

Body mass index, waist girth, and waist-to-hip ratio as indexes of total and regional adiposity in women: evaluation using receiver operating characteristic curves¹⁻³

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ABSTRACT Receiver operating characteristic (ROC) curves were constructed to assess the value of body mass index (BMI) as a screening measure for total adiposity and to examine waist-to-hip ratio (WHR) and waist circumference as measures of central fat distribution. Body fat reference measurements were determined by dual-energy X-ray absorptiometry (DXA). The study population comprised 96 healthy white women aged 16–80 y. A positive reference test was defined as a result at or above the 75th percentile for our study population for all DXA measurements. Sensitivity and specificity were calculated at several percentile cutoffs for BMI, WHR, and waist girth. The areas under the ROC curves were calculated to compare the relative ability of each anthropometric technique to correctly classify subjects according to the reference measurement for that technique. BMI (our 75th percentile = 27.3) performed well as a screening measure of total adiposity, correctly identifying 83% of subjects with a high body fat mass while misclassifying only eight subjects [four false-negatives (subjects with high fat mass who were in the low BMI category) and four false-positives (subjects with a low fat mass who were in the high BMI category)]. The screening performance of WHR (our 75th percentile = 0.81) was lower, accurately categorizing 58% of subjects while misclassifying 28 subjects. By contrast, waist circumference (our 75th percentile = 86.9 cm) was significantly better than WHR at screening for regional fat distribution, accurately classifying 83% of subjects and misclassifying eight subjects ($P < 0.05$). We conclude that BMI and waist circumference provide simple yet sensitive methods for the estimation of total and central adiposity in groups of adult women. *Am J Clin Nutr* 1998;67:44–9.

KEY WORDS ROC curve, receiver operating characteristic curve, WHR, waist-to-hip ratio, DXA, dual-energy X-ray absorptiometry, regional fat distribution, adiposity, women, waist circumference, body mass index

INTRODUCTION

Anthropometric indexes such as the body mass index (BMI) and waist-to-hip ratio (WHR) remain the most commonly used tools for assessing body composition because of their simplicity and low cost (1). However, these measurements also include lean tissue and bone and therefore are not direct measures of fat content. By contrast, dual energy X-ray absorptiometry (DXA) accurately measures total body

fat and also quantitates regional fat in the central (android) and hip and thigh (gynoid) areas (2). Thus, DXA can assess total and central fat deposition, uncompromised by bone and lean tissue content.

BMI and WHR measurements are used frequently to identify subjects as being above or below a certain cutoff that denotes increased metabolic risk (3, 4). The identification of the appropriate cutoff can be determined by using receiver operating characteristic (ROC) curves. ROC curves determine the efficacy of a screening measure to correctly identify subjects on the basis of their classification by a reference or gold standard test. Sensitivity (proportion of subjects classified as “positive” by both the screening and reference tests) and specificity (proportion of subjects classified as “negative” by both tests) are calculated over a range of cutoffs for the screening measure. This calculation identifies the optimal point that minimizes the number of participants misclassified while ensuring that most subjects are correctly identified (5). A false-positive is defined as a subject classified as positive for the screening measure but negative for the reference test, whereas a false-negative (1-specificity) is defined as a subject classified as negative for the screening measure and positive for the reference test.

The aims of the present study were first to evaluate the use of BMI and WHR as indicators of total and regional adiposity in adult women; second, to determine whether differences existed in the ability of waist circumference and WHR to accurately detect central adiposity; and third, to compare the use of manual with automatic analysis of regional fat distribution in DXA scanning.

SUBJECTS AND METHODS

Subjects

Ninety-six healthy white women aged 16–80 y were recruited by advertisement: 78 women aged 41–80 y participated in a study evaluating lactose malabsorption and bone density and 18 young

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women aged 16–19 y were involved in a nutritional study of body composition. None of the subjects were taking any medication that would affect bone metabolism. Both studies were approved by the Ethics Committee of the Southern Regional Health Authority and informed written consent was obtained from each subject.

Anthropometry

A short medical history was taken by questionnaire. Height was measured to the nearest mm with a wall-mounted stadiometer, weight was measured to the nearest 0.5 kg with standard scales, and BMI (in kg/m²) was calculated. Waist and hip girths (cm) were measured with an anthropometric tape over light clothing. Waist girth was measured at the minimum circumference between the iliac crest and the rib cage and hip girth at the maximum width over the greater trochanters. WHR was then calculated.

DXA scanning

DXA measurements of total and regional body fat were taken with a Lunar DPX-L scanner (Lunar Corporation, Madison, WI) and analyzed with software version 1.3y. The DXA scanner determines total fat mass (kg) and the fat content (kg) of specific anatomical regions of the body (arms, legs, and trunk) (2) as shown in **Figure 1** (the automatic default regions). The trunk region consists of the tissue area bordered by a horizontal line below the chin, vertical borders lateral to the ribs, and oblique lines passing through the femoral necks. The leg region includes all tissue below these oblique lines (6). The trunk-to-leg fat ratio (TLFR) was calculated as trunk fat (kg) divided by leg fat (kg). A manual analysis of regional fat distribution was also completed by using the method of Ley et al (7), also shown in Figure 1. Two regions of interest were defined, the manual waist region was a box 9.6 cm high with the lower border positioned superior to the iliac crest, and the manual

hip region was a box of the same width, positioned so that the center of the box was at the level of the greater trochanters. The waist-to-hip fat ratio (WHFR) was calculated as manual waist fat (kg) divided by manual hip fat (kg) from these manually drawn boxes. Total percentage fat determined by DXA was calculated as [fat mass/(fat mass + lean tissue mass + bone mineral content)] × 100/1. The CVs (%) for scanning precision completed on 10 consecutive scans of a subject were 2.6% for fat mass (kg), 2.5% for total body percentage fat, and <3.5% for all regional measurements.

Statistical analysis

All statistical analyses were performed with SPSS 4.04 for the Macintosh (Language Systems Corp, Chicago) and STATA Statistical Software Release 5.0 (STATA Corp, College Station, TX). Age trends were analyzed by one-way analysis of variance followed by Duncan's new post hoc tests for individual group comparisons. Spearman rank correlation coefficients were used to assess associations between anthropometric and DXA data. ROC curves were constructed by the method of Lazarus et al (5). The reference DXA measurements used were as follows: total fat (kg and % body wt), trunk fat (kg) and TLFR, and waist fat (kg) and WHFR, respectively. All DXA and anthropometric measurements were adjusted for age by linear regression. The residual value for each subject from the regression was divided by its SE to give a studentized residual. These residuals were then converted into percentile values (5). The 75th percentile for each age-adjusted DXA measurement estimated from the data was defined as the cutoff for identifying a subject as truly positive. Sensitivity and specificity were calculated at various percentile cutoffs (5th, 15th, etc, up to the 95th) for the screening measures, and ROC curves were then constructed. The point on a ROC curve closest to a sensitivity of 100% and a 1-specificity of 0% provides the optimal cutoff. In practice, this generally represents the point closest to the upper left corner of the ROC curve (5).

In addition, the areas under each ROC curve (AUCs) were calculated by using the logistic procedure in STATA in which the AUC is determined by integration. A bootstrapping procedure was used to estimate the 95% CI and to test for differences between the areas of particular curves (8). The AUCs of the six curves described in **Table 1** were derived and the differences of interest between the curves calculated. This was repeated 1000 times altogether by using the bootstrapping procedure provided by STATA, giving a distribution for each area and difference. In effect, the differences were paired, which was appropriate because the measures were likely to be correlated. Bias-adjusted 95% CIs were provided by the bootstrapping procedure and are presented for both the AUCs and the differences of interest. Values for each AUC can be between 0 and 1. A value of 0 indicates that the screening measure does not perform well whereas a value of 1 implies perfect performance. The AUC has been described as the probability that a test will correctly identify a pair of patients with and without a disease who were randomly selected from the population. An AUC of 0.5 means that the diagnostic test is no better than chance. Obviously, values >0.5 are more desirable (9).

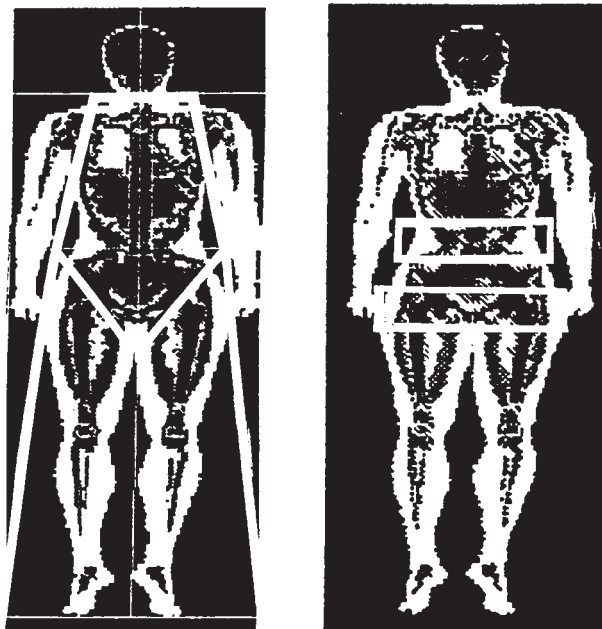


FIGURE 1. Automatic and manually drawn regions of interest for body fat distribution by dual-energy X-ray absorptiometry. In the left panel is shown the central region separated from the leg region by oblique lines passing through the femoral neck. In the right panel are shown the waist and hip regions by manual analysis.

RESULTS

Weight, BMI, percentage fat, WHR, TLFR, and WHFR tended to be higher in older age groups ($P < 0.01$ for trend), whereas height was on average the lowest in the women aged 71–80 y

TABLE 1
Areas under the receiver operating characteristic (ROC) curves¹

ROC curve	Area	95% CI
1: BMI and total fat (kg)	0.98 ²	0.95, 0.99
2: BMI and total fat (%)	0.96	0.91, 0.99
3: WHR and TLFR	0.73 ³	0.62, 0.84
4: WHR and WHFR	0.84 ⁴	0.74, 0.92
5: Waist circumference (cm) and trunk fat (kg)	0.92 ⁵	0.85, 0.97
6: Waist circumference (cm) and waist fat (kg)	0.96 ⁶	0.92, 0.99

¹ WHR, waist-to-hip ratio; TLFR, trunk-to-leg fat ratio; WHFR, waist-to-hip fat ratio.

²⁻⁶ Differences between curves (95% CIs for the difference): ² difference between curves 1 and 2 = 0.02 (-0.01, 0.09), ³ difference between curves 3 and 4 = 0.11 (0.02, 0.22), ⁴ difference between curves 4 and 6 = 0.12 (0.04, 0.22), ⁵ difference between curves 3 and 5 = 0.19 (0.07, 0.32), ⁶ difference between curves 5 and 6 = 0.04 (0.01, 0.12).

($P < 0.01$ for trend) (Table 2). The heterogeneity of the population was reflected in the wide variability noted for each body-composition variable.

Simple correlations between BMI and DXA measures of total body fat were high [BMI and total body fat (kg), $r = 0.91$; BMI and total body fat (%), $r = 0.84$] and did not change significantly after adjustment for age (0.94 and 0.79, respectively). Correlations between waist girth (cm) and trunk fat (kg) or waist girth (cm) and waist fat (kg) were also high ($r = 0.89$ and $r = 0.92$, respectively). However, lower correlations were noted between WHR and TLFR ($r = 0.62$) and WHR and WHFR ($r = 0.78$).

The ROC curves for BMI and total body fat in kg or as a percentage of body weight (total percentage fat) are shown in Figure 2. The difference in area between the two curves was not significant. The 75th percentile for BMI resulted in a high sensitivity of 83% and a specificity of 94% compared with both DXA indexes. The point on the ROC curve closest to 1 corresponded to the 70th percentile for BMI, illustrating higher sensitivity [92% for total fat (%) and 96% for total fat (kg)] and slightly lower specificities (90% and 92%, respectively, data not shown).

The ROC curves for WHR compared with two DXA indexes of regional adiposity (TLFR and WHFR) are shown in Figure 3. We obtained a true-positive rate of 0.42 (10 of 24 subjects), a false-positive rate of 0.58 (14 of 24 subjects), and a false-negative rate of 0.19 (14 of 72 subjects) when TLFR was used as the reference test. The use of WHFR as the reference test improved the true-

positive (14 of 24 subjects, 0.58), false-positive (10 of 24 subjects, 0.42), and false-negative (10 of 72 subjects, 0.14) rates.

The use of waist circumference as the screening test resulted in higher sensitivity with either DXA reference test (67% for trunk fat and 83% for waist fat) than the sensitivity observed when WHR was the screening measurement (Figure 4). Moreover, specificity was also higher (89% for trunk fat and 94% for waist fat).

The AUCs and their 95% CIs are shown in Table 1. The areas calculated by comparing BMI with total body fat were high, as were those obtained for waist circumference compared with DXA measurements of regional fat distribution. The areas calculated for WHR were somewhat lower. Furthermore, ROC curve areas were significantly larger for waist circumference than for WHR (0.92–0.96 compared with 0.73–0.84, $P < 0.05$). The use of manual regions yielded higher AUCs than the automatic default regions for both WHR and waist circumference.

DISCUSSION

Our results support earlier work showing that considerable differences are observed in total and regional body composition with age in white women (7, 10, 11). Body fat as a percentage of body weight was higher in older age groups and the increased WHR and TLFR values indicated a more central fat distribution. The tendency for a more central body shape to develop with age in women is well established (10, 12), although the exact mechanisms for this tendency remain unclear. The development of this body shape may be attributed in part to the loss of estrogenic activity that occurs during menopause, as research has shown that women undergoing hormone replacement therapy do not experience the adverse changes in regional body fat distribution typically seen in women not taking hormone replacement therapy (13). Declining physical activity may also enhance a more central shape; Davy et al (14) found that middle-aged women undergoing endurance exercise training did not show the altered regional fat deposition shown by their sedentary counterparts.

The 75th percentile for BMI in our population (which corresponded to a BMI of 27.3) correctly identified 83% of the women with a high body fat percentage and misclassified only 8 of 96 subjects (4 false-positives and 4 false-negatives). At the 70th percentile for BMI (26.4), sensitivity was higher (92%) but slightly more subjects were misclassified (7 false-positives and 2 false-negatives). The choice of the most appropriate cutoff depends on the relative importance placed on maximizing sensi-

TABLE 2
Characteristics of the study population¹

Age (y)	Weight	Height	BMI	Percentage fat	WHR	TLFR	WHFR
	kg	m	kg/m ²	%			
16–19 ($n = 18$)	60.7 ± 6.3 ^b	1.67 ± 0.05 ^a	21.9 ± 2.3 ^a	30.0 ± 5.7 ^a	0.73 ± 0.04 ^a	1.01 ± 0.20 ^d	0.57 ± 0.13 ^a
41–50 ($n = 20$)	68.3 ± 11.0 ^{ab}	1.64 ± 0.06 ^{ab}	25.2 ± 3.1 ^b	35.6 ± 7.8 ^b	0.78 ± 0.05 ^b	1.11 ± 0.33 ^{ad}	0.67 ± 0.18 ^a
51–60 ($n = 20$)	72.7 ± 16.9 ^a	1.63 ± 0.05 ^{ab}	27.2 ± 5.3 ^b	40.6 ± 6.4 ^b	0.79 ± 0.05 ^b	1.38 ± 0.34 ^b	0.81 ± 0.15 ^b
61–70 ($n = 20$)	67.8 ± 13.4 ^{ab}	1.62 ± 0.05 ^b	25.8 ± 5.4 ^b	38.4 ± 7.8 ^b	0.81 ± 0.06 ^b	1.36 ± 0.37 ^b	0.78 ± 0.14 ^b
71–80 ($n = 18$)	62.4 ± 8.9 ^b	1.58 ± 0.04 ^c	24.9 ± 3.6 ^b	39.0 ± 10.1 ^b	0.80 ± 0.07 ^b	1.29 ± 0.45 ^{ab}	0.76 ± 0.17 ^b
All ($n = 96$)	66.6 ± 12.5	1.63 ± 0.06	25.1 ± 4.4	36.8 ± 8.4	0.78 ± 0.06	1.23 ± 0.38	0.72 ± 0.18
Range	46–115	1.52–1.73	16.5–39.3	13.8–51.9	0.67–0.98	0.54–2.58	0.32–1.17

¹ $\bar{x} \pm$ SD. WHR, waist-to-hip ratio; trunk-to-leg fat ratio (TLFR) = trunk fat (kg) divided by leg fat (kg); waist-to-hip fat ratio (WHFR) = waist fat (kg) divided by hip fat (kg). Age trends analyzed by one-way ANOVA after log-transformation of the data, $P < 0.05$. Means in a column with different superscript letters are significantly different, $P < 0.05$.

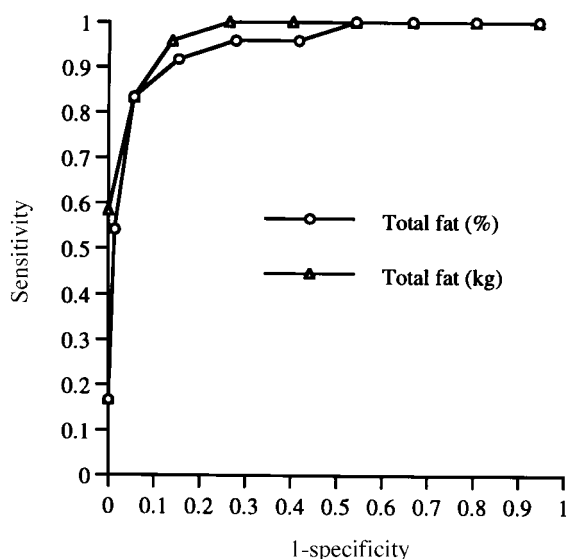


FIGURE 2. Receiver operating characteristic curve comparing body mass index with total body fat by dual-energy X-ray absorptiometry.

tivity or specificity. Nevertheless, the high AUCs obtained for these comparisons strongly support the use of BMI as an index of adiposity in groups of adult women. To our knowledge, only two other papers have published ROC curves comparing BMI with body fat: one in adults (15) and one in children (5). A sensitivity of only 27% was shown with a cutoff of BMI > 27 by Hortobagyi et al (15), with a specificity of 98%. However, Hortobagyi et al defined obesity as a percentage body fat of > 30% (using hydrodensitometry) whereas we used the 75th percentile cutoff for our study population. Only 26% of the current study subjects had a body fat percentage < 30% and our 75th percentile corresponded to a value of 43%. Either a large proportion of our study population was overfat, or cutoff values such as 30% body fat are no longer appropriate with the increasing amounts of fatness seen today. However, the mean BMI of our study sample did not differ from local New Zealand reference data (16). Because we did not measure skinfold thicknesses and national data do not exist for body fatness by DXA we cannot rule out the possibility that our subjects were of similar weight but may have had a higher body fat content than the national average. However, the close relation observed between BMI and body fat in this study would tend to not support this conclusion.

The choice of a reference point to define obesity by total percentage fat is subjective in that universally accepted figures do not exist. We therefore chose to use an arbitrary percentile cutoff (75th percentile for our population) that ensured adequate numbers for statistical analysis, but may limit extrapolation to other populations. Despite the volume of research concerning BMI and fatness, controversy remains concerning the most appropriate BMI cutoffs for designating obesity. Therefore, we also used percentile cutoffs for our screening measures. The 75th percentile used in the present study, BMI \geq 27.3, corresponds closely with the 1990 US guideline for women aged > 35 y (17).

We found that relations between WHR and DXA measurements of regional fatness were not as strong as those between BMI and DXA-derived total fat. A WHR cutoff of 0.81 (75th percentile) correctly identified only 42% of subjects with high

central adiposity as measured by DXA (TLFR) and misclassified 28 subjects. Unfortunately, as with total percentage fat, commonly used standards for defining central adiposity by DXA do not yet exist, and the use of TLFR as the gold standard may not be the most appropriate. Unlike magnetic resonance imaging and computed tomography, DXA cannot differentiate between visceral and subcutaneous fat (18). Visceral fat is thought to be responsible for the adverse metabolic profile noted with central adiposity (19). However, DXA involves a lower radiation dose than computed tomography and is suitable for the whole population (20, 21). Moreover, recent work showing that DXA combined with anthropometry can predict visceral fat content well in adult women (22) has strengthened the value of DXA for body-composition analysis.

Although WHR may be considered the traditional anthropometric technique for assessing central adiposity, the use of waist circumference is gaining support as an alternative, simpler option (23–25). Use of a single measurement reduces the chance of error, and it has been suggested that hip girth may be strongly affected by pelvic structure (7). Moreover, the use of ratios in obesity measurement may have statistical limitations (26). Simple waist circumference measurements appear to predict fatness as estimated by BMI and regional adiposity as estimated by WHR well in adults (24), although not in all populations (27). Furthermore, waist circumference may be a more suitable anthropometric indicator than WHR of critical amounts of visceral fat depots because it appears to be unaffected by sex or the degree of overall adiposity (25).

Zimmet et al (28) showed recently that serum leptin concentrations are more strongly associated with waist circumference than with WHR in both men and women. This may be related in part to the stronger relation observed between waist circumference and BMI than between WHR and BMI (data not shown) because serum leptin concentrations are highly correlated with

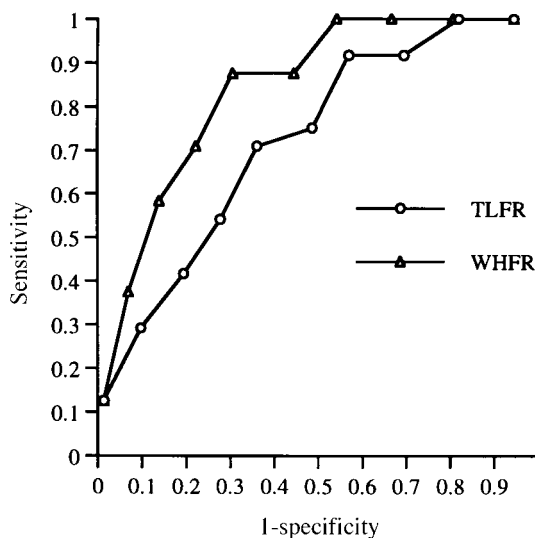


FIGURE 3. Receiver operating characteristic curve comparing waist-to-hip ratio with regional body fat by dual-energy X-ray absorptiometry. Trunk-to-leg fat ratio (TLFR) = trunk fat (kg)/leg fat (kg) by standard definitions (2). Waist-to-hip fat ratio (WHFR) = waist fat (kg)/hip fat (kg) by manually drawn boxes (7).

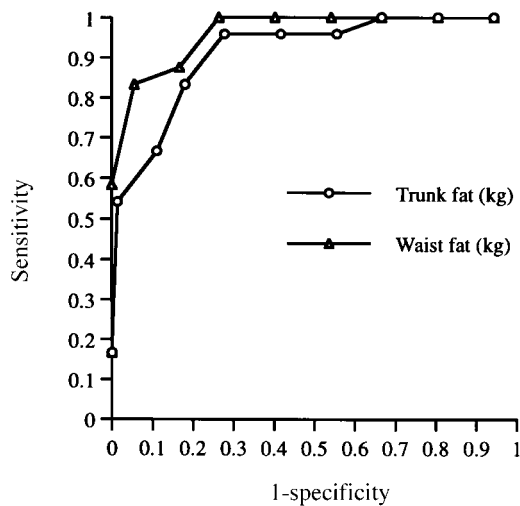



FIGURE 4. Receiver operating characteristic curve comparing waist circumference with central fat by dual-energy X-ray absorptiometry.

measures of total adiposity, including BMI (29). In our study, analysis of waist circumference in comparison with measures of DXA-derived central fat content showed that waist circumference correctly identified more and misclassified fewer subjects than WHR ($P < 0.05$, 75th percentile cutoff for waist circumference: 86.9 cm). This was clearly illustrated by the high ROC curve area values for waist circumference, indicating high screening performance, comparable with that of BMI and total body fat.

Reanalysis of the DXA measurements by manually drawing regions of interest showed improved predictive value of both WHR and waist circumference. These regions were based on those of Ley et al (7) and were determined from bony landmarks with high precision ($CV < 3\%$). The use of manual analysis is more effective for showing the true relation between WHR or waist circumference and regional fat content. This is because DXA-derived measurements of fat are separate from lean and bone and were taken at the same sites as the circumference measurements.

The present study sample was relatively small and we did not have body-composition information on the women aged 20–40 y. Furthermore, we recruited our subjects by advertisement. These factors may introduce bias and limit the extrapolation of our data to other populations. However, the ranges of all measurements in our population were wide and the population mean BMI reflected national population data (16). Therefore, any relations we observed are likely to have been conservatively estimated. In the future, it would be of interest to undertake ROC curve analyses in both sexes with larger samples for all ages. In this study, waist girth and WHR were compared with different DXA indexes of regional fat distribution. However, further analysis comparing waist girth or WHR with trunk fat (kg) as the reference measurement showed that waist girth alone was superior in correctly categorizing subjects according to the actual amount of fat present in the central region (data not shown).

In conclusion, BMI and waist circumference predicted total and abdominal fat content well in adult women. Simple anthropometric techniques will always misclassify subjects to some extent, but a tradeoff can be made that minimizes misclassification as much as possible and correctly identifies most subjects. The construction of ROC curves allows the easy identification of

the cutoff point at which the best tradeoff occurs. 

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