. For the assessment of CFM, the skinfolds SS and SI and the sum of these were used. Several combinations of skinfolds were calculated to assess PFM: BI + TRI + LEG, BI + TRI, TRI + LEG, BI + LEG and LEG. The anthropometrics that
were correlated best with either central or peripheral fat as measured with DXA were used to calculate CFM-to-PFM ratios. In women, the ratio (SS + SI)/BMI, and in men, the ratio waist/(BI + TRI) were calculated. Two other well-known ratios were used for analysis: SS/(SS + TRI) (20) and SS/TRI (18). Furthermore, the best correlated central-to-peripheral skinfold ratio was also analysed (i.e. (SS + SI)/(TRI + LEG)).

To determine WHR, we measured the circumferences of the waist (at umbilicus height) and hip (at the level of widest circumference over the buttocks) with a flexible steel tape to the nearest 0.1 cm.

**Statistical analysis**

Data were analysed with a statistical software package (SPSS 11 for Windows, SPSS Inc., Chicago, IL, USA). Results are given as means ± s.d. The Pearson correlation coefficient ($r$) was calculated to estimate the predictive value of various anthropometrics. To assess significance, a $P < 0.05$ was considered to be statistically significant. For multiple comparisons, the significance level was adjusted by multiplying the number of comparisons of each DXA measurement according to Bonferroni correction (27). Linear regression analysis was used to develop equations containing anthropometric measurements, which correlate with body fat distribution. The anthropometric measurements of body fat considered were (the combination of) skinfolds, waist or hip circumference, BMI, WHR, waist-to-length ratio, weight and length; and the DXA measurements considered were CFM and CFM-to-PFM ratio. Selection of variables was done in a forward stepwise fashion with strict variable entry ($P < 0.05$) and elimination criteria ($P ≥ 0.05$). Comparing $R^2$ values of the models obtained from each set assessed the associative value of each set of measurements. Incremental additive value was judged by the increase in $R^2$ obtained when anthropometric measurements were added to the model. Three types of association models of CFM and CFM-to-PFM ratio were constructed (Table 3). The first type is developed for situations in which skinfold measurements are not available. The second type is the first equation combined with the best associative skinfold. The third equation represents the optimal model. All analyses were performed separately for males and females.

**Results**

Characteristics of the study group are presented in Table 1 and Fig. 2. Fourteen women and eight men refused to undergo DXA measurements, resulting in minor loss of subjects.

**Women**

Table 2 shows the correlation coefficients regarding the anthropometric indices and DXA measurements for both men and women. CFM is highly correlated with the sum of two skinfolds SS + SI ($r = 0.82$), skinfold SS ($r = 0.82$), BMI ($r = 0.82$) and waist ($r = 0.82$). BMI has a good correlation with both CFM and PFM. The ratio CFM-to-PFM, determined by DXA, is correlated best with the ratio (SS + SI)/BMI ($r = 0.66$) and SS + SI ($r = 0.65$). The skinfold ratio (SS + SI)/(TRI + LEG) has a correlation coefficient of 0.62. Just as CFM, PFM shows good correlations with anthropometry: BMI ($r = 0.85$), weight ($r = 0.84$), BI + TRI ($r = 0.82$) and BI + TRI + LEG ($r = 0.82$). In contrast, WHR correlates only marginally with any of the DXA ratios.

**Men**

Just as in women, CFM in men is highly correlated with waist ($r = 0.85$) and the skinfold SS + SI ($r = 0.84$) (Table 2). In contrast to women, waist/length ($r = 0.71$) has the highest correlation with CFM-to-PFM ratio. Correlations of PFM with anthropometry are slightly lower in men than in women; the best relation is found with the same combination of skinfolds as in women: BI + TRI + LEG ($r = 0.78$) and BI + TRI ($r = 0.78$). As in women, WHR correlates only marginally with any of the DXA ratios.

**Table 1** Descriptive statistics for age, height, body mass, body mass index (BMI) and waist-to-hip ratio (WHR).

<table>
<thead>
<tr>
<th></th>
<th>Women ($n=200$)</th>
<th></th>
<th>Men ($n=176$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>s.d.</td>
<td>Range</td>
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<td>21.2–24.9</td>
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<td>Waist (cm)</td>
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<td>8.4</td>
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<tr>
<td>Hip (cm)</td>
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<tr>
<td>WHR</td>
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<td>0.1</td>
<td>0.8–0.8</td>
</tr>
</tbody>
</table>

DXA, dual-energy X-ray absorptiometry; CFM, central fat mass; PFM, peripheral fat mass; s.d., standard deviation.

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Linear regression analyses

As shown in Table 3, association models consisting of simple anthropometric measurements are a good alternative for the measurement of CFM. The optimal model of CFM in women is a combination of waist, BMI, hip circumference and the skinfold SS, which accounted for 82% of the variance in CFM measured by DXA ($R^2 = 0.82$). In men, the combination of waist, BMI and SS + SI is the best correlation with CFM ($R^2 = 0.83$). In both women and men, a reliable model of simple anthropometric measurements, when skinfolds are not available, is the combination of waist and BMI ($R^2 = 0.75$ and $R^2 = 0.77$ respectively). The additional variance explained when the skinfold SS is added to the models was 4 and 5% respectively ($R^2 = 0.79$ in women and $R^2 = 0.82$ in men). The optimal model of CFM-to-PFM ratio for women and men is the combination of the following anthropometrics: the waist/length ratio and the skinfold ratio [(SS/SCI)/(TRI/LEG)]; $R^2 = 0.50$ and $R^2 = 0.56$ respectively. Simple, commonly used anthropometric measurements, such as waist and BMI, account for 30% in women and 38% in men of the variance in CFM-to-PFM ratio measured by DXA. The skinfold ratio (SS/SCI)/BMI in women and the skinfold ratio (SS/SCI)/(TRI/LEG) in men explained a further 17 and 12% of variance respectively ($R^2 = 0.47$ and $R^2 = 0.50$ respectively).

Discussion

The results of this study indicate that in a population-based cohort of Dutch Caucasians, CFM and PFM
Women
CFM

-18.53 + 0.20 waist + 0.51 BMI
-12.90 + 0.13 waist
+0.36 BMI + 0.23 (SS)
-17.67 + 0.13 waist + 0.16 BMI
+0.11 hip circumference + 0.20 (SS)

Men

-33.00 + 0.34 waist + 0.48 BMI
-25.40 + 0.25 waist + 0.32 BMI
+0.31 (SS)
-22.80 + 0.22 waist
+0.31 BMI + 0.16 (SS + SI)

CFM/PFM

Women

Waist + BMI

-0.21 + 0.01 waist + 0.25 ((SS + SI)/BMI)
-0.17 + 1.35 (waist/length)
+0.37 ((SS + SI)/(TRI + LEG))

Men

-1.25 + 0.01 waist + 0.04 BMI

-1.17 + 0.02 waist + 0.22 ((SS + SI)
/(TRI + LEG))
-1.42 + 4.36 (waist/length)
+0.29 ((SS + SI)/(TRI + LEG))

Table 3 Association models containing simple anthropometrics correlated with central fat mass and body fat distribution (i.e. central (CFM)-to-peripheral fat mass (PFM) ratio) measured with dual-energy X-

| R² |

measure by DXA were highly correlated with central and peripheral skinfolds respectively. Waist circumference is a good alternative for the assessment of CFM measured by DXA. In addition, BMI and weight had a good correlation; however, these measurements do not differentiate between central or peripheral fat measured by DXA. The (SS + SI)/BMI ratio in women and the waist/leg ratio in men are the best anthropometric alternative for CFM-to-PFM ratio. WHR does not seem appropriate for the DXA measurement of body fat mass. Equations based on several anthropometric variables are correlated with CFM, PFM and CFM-to-PFM ratio even better.

For the determination of central adiposity, DXA CFM is most commonly used. Clearly, DXA CFM is related with cardiovascular factors (2, 9, 28). Commonly used standards for defining central versus peripheral adiposity do not yet exist.

Central and peripheral measurements and, to a lesser extent, DXA ratios are often used for the determination of fat distribution (2, 4, 5, 9, 29). Due to the importance of body fat distribution, specifically central in relation to peripheral fat, the use of DXA ratios does seem interesting. Moreover, several studies showed correlations of DXA ratios with cardiovascular risk factors (5, 17). DXA derived ratios in this study were aimed at partitioning trunk fat from the remainder of the body. The ratio (trunk/(arms + legs)) segments the body into central and peripheral portions.

Traditionally, skinfold thickness has been used for the assessment of body composition. Central skinfolds, mainly the SS skinfolds (30), are positively linked to cardiovascular risk factors in contrast to peripheral skinfolds, which are negatively related to cardiovascular disease (31, 32). Skinfold ratios have been widely used for the assessment of fat distribution (17, 19, 20, 33) and correlate well with several factors of cardiovascular disease (18). Our study shows that these skinfold ratios are moderately correlated with CFM-to-PFM ratio, as measured with DXA. As far as we know, the specific skinfold ratio (SS + SI)/BMI, which we found to be the best anthropometric alternative for CFM-to-PFM ratio, has not yet been correlated with cardiovascular disease. The possible usefulness in the context of a relationship with cardiovascular disease needs to be shown in future studies. So far, each of the individual parameters of which this ratio consists is related to cardiovascular risk factors.

Weight, which is easy to measure and investigator independent, does not make any differentiation between CFM and PFM. Moreover, weight alone does not represent a person’s body fat mass, if one is not taking length into account. BMI, WHR and waist circumference are all markers of body composition and therefore considered as predictive measurements for cardiovascular disease. BMI, a ratio of weight and length, is often used and assumed to represent the degree of body fat (and muscle in adolescents), but does not capture body fat distribution (34). In particular, WHR is considered the traditional anthropometric technique for assessing CFM-to-PFM ratio (12). It is widely used and established in cross-sectional (35), longitudinal (36) and intervention studies, and it is a robust predictor of disease risk and mortality (35, 37, 38). In this context, WHR, rather than BMI, has therefore recently been recommended for the assessment of body fatness (38). However, in the present study, we could not validate WHR against DXA data for the distribution of body fat. The likely explanation for this is that WHR, being largely dependent on pelvic bone structures, contains variability that makes differentiation between distribution of fat and fat-free tissues less accurate and thus less reliable (39, 40). In this context, the importance of waist instead of WHR has recently been recognized (29, 41, 42). Remarkably, the waist circumference, however, is not always a stronger predictor of cardiovascular risk than the WHR (34). In the present study, the waist indeed showed good relation with CFM.

Skinfolds and waist circumference are easy to perform in daily practice, cost effective, non-invasive, non-time consuming and widely applicable, especially for large cohort studies. Moreover, with respect to skinfolds, different sites of the body can be measured, which is an advantage in the assessment of body fat distribution.
A limitation of the present study is that mostly lean persons (BMI ≤2.5) were measured (151 women and 101 men), who might not have an increased risk of cardiovascular diseases because of their weight. However, people with a BMI in the normal weight range can still be at increased risk of metabolic disturbances if their WHR or waist circumference is increased. To obtain an impression as to whether the results could be applicable to an overweight population, the analyses were done on a subset of individuals (BMI between 2.5 and 3.0, n = 99 (36 women)). Just as in the entire cohort, in overweight women, DXA CFM was highly correlated with central skinfolds (SS + SI; r = 0.84). Peripheral skinfolds were correlated slightly less with DXA PFM (BI + TRI; r = 0.69), whereas the skinfolds ratios were correlated slightly higher with DXA ratio ((SS + SI)/(TRI + LEG); r = 0.72). In overweight men, DXA CFM was highly correlated with waist circumference (r = 0.83). Of the skinfold measurements, SS + SI had the highest correlation r = 0.69. The waist/length ratio in men was again the best anthropometric alternative for CFM-to-PFM ratio (r = 0.69). As in the entire cohort, WHR does not seem appropriate for the measurement of body fat mass distribution (r ≤0.4).

Since our study was underrepresented for the purpose of the prediction of body fat distribution in an obese population (BMI > 30), this needs further investigation.

Another limitation of the study is that the study group was Caucasian. Ethnic variation of body fat distribution is well known. Black women, for example, have more bone and muscle mass, but less fat as a percentage of body weight than white women, after controlling for ethnic differences in age, body weight and height. Therefore, heterogeneity of waist circumference (44) and skinfold (45) cut-off points have been reported. Conclusions derived from the present study should only be used in Caucasian populations.

It should be noticed that our results are applicable on a population level. Since DXA is expressed in kilograms and skinfolds in millimetres, the Bland–Altman analysis with standardized s.d. of DXA and anthropometrics, to circumvent problems with different units of the measurements, will not gain more information than Pearson’s correlation (46). In conclusion, our study suggests that for predicting central and peripheral body fat mass, anthropometric measurements such as waist circumference and skinfolds are good alternatives in large epidemiological studies that do not allow application of DXA or CT. In daily practice, for the assessment of CFM-to-PFM ratio, the ratio (SS + SI)/BMI in women and the waist/length in men are the best alternatives. According to our study, WHR should not be used to determine fat distribution. These findings might improve the prediction of diabetes and cardiovascular risk in men and women in future studies. Therefore, longitudinal data must be collected to establish the value of waist circumference and skinfold thickness.

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Waist and skinfold for body fatness