Is It Possible to Derive a Reliable Estimate of Human Visceral and Subcutaneous Abdominal Adipose Tissue From Simple Anthropometric Measurements?

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The aim of the study was to generate equations predicting visceral (VAT) and subcutaneous (SAT) abdominal adipose tissue (AT) from simple anthropometric measurements. Magnetic resonance imaging (MRI) was used to measure VAT and SAT cross-sectional areas at the level of L4 in 49 subjects (19 men and 30 women) with a large range of age and body mass index (BMI). BMI, waist and hip circumferences, waist to hip ratio (WHR), subscapular and paraumbilical skinfolds (ie, "simple" anthropometric measurements), total body fat content by the isotope-dilution method, and abdominal sagittal diameter by MRI (ie, "nonsimple" anthropometric measurements) were also measured. Equations to estimate VAT and SAT from age and simple anthropometric measurements (ie, excluding total body fat and abdominal sagittal diameter) were developed. These equations were then used in 24 subjects (nine men and 15 women) to cross-validate them. The best regression equations, including waist circumference in men and waist circumference and age in women, explained 56% and 68% of VAT variability, respectively. The corresponding standard error of the estimate (SEE) in men was approximately 40% and in women approximately 37% of the mean value of VAT measured by MRI. The best regression equations developed to predict SAT had a higher explained variability (~87% in both men and women) and a lower SEE (<20% of the mean values of SAT measured by MRI). In men, the equation included BMI and hip circumference, and in women, BMI and age. The inclusion of a higher number of simple anthropometric parameters in the predictive models neither significantly increased the explained variability of VAT or SAT nor significantly decreased the SEE of VAT or SAT. Also, inclusion in the multiple regression analysis of total body fat content and abdominal sagittal diameter did not improve prediction. In the cross-validation study, differences between predicted and observed values of VAT were large, with a tendency to overestimation in both men and women. In contrast, differences between predicted and observed values of SAT were small. We suggest that SAT but not VAT can be estimated from age and simple anthropometric measurements. Direct methods (MRI, computed tomography [CT], or other options) should be used for assessment of VAT.

RECENT STUDIES have substantiated the initial observation by Vague[1] that adipose tissue (AT) located in the central part of the human body has a deleterious impact on a variety of important metabolic and hemodynamic parameters. In particular, an excess of central (or upper-body, abdominal, truncal, or android) AT relative to peripheral (or lower-body, gluteofemoral, or gynoid) AT is frequently associated with diabetes mellitus, dyslipoproteinemia, gout, and hypertension.[2-15] Because of these associations, and perhaps for other as yet unknown relationships, central adiposity in both non-obese and obese subjects is associated with an increased risk of cardiovascular death.[16-20]

Measurement of the waist to hip ratio (WHR) currently is the most frequently used method to assess regional distribution of AT and to detect central adiposity in man.[21] However, whereas hip circumference gives a highly reliable estimate of subcutaneous AT in the gluteofemoral region (ie, peripheral fat), waist circumference is a function of both subcutaneous (SAT) and visceral (VAT) abdominal AT. As a consequence, WHR cannot distinguish between the subcutaneous and visceral subtypes of central adiposity. Such a distinction is crucial since among AT depots in the central part of the body, VAT more than SAT is related to metabolic and hemodynamic abnormalities that represent risk factors for atherosclerotic cardiovascular disease.[22,23]

A direct assessment of VAT and SAT abdominal AT can be achieved by the use of computed tomography (CT)[24-26] or magnetic resonance imaging (MRI).[27-29] The latter method, which was introduced in recent years, should be preferred because it does not involve exposure of the subject to ionizing radiation. Both CT and MRI are valuable tools in determining AT distribution in the central part of the body. However, they are costly and time-consuming. As a consequence, the use of these techniques cannot be extended to studies that involve large numbers of subjects (ie, epidemiological studies, especially those performed "in the field"), nor can they be used by family physicians in their office for assessing cardiovascular risk in the individual patient. To circumvent these limitations, in the present study we tried to generate equations using multiple regression analysis to predict the amount of VAT and SAT areas from easily accessible parameters, including age, height, weight, body circumferences, and skinfold thicknesses. We also measured the total amount of fat by isotopic dilution and the abdominal sagittal diameter by MRI to evaluate whether these two parameters can contribute to VAT and SAT prediction.

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Submitted January 4, 1995; accepted March 21, 1995.

Supported by grants from the Italian National Research Council and the Italian Ministry of University and Technological Research, and in part by National Institutes of Health Grant No. DK24092, a Veterans Affairs Merit Award, the Veterans Administration Medical Research Service, the General Research and Educational Clinical Center, and Clinical Research Center Grant No. M01-RR-0.1346.

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0026-0495/95/4412-0018$03.00/0

SUBJECTS AND METHODS

Subjects

Seventy-three subjects (28 men and 45 women) volunteered for the study. Most of them (n = 57) had a MRI study as part of research protocols that examined relationships between body fat distribution and glucose metabolism in vivo.[30,31] A few subjects (n = 16) had MRI for diagnostic purposes, ie, clinical suspicion of a herniated lumbar disc. The age of subjects ranged from 22 to 70 years, with a median of 55 years in men and 41 years in women. Body mass index (BMI) ranged from 20.3 to 44.9 kg/m^2, with a median of 28 kg/m^2 in men and 30 kg/m^2 in women. Thirty-four subjects (46%) were obese as defined by a BMI greater than 30 kg/m^2.

Subjects who participated in the study were submitted to the following procedures: (1) measurement of simple anthropometric parameters, (2) measurement of body composition by isotopic dilution, and (3) measurement of SAT and VAT areas and abdominal sagittal diameter by MRI.

Written informed consent was obtained from all subjects before participation in the study. The experimental protocol was approved by the Institutional Review Board of the University of Texas Health Science Center, and the General Clinical Research Center and the Research and Development Committee of the Veterans Administration Hospital, San Antonio, TX.

Anthropometric Measurements

Weight (to the nearest 0.1 kg) and height (to the nearest 0.5 cm) were measured while the subjects were fasting and wearing only undergarments. BMI was computed as weight in kilograms divided by height in meters squared. The following two circumferences were recorded (to the nearest 0.5 cm) with a plastic tape measure while the subjects were standing: waist (widest diameter between the xiphoid process of the sternum and the iliac crest, at the level of the umbilicus) and hip (widest diameter over the greater trochanters).[32] WHR was then calculated and used as an index of regional distribution of AT. A higher WHR was interpreted to represent a predominance of central AT, whereas a lower value indicated a predominance of peripheral AT. Subscapular skinfold (at the angle of the right scapula) and paraumbilical or abdominal skinfold (5 cm to the umbilicus on the horizontal umbilical line, on the right side of the subject) thicknesses were measured (to the nearest 0.5 mm) with a Lange skinfold caliper (Cambridge Scientific, Cambridge, MD).[33]

Body Composition

Body composition was assessed by the tritiated-water dilution method. Briefly, 80 μCi ^3H_2O was injected intravenously as a bolus, and venous blood was collected at times 90, 120, and 180 minutes for measurement of tritiated-water radioactivity. The ratio between total radioactivity administered (disintegrations per minute) and steady-state ^3H_2O radioactivity (disintegrations per minute per milliliter) provided a measure of total body water.[34] Assuming that total body water represents 73% of fat-free mass,[35] fat mass was computed as the difference between body weight and fat-free mass.

SAT and VAT Areas

SAT and VAT areas were quantified by nuclear MRI using a Signa 1.5-T imager (GE Medical Systems, Milwaukee, WI). A sagittal localizing image was used to center transverse sections at the level of the fourth lumbar vertebra, and four 5.0-mm thick sections were acquired with a gap of 1.5 mm to prevent signal crossover from adjacent sections. The extent of the four sections was chosen to average abdominal AT measurements in a sample volume approximately 2.5 cm thick. Phase encoding was in the anteroposterior direction to minimize the effect of motion-induced phase artifacts that might otherwise be distributed laterally through a large portion of the abdomen. Images were acquired with 128 phase-encoding steps to form 256 × 256 images that were stored in a 16-bit format. Signal averaging (four signals averaged) was used to further reduce effects of motion-related artifacts. Imaging time for a four-section sequence was less than 5 minutes.

Outline regions of interest were drawn manually for SAT and VAT. The SAT cross-sectional area (in centimeters squared) was computed (number of pixels times pixel area) from the region of interest drawn around the outer and inner margins of subcutaneous AT. The VAT cross-sectional area (in centimeters squared) was calculated (number of pixels times pixel area) with an adaptive method that uses the "valley" between "fat" and "nonfat" distributions of pixel values in the average visceral histogram curve as the threshold value for integrating "fat" pixels. In brief, a single outline was drawn around the visceral region of each section. This outline was drawn to include all VAT and exclude AT associated with muscle between the viscera and the inner margin of SAT. No attempt was made to exclude low–signal-intensity "nonfat" areas within the visceral region. A histogram curve for each section was calculated, tabulating the number of pixels associated with each pixel value within the visceral region. Fat was indicated by a characteristically high pixel value distribution and nonfat structures by a low pixel value distribution within the visceral histogram curve. The pixel value associated with the valley between fat and nonfat peaks of the visceral histogram curve was selected as the threshold value for integrating fat pixels. Fat pixel values less than this threshold were not counted, but this loss was somewhat counterbalanced by the inclusion of nonfat pixels that have values above the threshold.

In all subjects, MRI images were read by the same observer (J.L.L.), to prevent interobserver variability. Intraobserver variability was calculated using 20 repeated MRI measurements of VAT and SAT in the same individual. This analysis gave values of 0.9% for VAT and 3.0% for SAT. More details about the MRI procedure, including calibration, reproducibility, cross-checking, and validation, were previously described.[36]

Abdominal sagittal diameter was assessed by MRI using the recommendations of Sjostrom.[37]

Statistical Analysis

For all parameters, the ranges were large. The Kolmogorov-Smirnov test[38] did not show significant differences from a normal distribution for any of the considered variables in men or women.

Simple (Pearson's) correlations and multiple regression analysis were used for statistical purposes. Multiple regression analysis was used to generate equations to predict VAT and SAT from age and simple anthropometric parameters of 49 subjects (30 women and 19 men) randomly selected from the overall sample. All possible combinations of independent variables (age, body weight, BMI, paraumbilical and subscapular skinfolds, waist and hip circumferences, and WHR) were evaluated using the all-possible-regression selection procedure.[39] This procedure was performed in two steps. First, for a given number of independent variables (ranging from one to eight), the regression equation with the highest R^2 value was found. With this procedure, eight different regression equations including one to eight independent variables were found. In the second step, among the eight equations found in the first step, the equation that had the highest R^2 value and included independent variables whose regression coefficients were all significantly different from zero at the .05 level was selected. This equation was defined as the best regression equation or the best predictive model. The goodness of fit of the best regression equation was assessed by examining the residuals, looking for outliers and/or influential observations.[40] We also examined the standard error of the estimate (SEE), which was calculated as described by Draper and Smith.[40] The best regression equations were then cross-validated in the remaining 24 subjects (15 women and nine men) of the overall sample. In these subjects, predicted versus observed values and differences between predicted and observed versus predicted values were plotted.[40] Sex-specific analyses were always performed. Results are presented as the mean ± SD.

RESULTS

Anthropometric Data and Their Correlations

Table 1 lists age and anthropometric data of 49 subjects who participated in the study aimed to generate predictive equations. Waist circumference was the simple anthropometric parameter most strongly correlated with VAT (r = .751 in men and .725 in women), and BMI was that most strongly correlated with SAT (r = .890 in men and .918 in women). Correlation coefficients of abdominal sagittal diameter and total body fat with VAT and SAT were generally lower. Correlation coefficients of abdominal sagittal diameter with VAT were .472 in men and .763 in women, and those of abdominal sagittal diameter with SAT were .744 in men and .810 in women. Correlation coefficients of total body fat with VAT and SAT were .681 and .824 in men and .685 and .864 in women, respectively. Correlations of WHR with VAT and SAT were weaker. In men, correlation coefficients of WHR with VAT and SAT were .665 and .609, respectively, and in women, .535 and .212, respectively.

Table 2 reports age and anthropometric data of 24 subjects who participated in the cross-validation study. In these groups, correlations similar to those previously described were found.

Prediction of VAT Area

Figure 1 depicts the multiple-determination coefficients (adjusted R^2 values) as a function of the number of variables used in the multiple regression analysis. In this analysis, VAT was the dependent variable and age and simple anthropometric parameters (weight, BMI, waist and hip circumferences, WHR, and paraumbilical and subscapular skinfolds) were the independent variables. Regression equations generated by models including one to eight variables were considered. A different pattern was observed in men and women. As stated earlier, waist circumference was the variable that displayed the highest simple correlation with VAT in both men and women. In women, when models with two variables were considered, a significant increase in the multiple-determination coefficient was observed with a model including waist circumference and age, but when models including a higher number of variables were considered, not all of these variables had regression coefficients significantly different from zero. In men, all models with more than one variable showed that only waist circumference had a regression coefficient significantly different from zero. The goodness of selection of the best regression equation to predict VAT is supported by data presented in Fig 1, where R^2 values adjusted for degrees of freedom and the relative SEE were reported. In women, models with more than two variables had similar values of adjusted R^2. In men, models with one to four variables had similar values of adjusted R^2, with a progressive reduction of adjusted R^2 values when other variables were included in the multivariate analysis. In women the SEE, which was lower than in men, was similar in models with two to eight variables, whereas in men the SEE tended to increase slightly with inclusion of more variables into the model (Fig 1). Therefore, two different best regression equations predicting VAT from simple anthropometric measurements and age were found in men and women (Table 3). In men, the equation explained 56.5% of VAT variability, with a SEE of 66 cm², a value corresponding to approximately 40% of the mean value of VAT measured by MRI. In women, the equation explained 67.6% of VAT variability, with a SEE of 42 cm², a value corresponding to approximately 37% of the mean value of VAT measured by MRI.

Table 1. Variables Examined in Men and Women of the Groups Used to Develop Predictive Equations

	Women		Men	
Variable	Mean ± SD	Range	Mean ± SD	Range
No.	30		19	
Age (yr)	39 ± 11	20-66	54 ± 10	35-70
Body weight (kg)	75 ± 17	49-115	81 ± 18	56-127
BMI (kg/m²)	30 ± 6	20-43	28 ± 5	21-38
Paraumbilical skinfold (mm)	36 ± 10	12-52	29 ± 8	10-43
Subscapular skinfold (mm)	32 ± 10	7-50	24 ± 11	6-50
Waist circumference (cm)	95 ± 12	71-119	97 ± 11	74-117
Hip circumference (cm)	108 ± 12	88-137	99 ± 7	87-113
WHR	0.88 ± 0.08	0.75-1.03	0.98 ± 0.07	0.85-1.12
Total body fat (kg)	29 ± 11	13-55	26 ± 13	8-62
SAT (cm²)	305 ± 162	89-743	182 ± 84	55-346
VAT (cm²)	114 ± 71	12-323	165 ± 97	12-376
Sagittal diameter (cm)	21 ± 5	14-30	21 ± 5	14-30

Table 2. Variables Examined in Men and Women of the Cross-Validation Groups

	Women		Men	
Variable	Mean ± SD	Range	Mean ± SD	Range
No.	15		9	
Age (yr)	41 ± 10	25-59	52 ± 15	30-67
Body weight (kg)	78 ± 18	53-115	87 ± 12	70-106
BMI (kg/m²)	30 ± 7	22-45	29 ± 4	24-35
Paraumbilical skinfold (mm)	39 ± 11	20-53	32 ± 11	19-53
Subscapular skinfold (mm)	37 ± 14	10-50	30 ± 9	18-44
Waist circumference (cm)	98 ± 17	73-130	103 ± 8	94-116
Hip circumference (cm)	112 ± 16	93-148	105 ± 8	94-116
WHR	0.88 ± 0.10	0.73-1.12	0.98 ± 0.04	0.91-1.04
Total body fat (kg)	32 ± 14	13-62	30 ± 6	23-40
SAT (cm²)	338 ± 187	81-797	238 ± 82	147-356
VAT (cm²)	103 ± 49	11-194	159 ± 90	84-360
Sagittal diameter (cm)	21 ± 4	13-27	21 ± 4	17-27

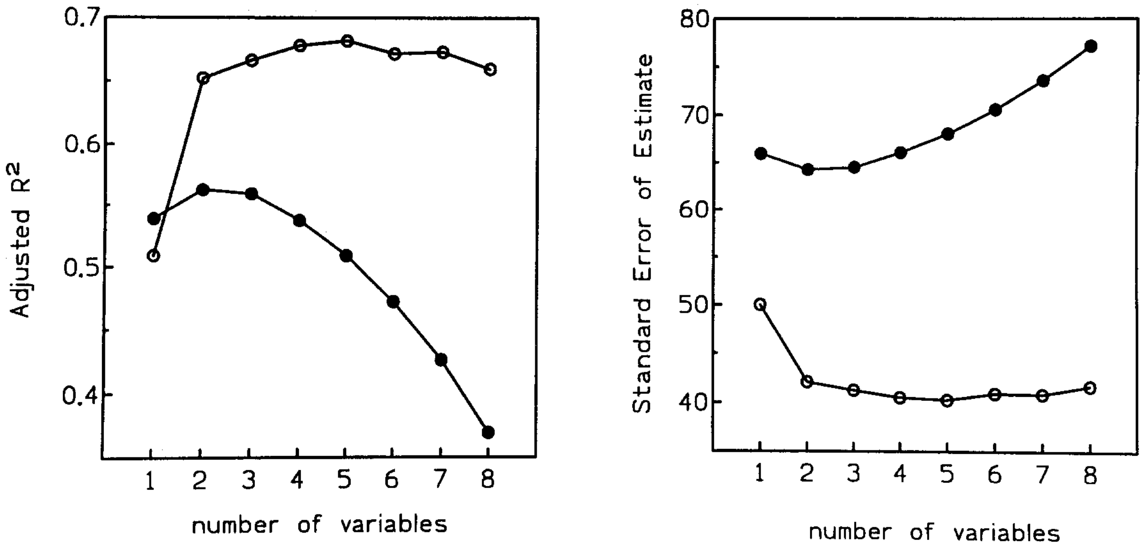

Fig 1. Adjusted R^2 values and SEE as a function of the number of variables included in multiple regression models predicting VAT from age and simple anthropometric parameters. In men (●), variables included in the models were as follows: 1, waist; 2, waist and paraumbilical skinfold; 3, waist, paraumbilical skinfold, and age; 4, paraumbilical skinfold, age, hip, and WHR; 5, paraumbilical skinfold, waist, age, hip, and WHR; 6, waist, paraumbilical skinfold, BMI, age, hip, and WHR; 7, all variables except for subscapular skinfold; and 8, all variables. In women (○), variables included in the models were as follows: 1, waist; 2, waist and age; 3, waist, paraumbilical skinfold, and age; 4, waist, paraumbilical and subscapular skinfolds, and age; 5, WHR, paraumbilical and subscapular skinfolds, BMI, and age; 6, waist, paraumbilical and subscapular skinfolds, age, BMI, and body weight; 7, all variables except for BMI; and 8, all variables.

The inclusion in the multiple regression analysis of total body fat content and abdominal sagittal diameter (ie, nonsimple anthropometric measurements) did not result in the development of equations with higher predictive power. By using 10 independent variables in the multiple regression equation, the best regression equation included total body fat and abdominal sagittal diameter in men, and explained 61% of VAT variability. In women, the best regression equation included abdominal sagittal diameter and age and explained 68% of VAT variability. In both sexes, models including a higher number of variables in the regression equation did not significantly improve their power of prediction.

Prediction of SAT Area

When SAT was taken as the dependent variable in multiple regression analysis, we found that in both sexes the best regression equations were those with two variables, since models with a higher number of variables included one or more regression coefficients not significantly different from zero. Interestingly, in both equations there was BMI, but in men the other variable was hip circumference, and in women, age (Table 3). In both men and women, the variability of SAT explained by the model was approximately 87%, a value consistently higher than that found in the prediction of VAT. Also, the SEEs were lower than those found in the prediction of VAT, being approximately 14% (in men) and approximately 18% (in women) of the mean values of SAT measured by MRI. Adjusted R^2 values and the SEE of models including one to eight variables are reported in Fig 2. It can be appreciated that R^2 values did not substantially increase from models with two up to models with eight variables. The SEE had a pattern opposite to that of R^2 and was similar in men and women (Fig 2).

The inclusion in the regression analysis of total body fat content and/or abdominal sagittal diameter did not result in the development of equations with higher predictive power. By using 10 independent variables in the multiple regression analysis, the best regression equation included total body fat and hip circumference in men and explained 87% of SAT variability. In women, the best regression equation included total body fat, BMI, and age and explained 88% of VAT variability. In both sexes, inclusion of more variables in the models did not significantly improve their power of prediction.

A separate analysis of non-obese and obese subjects, ie, those with a BMI greater than or less than 30 kg/m², did not

Table 3. Predictive Equations of VAT and SAT Areas

AT	Equation	R^2	SEE
VAT (cm²)			
Men	−453.7 + [6.37 · waist] (132.5) (1.36)	.56	66.0
Women	−370.5 + [4.04 · waist] + [2.62 · age] (65.4) (0.63) (0.74)	.68	42.1
SAT (cm²)			
Men	−621.0 + [9.37 · BMI] + [5.51 · hip] (127) (2.65) (1.79)	.87	32.1
Women	−332.9 + [24.5 · BMI] + [2.26 · age] (71.2) (1.89) (1.09)	.87	61.7

NOTE. Standard errors of the regression coefficients are shown in parentheses. R^2 = adjusted multiple R^2.

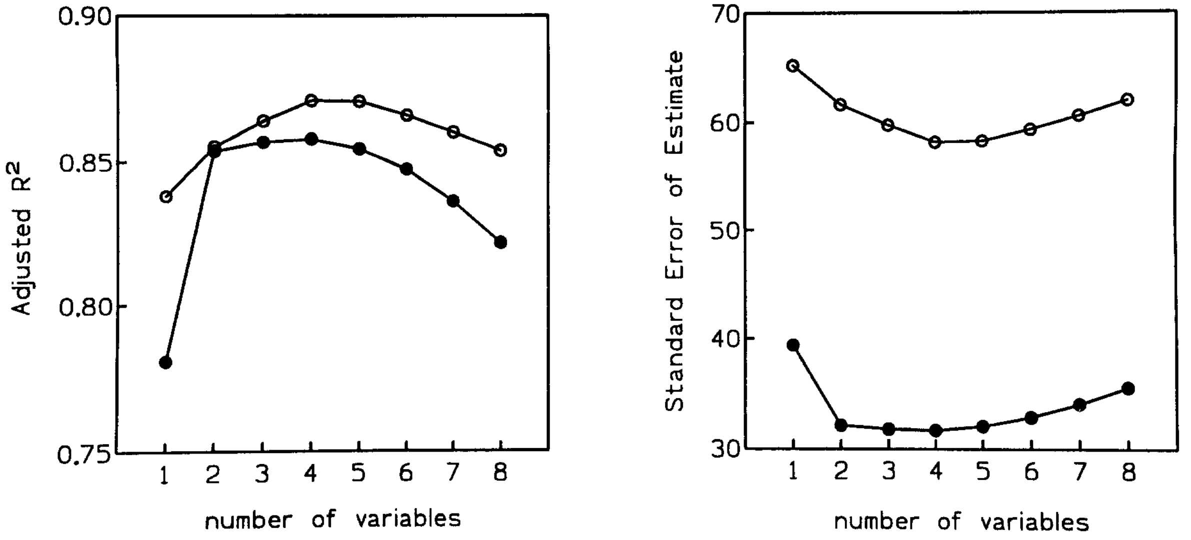

Fig 2. Adjusted R^2 values and SEE as a function of the number of variables included in multiple regression models predicting SAT from age and anthropometric parameters. In men (●), variables included in the models were as follows: 1, BMI; 2, BMI and hip; 3, BMI, paraumbilical skinfold, and hip; 4, BMI, paraumbilical and subscapular skinfolds, and hip; 5, BMI, paraumbilical and subscapular skinfolds, hip, and WHR; 6, BMI, paraumbilical and subscapular skinfolds, waist, hip, and WHR; 7, all variables except for body weight; and 8, all variables. In women (○), variables included in the models were as follows: 1, BMI; 2, BMI and age; 3, BMI, waist, and age; 4, BMI, paraumbilical skinfold, age, and body weight; 5, BMI, paraumbilical skinfold, waist, age, and body weight; 6, BMI, paraumbilical and subscapular skinfolds, waist, age, and body weight; 7, all variables except for waist; and 8, all variables.

reveal any significant difference in the predictive power of these equations, or those predicting VAT (data not shown).

Cross-Validation Study

Figures 3 and 4 illustrate the relationships between predicted and observed values of VAT and SAT in men and women in the cross-validation study. Prediction of SAT was more reliable than that of VAT. Indeed, in both men and women, differences between predicted and observed values of SAT were generally small, and predicted values were rarely higher or lower than 10% to 15% of observed values. On average, predicted and observed values of SAT were 238 and 232 cm^2 in men and 315 and 338 cm^2 in women. In contrast, in women and to a greater extent in men, the predictive equations tended to overestimate VAT. In men the phenomenon occurred in almost all subjects, whereas in women it was less frequent but remarkable for VAT values above the mean. On average, predicted VAT was approximately 30% higher than observed VAT in both men (205 *v* 169 cm^2) and women (135 *v* 103 cm^2). This overestimation of VAT is better appreciated when the data are plotted as the differences between values predicted and observed (ie, the residuals) against the values predicted (Figs 5 and 6). With this analysis, it can be seen that differences between predicted and observed VAT were positive in eight of nine men. In women, there were eight subjects of 19 who had remarkable positive differences (>45 cm^2) between predicted and observed values of VAT, and this occurred when predicted values were greater than 150 cm^2.

DISCUSSION

Numerous studies have shown that a central (or upper-body, abdominal, truncal, or android) type of regional AT distribution is an important risk factor for development of

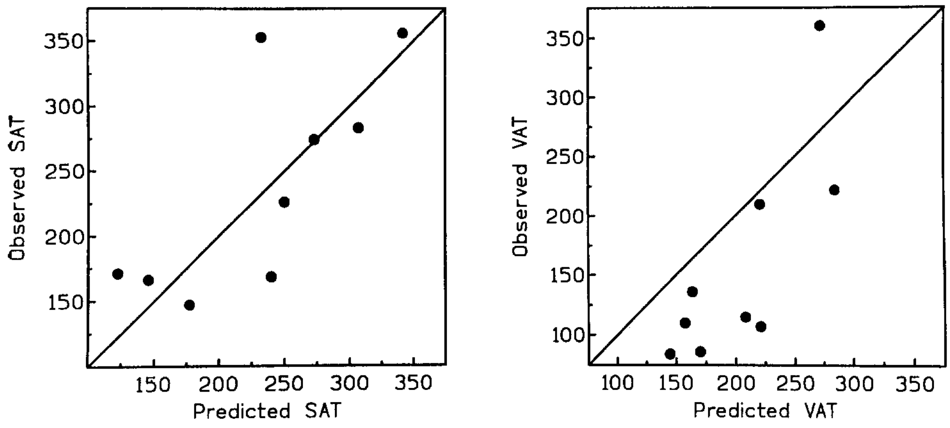

Fig 3. Predicted *v* observed values of SAT and VAT in men of the cross-validation groups. Identity lines are drawn.

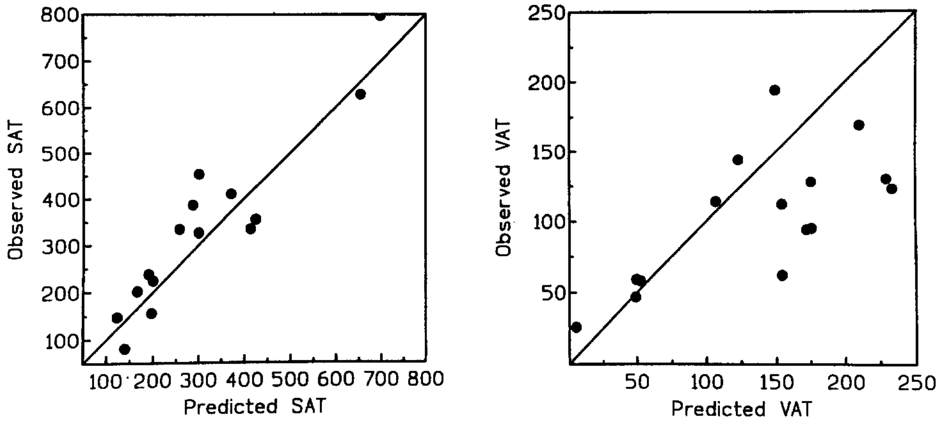

Fig 4. Predicted *v* observed values of SAT and VAT in women of the cross-validation groups. Identity lines are drawn.

cardiovascular disease.[1-20] As a consequence, it has been argued that evaluation of regional AT distribution should become a routine component of any medical assessment. Recent studies based on the use of CT or MRI have indicated that metabolic and hemodynamic abnormalities that contribute to increased cardiovascular risk in subjects with a central pattern of AT distribution are related to an increased amount of abdominal VAT rather than SAT.[22,23] As a consequence, an exhaustive medical assessment should include possibly an estimate of the amount of both VAT and SAT abdominal AT. Since CT and MRI can hardly be used in epidemiological studies or in the single individual consulting the family physician, we tried to develop a set of simple but reliable equations to estimate SAT and VAT based on easily quantifiable variables.

We measured VAT and SAT by MRI in 49 subjects of both sexes, who displayed a large range of age and BMI, to develop predictive equations to estimate the cross-sectional areas of VAT and SAT from simple anthropometric measurements including weight, BMI, waist and hip circumferences, WHR, and subscapular and paraumbilical skinfold thicknesses. All these measurements can be easily obtained during routine clinical assessment. We also considered age as a variable possibly to be included in the models, since regional distribution of AT is strongly affected by age.[40-43] These equations were cross-validated in 24 subjects.

We found that in both men and women, the simple anthropometric parameter best correlated with VAT was waist circumference. This is in agreement with other studies.[42-44] However, waist circumference alone explained less than 60% of VAT variability. Indeed, as also shown by Fujioka et al,[45] under some circumstances the AT contribution to waist circumference can be almost exclusively subcutaneous, whereas under other circumstances it can be almost exclusively visceral. In other words, waist circumference itself cannot provide a reliable insight into AT distribution within the abdominal region. For this reason, we tried to develop better predictive models using the all-possible-regression procedure. However, in men, no model including two to eight variables was able to improve prediction of VAT. In women, the best and simplest model that predicted VAT was that including waist circumference and age. This model explained approximately 68% of VAT variability. Models with more variables had no higher power of prediction. Of note is that the SEE was remarkably high, being approximately 40% and approximately 37% of the mean values of VAT measured by MRI in men and women, respectively. Interestingly, models including more sophisticated parameters, such as total body fat content and/or abdominal sagittal diameter, did not significantly improve prediction. The fact that abdominal sagittal diameter had a power of prediction of VAT not sustantially higher than waist circumference is in agreement with recent data reported by Pouliot et al.[46]

The equations we present in this report have a predictive power similar to that of equations developed by other investigators who used CT.[47-50] These researchers described models that included age, weight, BMI, waist and hip

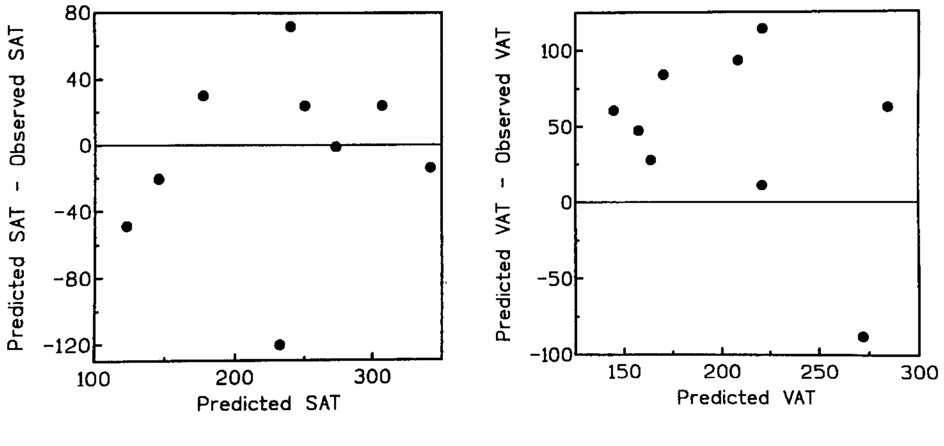

Fig 5. Differences between predicted and observed values of SAT and VAT plotted against predicted values of SAT and VAT in men.

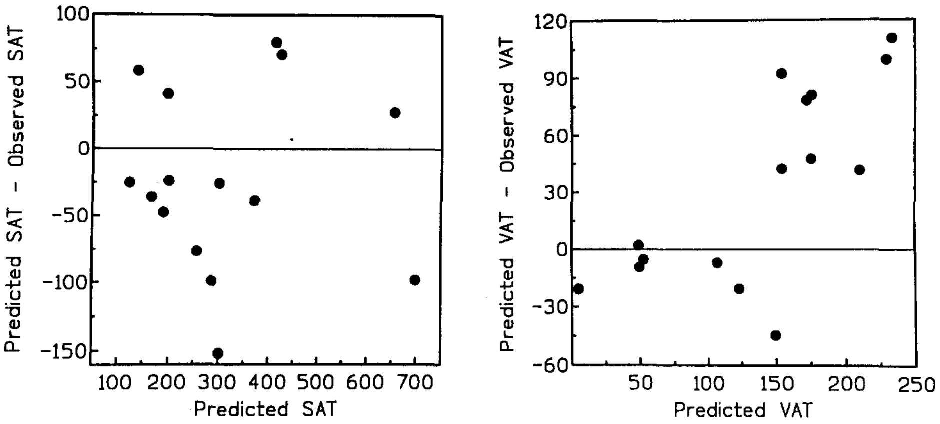

Fig 6. Differences between predicted and observed values of SAT and VAT plotted against predicted values of SAT and VAT in women.

circumferences, WHR, percentage of body fat, and/or skinfolds. In the literature, there also are reports of equations with a higher predictive power. Indeed, Seidell et al[51] and Kvist et al,[52] with the use of CT, derived equations with an explained variability of VAT of 80% and 90%, respectively. However, the study by Seidell et al[51] was conducted in subjects who were mostly non-obese, whereas the study by Kvist et al[52] involved a small number of subjects. Most importantly, the validation of Seidell's equation made by Koestner et al[50] showed an explained variability of 59%, ie, a value similar to that found in the present study, whereas the study by Kvist et al[52] was based on CT-derived measures of abdominal diameters and circumferences instead of true simple anthropometric measurements. To our knowledge, the only study based on MRI measurements of AT was reported by Ross et al,[53] who described a regression model that explains approximately 80% of VAT variability. However, the study examined only 27 subjects, all males, and the equation was not cross-validated. Moreover, the SEE of the equation developed by Ross et al[53] was approximately 30% of the mean value of VAT they measured, ie, similar to what we found. This value cannot be regarded as satisfactory. More recently, Svendsen et al[54] described an equation based on the combined use of anthropometry and dual-energy x-ray absorptiometry that predicted VAT with a greater accuracy (~90% of explained variance). However, this method has not been validated, has never been tested in men and premenopausal women, and is not based exclusively on simple anthropometric measurements. Thus, their equation is hardly proposable for large studies, nor can it be offered to the family physician for use in daily clinical practice.

Our data, along with those reported by other investigators,[47-50] indicate that simple anthropometric measurements cannot be used to estimate the amount of abdominal VAT, because the estimate is inaccurate. In fact, a large percentage (up to 45%) of the variability in VAT remains unexplained, and the SEE is considerable (30% to 40% of the mean values). Even though in epidemiological studies the error one can make using VAT-predictive equations that we and others have developed is diluted by the large number of subjects who are examined, the error seems to be too large to allow the use of these equations. As a consequence, assessment of VAT should be made with MRI, CT, or other techniques that, with few exceptions, are inevitably confined to small series of subjects who are studied for research purposes.

It is important to note that our study, as well as those in the literature,[47-54] indicates that WHR is a good index of central versus peripheral fat distribution but a poor index of the amount of VAT. In fact, the variability in VAT that is explained by WHR is low, especially after adjusting for age and other anthropometric parameters. Therefore, if one requires an estimate of the amount of VAT to interpret metabolic data or to assess the cardiovascular risk in a given patient, WHR is not an adequate measurement and has an intrinsic value not much higher than a thorough physical examination, including inspection of the subject, palpation of the abdomen, and pinching of abdominal skinfolds.

VAT and SAT areas can vary considerably according to the longitudinal level at which they are measured,[55] and the maximum area occurs at different levels for different subjects. Nevertheless, in the vast majority of subjects, the maximum area occurs at the level of the fourth lumbar vertebra (ie, at the level of the umbilicus), ie, the same level where we measured waist circumference by anthropometry and abdominal AT areas by MRI. Since we calculated VAT and SAT areas by averaging four 5-mm thick scans acquired with a gap of 1.5 mm, for a total sample volume approximately 2.5 cm thick, we believe that in most of the subjects we examined, we measured at the same level both the maximum VAT and SAT areas and the maximum waist circumference. These good anatomical consistencies between anthropometric and MRI measures are crucial, since waist circumference was one of the predictors of AT abdominal areas.

Concerning the estimation of SAT, we presented two equations for which the power of prediction was good. These equations explained 87% of SAT variability, with a relatively low SEE (<20%). These equations, which included BMI and hip circumference in men and BMI and age in women, have a predictive power higher than those developed by Seidell et al,[51] Weits et al,[47] and Koestner et al,[50] for which the explained variability did not exceed 80%. Our data, as well as those reported by others,[47,50,51] indicate that prediction of SAT from simple anthropometric measurements is feasible, since almost 90% of the variability can be explained. WHR per se does not provide a reliable estimate of SAT, especially in women. Also, skinfold thicknesses per se do not give a reliable estimate of SAT. Conversely, a more reliable estimate of SAT is provided by BMI, a parameter that is easy to quantify.

In conclusion, in this report, we present a series of equations that could be used to derive an estimate of VAT and SAT from age and simple anthropometric measurements. However, only the equations for predicting SAT seem to be reliable, whereas those for estimating VAT have a too low power of prediction and a too large SEE. These results, which agree with other reports, suggest that equations to predict SAT may be used in epidemiological studies and in clinical practice to evaluate the impact of SAT on the metabolic and cardiovascular-risk profile of a given individual. Unfortunately, estimation of SAT has a lower priority than estimation of VAT, whose relationships with cardiovascular risk and with clinical manifestations of atherosclerosis are closer.[22,23] When VAT is to be evaluated for clinical, epidemiological, or research purposes, a direct assessment of this variable by MRI, CT, or other sophisticated techniques is necessary.

ACKNOWLEDGMENT

The excellent technical support of Robert Nickell, Cono Farias, and Paola Branzi is gratefully acknowledged.

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