Assessment of adipose tissue distribution by computed axial tomography in obese women: association with body density and anthropometric measurements

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1. Abdominal obesity is associated with numerous metabolic complications. Deep abdominal adipose tissue is critical in the association between the level of abdominal obesity and cardiovascular risk factors.

2. Adipose tissue localization was assessed by computed axial tomography (CAT), and its association with body density and anthropometric measurements was investigated in a sample of fifty-one obese women (percentage body fat 45·9 (SD 5·6)) aged 35·7 (SD 5·5) years. The CAT scans were performed at three levels: lower chest, abdomen and mid-thigh.

3. The total adipose tissue volume computed from these three scans was highly correlated with body fat mass (r 0·94, $P < 0·001$). The proportion of deep abdominal fat as measured by the ratio of deep: total adipose tissue areas at the abdominal level was not significantly correlated with body fat mass, but it was moderately associated with the ratio of waist: hip circumferences (WHR) (r 0·49, $P < 0·001$). The absolute amount of deep abdominal fat was, however, significantly correlated with body fat mass (r 0·72, $P < 0·001$).

4. The subscapular (r 0·38) and the abdominal (r 0·38) skinfolds were the only two skinfolds that were significantly associated with the proportion of deep abdominal fat ($P < 0·01$). These skinfolds were also those which showed the highest correlation with the absolute amount of deep abdominal fat (r 0·65, $P < 0·001$, for both skinfolds).

5. A three-site CAT-scan procedure can be used for the estimation of body fat mass in premenopausal obese women.

6. In these obese women, there was no significant association between total adiposity and the proportion of deep adipose tissue at the abdominal level.

7. In premenopausal obese women, the absolute amount of deep abdominal fat can be predicted from anthropometric measurements with more accuracy than the relative amount of deep abdominal fat.

It is well established that obesity is associated with cardiovascular risk factors such as hypertension, diabetes and hyperlipidaemia (Lew & Garfinkel, 1979; Van Itallie, 1979; Berchtold *et al.* 1981; Larsson *et al.* 1981; Hubert *et al.* 1983; Royal College of Physicians, 1983; Castelli, 1984). Although obesity represents an independent risk factor for cardiovascular disease (CVD) when the duration of the obese state is taken into account (Hubert *et al.* 1983), there is some controversy on the relation between obesity and CVD (Montenegro & Solberg, 1968; Weinsier *et al.* 1976; Keys, 1980; Barret-Connor, 1985). It has been shown that body fat distribution is an important variable to consider in the association between obesity and CVD. It has also been observed that subjects with abdominal obesity display greater metabolic complications than those with predominantly peripheral fat accumulation (Vague, 1947; Kissebah *et al.* 1982; Krotkiewski *et al.* 1983; Lapidus *et al.* 1984; Larsson *et al.* 1984; Després *et al.* 1985*a*; Donahue *et al.* 1987). Furthermore, it has been recently suggested that the omental fat depot is critical in the association between the level of abdominal fat and cardiovascular risk factors since the

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level of deep abdominal fat deposition is the primary variable associated with metabolic complications (Shuman *et al.* 1986; Fujioka *et al.* 1987). Although some attempts have been made to estimate the magnitude of deep adipose tissue deposition (Björntorp, 1984; Després *et al.* 1985*b*), none of these procedures have been validated against direct measurements of body fat.

Computed axial tomography (CAT) is a reliable technique for the measurement of adipose tissue distribution and for the assessment of subcutaneous and particularly deep fat depots. This technique has been shown to yield reproducible measures of the amount of fat at any site of the body (Borkan *et al.* 1982; Grauer *et al.* 1984; Enzi *et al.* 1986; Kvist *et al.* 1986; Sjöström *et al.* 1986; Sjöström, 1988). However, because of the irradiation involved and the cost of utilization, CAT is unlikely to become widely used, particularly in studies where large samples are examined. Thus, the development of anthropometric methods to predict the amount of deep abdominal fat deposition is warranted.

We therefore performed anthropometric and densitometric measurements in comparison with CAT measurements in a sample of premenopausal obese women. Our results suggest that multiple-regression models using anthropometric measurements can satisfactorily predict the amount of deep abdominal fat but they have only a limited ability to predict the proportion of deep abdominal fat.

METHODS

Subjects

Fifty-one premenopausal obese women were recruited by solicitation through the media in the Quebec city metropolitan area. They gave their informed written consent to participate in the study, which was approved by the Laval University Medical Ethics Committee. Before entering the study, subjects were submitted to a complete medical examination, and their medical history was established by a physician. Women with CVD, diabetes or with any endocrine disorders, were excluded.

CAT

CAT was performed on a Siemens Somatom DRH scanner (Erlangen, West Germany) using the procedures described by Sjöström *et al.* (1986) and Kvist *et al.* (1986). The scanning was performed at 125 kV. The subjects were examined in supine position with their arms stretched above their head (Kvist *et al.* 1986). The CAT scans were performed at three sites: at the level corresponding to the disk between the 8th and 9th thoracic vertebrae (lower chest), between the 4th and 5th vertebrae (abdomen), and at the mid-distance between the knee joint and the iliac crest (mid-thigh). In order to obtain high accuracy and reproducibility for these measurements, a skeleton radiograph was used as the reference to establish the position of the scans to the nearest 1 mm. The attenuation interval used for adipose tissue calculations was −30 to −190 Hounsfield units. Total and deep fat areas were calculated by delineating their surfaces with a graph pen. Deep abdominal fat area was measured by drawing a line within the muscle wall surrounding the abdominal cavity. Subcutaneous fat was calculated by subtracting the deep fat area from the total area. The ratio of deep: total adipose tissue (D:T ratio) was used as an indicator of the relative amount of deep fat. Finally, the distance between adjacent scans was measured and the adipose tissue volume between these scans was calculated (Kvist *et al.* 1986). Total adipose tissue volume from lower chest to mid-thigh was obtained by simply adding up the partial volumes. The assumption underlying this procedure is that there is a linear change in adipose tissue surface between adjacent scans (Sjöström *et al.* 1986; Kvist *et al.* 1986).

Anthropometry and body density

Skinfold thicknesses were measured with a Harpenden caliper following the procedures recently adopted by the Airlie Conference on the standardization of anthropometric measurements (Harrison *et al.* 1988). Measurements were performed on the left side of the body in seven regions: biceps, triceps, subscapular, suprailiac, abdomen, thigh and calf. The ratio of trunk (subscapular, abdomen and suprailiac skinfolds): extremity (biceps, triceps, thigh and calf skinfolds; T:E ratio), was used as an indicator of the relative distribution of subcutaneous fat (Després *et al.* 1985*b*). The sum of seven skinfolds was used as an indicator of subcutaneous fatness. Body-weight was measured to the nearest 0·1 kg on a clinical scale, and body height was measured to the nearest cm, subjects not wearing shoes. Body mass index (BMI) was calculated from body-weight and height (kg/m^2). Waist and hip circumferences were measured following the procedures of the Airlie Conference (Callaway *et al.* 1988). The ratio of waist: hip circumferences (WHR) was used as an anthropometric estimation of the proportion of abdominal relative to lower-extremity fat. Body density was assesssed by the hydrostatic weighing technique described by Behnke & Wilmore (1974). Percentage body fat was calculated from body density according to the equation of Siri (1956). The mean value of six valid body density measurements was used in the calculation of percentage body fat. Pulmonary residual volume was measured using the helium dilution technique (Meneely & Kaltreider, 1949).

Statistical analyses

Pearson's product–moment correlation coefficients were used to quantify the relations between variables. Considerable attention was devoted to the selection of the best anthropometric predictors of the absolute and relative amounts of deep abdominal fat, using the all-possible-regressions selection procedure, residual analysis and influence diagnostics (Neter *et al.* 1985). The Statistical Analysis System (SAS) was used to perform the analyses.

RESULTS

The characteristics of the premenopausal women are presented in Table 1. Ages ranged from 23 to 50 years, but most women were between 30 and 40 years of age. Body mass index, percentage body fat and fat mass values reveal that there was substantial variation in subjects' adiposity, ranging from moderate to massive obesity. Mean WHR value was 0·81 and ranged from 0·64 to 0·93. Although the D:T ratio at the abdominal level was comparable to that measured at the lower chest region, the absolute amount of deep abdominal fat was higher than the amount of deep fat at the lower chest region. The percentage of deep relative to total adipose tissue areas at the abdominal region ranged from 9 to 33 %.

Relations between adipose tissue areas obtained from CAT scans, and total body fatness and the WHR are shown in Table 2. Total adipose tissue area from the abdominal level was highly correlated with body fat mass (r 0·93, $P < 0·001$), whereas total adipose tissue areas from lower chest and mid-thigh regions showed lower correlations with body fat mass (r 0·77 and 0·69 respectively, $P < 0·001$) than abdominal area. The body fat mass was not significantly associated with the D:T ratio at the abdominal region. The relation between D:T ratio at the abdominal level and the WHR was only moderately high (r 0·49, $P < 0·001$). Although the age variation was relatively small in our sample, there was nevertheless a significant association between age and the percentage, as well as the absolute amount, of deep abdominal fat (r 0·39 and 0·30 respectively, $P < 0·01$).

Fig. 1 illustrates the relation between total adipose tissue volume computed from three

Table 1. *Characteristics of the sample of fifty-one obese women*
(Mean values and standard deviations)

	Mean	SD	Range
Age (years)	35·7	5·5	23·0–50·0
BMI (kg/m²)	34·2	5·0	25·6–46·5
Percentage body fat	45·9	5·6	32·1–58·3
Fat mass (kg)	41·0	10·5	22·0–66·8
WHR	0·81	0·05	0·64–0·93
Computed tomography*			
Lower-chest:			
Deep fat	70·42	32·60	17·48–181·00
Subcutaneous fat	283·65	85·12	142·42–526·00
Deep:total fat ratio	0·20	0·06	0·05–0·34
Abdomen:			
Deep fat	128·12	47·22	49·50 – 234·00
Subcutaneous fat	533·94	125·56	250·16–812·00
Deep:total fat ratio	0·19	0·05	0·09–0·33
Mid-thigh:			
Deep fat	18·89	27·09	4·46–202·58
Subcutaneous fat	464·51	90·06	288·12–646·30
Deep:total fat ratio	0·04	0·05	0·01–0·35

BMI, Body mass index (body-weight/height²); WHR, waist: hip circumferences ratio.
* Adipose tissue areas are expressed in cm².

Table 2. *Correlations between adipose tissue areas obtained from three computed axial tomography scans, and total adiposity and the waist:hip circumferences ratio (WHR)*

Adipose tissue areas from scans	Age	BMI	Fat mass	Sum of seven skinfolds	WHR
Lower-chest:					
Total fat	−0·01	0·80***	0·77***	0·48***	0·57***
Deep fat	0·06	0·66***	0·64***	0·38**	0·39**
Subcutaneous fat	−0·04	0·75***	0·73***	0·46***	0·58***
Deep:total fat ratio	0·08	0·19	0·18	0·14	0·03
Abdomen:					
Total fat	0·11	0·85***	0·93***	0·66***	0·32*
Deep fat	0·30*	0·70***	0·72***	0·62***	0·55***
Subcutaneous fat	0·02	0·79***	0·88***	0·58***	0·18
Deep:total fat ratio	0·39**	0·20	0·17	0·28*	0·49***
Mid-thigh:					
Total fat	0·17	0·61***	0·69***	0·56***	−0·03
Deep fat	0·01	0·05	0·10	0·22	0·19
Subcutaneous fat	0·17	0·60***	0·67***	0·50***	−0·09
Deep:total fat ratio	−0·01	0·01	0·04	0·17	0·20

BMI, body mass index (body-weight/height²).
$*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

scans and body fat mass measured by underwater weighing. A highly significant correlation (r 0·94, $P < 0.001$) was observed between these two variables.

There was moderate variation in the associations between the abdominal, subscapular and thigh skinfolds and the subcutaneous adipose tissue areas measured by CAT at the corresponding levels ($0.50 \leqslant r \leqslant 0.70$, values not shown). The subscapular and the abdominal skinfolds showed the highest correlation with the absolute amount of deep

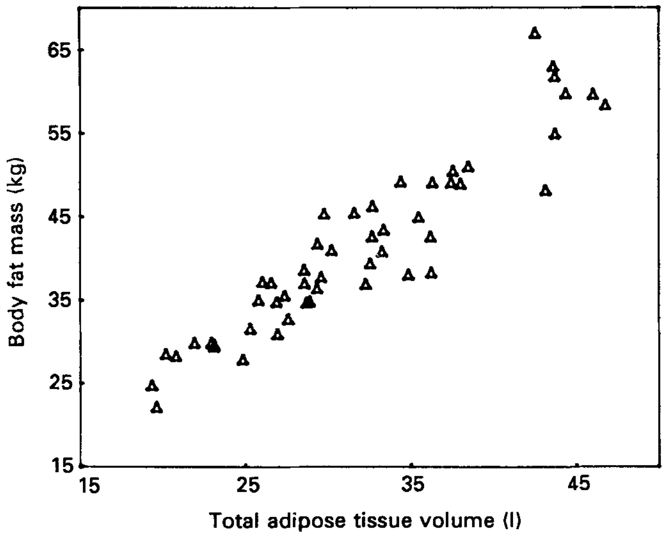

Fig. 1. Relation between total adipose tissue volume, calculated from three computed axial tomography scans, and body fat mass in a sample of fifty-one obese women. The regression equation is: $y = 1{\cdot}3342x - 1{\cdot}3537$, standard error of the estimate 3·77 kg, r 0·94, $P < 0{\cdot}0001$.

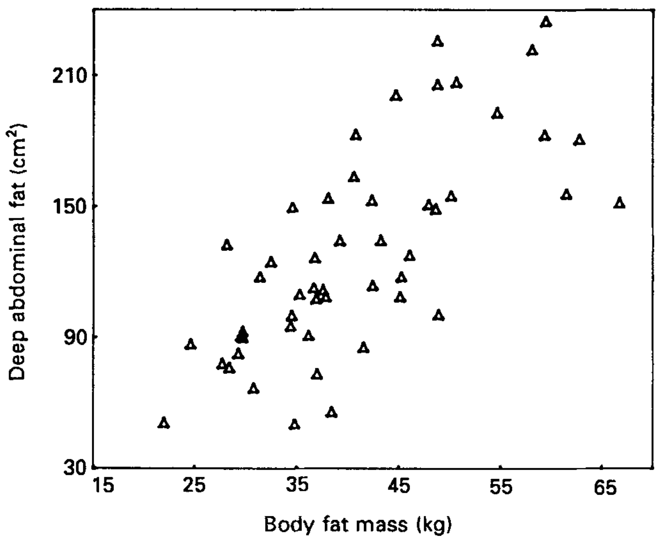

Fig. 2. Relation between deep abdominal fat deposition and body fat mass in a sample of fifty-one obese women. r 0·72, $P < 0{\cdot}0001$.

abdominal fat (r 0·65, $P < 0{\cdot}001$). These skinfolds were also the only two that were significantly correlated with the D:T ratio at the abdominal level (r 0·38, $P < 0{\cdot}001$, values not shown).

Fig. 2 illustrates the relation between the absolute amount of deep abdominal fat and body fat mass, and indicates that the absolute amount of deep abdominal fat was highly correlated with total adiposity. The absolute amount of deep abdominal fat as a function of the WHR is presented in Fig. 3. For a given WHR there was a substantial variation in the absolute amount of deep fat, indicating that a shared variance of only 30% was

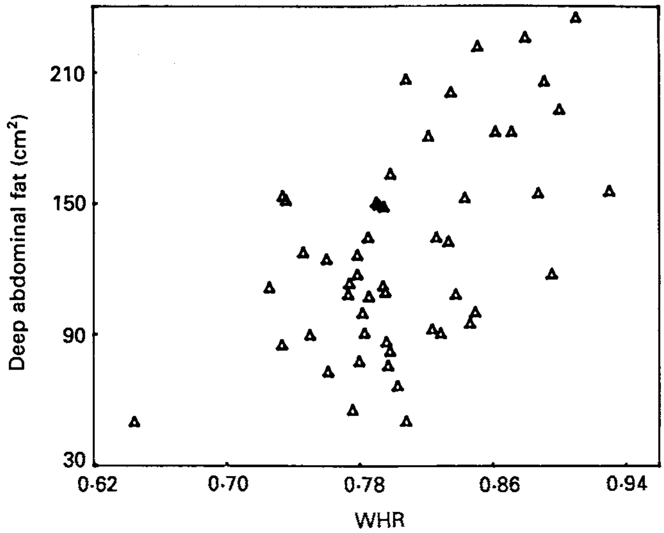

Fig. 3. Relation between deep abdominal fat deposition and the waist: hip circumferences ratio (WHR) in a sample of fifty-one obese women. r 0·55, $P < 0·0001$.

Table 3. *Multiple regression models linking the absolute and relative amounts of deep abdominal fat obtained by computed axial tomography scans to anthropometric measurements and age*

Dependent variable	Independent variable	Regression coefficient	Standard error of regression coefficient	Statistical significance: <	Total $R^2 \times 100$
Deep abdominal fat	Wt	1·0652	0·3378	0·0029	
	Abdominal skinfold	1·6649	0·6446	0·0131	
	Subscapular skinfold	1·6934	0·6938	0·0187	73·7%
	WHR	200·9726	76·0494	0·0113	(25·5)*
	Age	1·7137	0·6604	0·0127	(cm^2)
	Intercept	−292·1026	59·4019	0·0001	
Abdominal D:T ratio	WHR	0·5733	0·1278	0·0001	
	Age	0·0031	0·0009	0·0017	
	Subscapular skinfold	0·0037	0·0011	0·0020	
	Waist circumference	−0·0026	0·0008	0·0022	55·8%
	Abdominal skinfold	0·0023	0·0010	0·0219	(0·036)*
	Suprailiac skinfold	−0·0011	0·0007	0·1165	
	Intercept	−0·2887	0·0844	0·0014	

D:T ratio, deep: total adipose tissue areas; WHR, waist: hip circumferences ratio.
* Values in parentheses represent the standard error of the estimate.

observed between these two variables (r 0·55, $P < 0·001$). This variation in deep abdominal fat deposition may partially explain the moderate association between the WHR and the D:T ratio at the abdominal level.

Multiple-regression analyses were performed to predict the absolute and relative amounts of deep abdominal fat deposition from anthropometric measurements (Table 3). All possibilities were studied (see Methods) and these two regression models displayed the best fit using the anthropometric measures available. The first model used five independent variables, and accounted for 73·7% of the variance in deep abdominal fat deposition. The second model, which included six independent variables, accounted for 55·8% of the variance in the D:T ratio at the abdominal level. These results suggest that, in a sample of obese women, absolute deep abdominal fat deposition can be estimated with more accuracy than its relative amount.

DISCUSSION

Recently body fat distribution has been the subject of considerable attention. The independent contribution of abdominal obesity to several cardiovascular risk factors has contributed to justifying such an interest (Kissebah *et al.* 1982; Lapidus *et al.* 1984; Larsson *et al.* 1984; Després *et al.* 1985*a*; Donahue *et al.* 1987). In addition, studies in which deep abdominal fat was measured by CAT have highlighted its importance in the aetiology of the metabolic complications associated with body fat topography (Shuman *et al.* 1986; Fujioka *et al.* 1987). CAT is, however, expensive and the associated radiation limits its systematic utilization. It is, therefore, important to understand the relation between deep abdominal fat and anthropometric measurements in order to verify whether the former can be predicted by anthropometric methods.

Age and hormonal status

An important feature of the present study was the homogeneity of the subjects for age and hormonal status. Subjects were all premenopausal women and below 50 years of age. We therefore eliminated the variation in body fat distribution that was due to endocrine changes occurring after the menopause. Indeed, a male pattern of fat distribution has been shown to be more frequent in postmenopausal women (Fujioka *et al.* 1987; Enzi *et al.* 1986). On the other hand, our subjects were all obese, their obesity level ranging from moderate to massive. Therefore, these characteristics should be kept in mind in the evaluation of the anthropometric predictors that we have identified.

Three CAT scan procedure v. total adiposity

The close relation observed between the total adipose tissue volume obtained by CAT and body fat mass measured by underwater weighing suggests that a CAT procedure using only three scans can predict body fat mass with moderate accuracy. In the present study the standard error of prediction was 3·77 kg, whereas the mean value was 41·0 kg, representing an error of estimate of less than 10% of the mean.

Variation in deep abdominal fat deposition

As expected, the highest values of deep fat were found at the abdominal level (Table 1). However, there was substantial individual variation in the amount of deep abdominal fat. This situation was partly due to variation in the subjects' adiposity level; a correlation of 0·76 ($P < 0{\cdot}001$) was observed between the waist circumference and the level of deep abdominal fat (values not shown). Thus, there was still about 42% of the variance in deep abdominal fat deposition which remained unaccounted for by the waist circumference. In order to study further the association between the waist circumference and deep abdominal fat deposition, we corrected the waist circumference for the subcutaneous abdominal fat, as reflected by the mean value of the abdominal and suprailiac skinfolds. The resulting relation between the waist circumference corrected for the subcutaneous abdominal fat and the amount of deep abdominal fat was, however, not significant (values not shown). These results suggest that, at least for some individuals, the subcutaneous and deep abdominal fat compartments may expand independently from each other. These results are partly supported by the findings of Björntorp (1984), who estimated the variation in deep abdominal fat with increasing adiposity by correcting the waist circumference for the mean adipose tissue thicknesses of epigastrial and hypogastrial regions. He suggested that the increase in deep abdominal fat was not paralleled by an increase in subcutaneous fat. Our results are also concordant with those of Shuman *et al.* (1986) who reported that the waist circumference was not different between diabetic men and non-diabetics, whereas the area of deep abdominal fat was different, suggesting some independent variation between the waist circumference and deep abdominal fat deposition.

We also observed that in extremely high values of fat mass, the absolute amount of deep abdominal fat tended to level off (Fig. 2), suggesting that, in massively obese women, an increase in abdominal adiposity was due to an increase in subcutaneous fat.

Anthropometry, body density and deep abdominal fat

The abdominal and the subscapular skinfolds were the two skinfolds which showed the highest association with deep abdominal fat. This relation may account for the positive associations that have been reported between metabolic complications and these two skinfolds (Després *et al.* 1985*a*; Donahue *et al.* 1987; Haines *et al.* 1987).

In our sample, the WHR was the best single anthropometric variable associated with the D:T ratio at the abdominal region (values not shown). However, the ability of the WHR to predict the percentage of deep abdominal fat was rather weak (r 0·49, $P < 0{\cdot}001$). Fig. 3 shows that for a given WHR, there was substantial variation in the absolute amount of deep abdominal fat. These results further suggest that the subcutaneous and deep abdominal fat compartments may expand independently from each other in some individuals. Therefore, the independent variation of these two compartments contributes to the explanation of the moderate association between the WHR and the D:T ratio at the abdominal region.

The relation observed between the WHR and the proportion of deep abdominal fat in our sample is similar to the association reported by Sjöström (1988), but it is somewhat at variance with other studies (Ashwell *et al.* 1985; Seidell *et al.* 1987). However, there was large variation in the subjects' age and adiposity in these studies, and these characteristics may have affected the magnitude of the association between the WHR and the CAT scan measurements. This observation further emphasizes the importance of documenting the characteristics of the subjects when studying the association between anthropometry and CAT-derived measurements.

The relation between body fat mass and the D:T ratio at the abdominal level was not significant, indicating that, in premenopausal obese women, the relative amount of deep abdominal fat is not associated with the obesity level. This finding is in agreement with other reports using a similar approach (Ashwell *et al.* 1985; Seidell *et al.* 1987) in which no significant association was found between total adiposity and the percentage of deep abdominal fat.

Multiple-regression models

Even though considerable attention was devoted to the selection of anthropometric predictors, multiple-regression models fell short of accounting for more than 74 and 56% of the variance in absolute and relative amounts of deep abdominal fat respectively.

By using transversal and sagittal diameters of the abdomen in their calculations, Sjöström *et al.* (1985) have reported a correlation of 0·976 ($R^2 \times 100 = 95{\cdot}3$) between the visceral adipose tissue volume and the cross-sectional area of the body at the abdominal level. Seidell *et al.* (1987) also applied multiple-regression models in order to predict the absolute and the relative amounts of deep abdominal fat. Their models allowed a prediction of about 80 and 32% of the variance in the absolute and the relative amounts of deep abdominal fat respectively, results reasonably close to the findings of the present study. We believe that these results taken as a whole, in a homogeneous sample, show that deep abdominal fat deposition cannot be predicted from anthropometric measurements with a very high accuracy.

CONCLUSIONS

It is concluded that in premenopausal obese women, the utilization of three CAT scans (lower chest, abdomen and mid-thigh) can provide a reasonably good estimate of total body fat mass. Also, in these subjects, there is no significant association between total adiposity and the proportion of deep abdominal fat. The significant relation between subscapular and abdominal skinfolds and deep abdominal fat may account for the positive associations that have been frequently reported between metabolic complications and these two skinfold measurements. Finally, these results indicate that in a group of premenopausal obese women, the absolute amount of deep abdominal fat can be predicted from anthropometric measurements with more accuracy than the percentage of deep abdominal fat.

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REFERENCES

Ashwell, M., Cole, T. J. & Dixon, A. K. (1985). Obesity: new insight into the anthropometric classification of fat distribution shown by computed tomography. *British Medical Journal* **290**, 1692–1694.

Barret-Connor, E. L. (1985). Obesity, atherosclerosis, and coronary artery disease. *Annals of Internal Medicine* **103**, 1010–1019.

Behnke, A. R. & Wilmore, J. H. (1974). *Evaluation and Regulation of Body Build and Composition*. Englewood Cliffs, New Jersey: Prentice-Hall.

Berchtold, P., Jorgens, V., Finke, C. & Berger, M. (1981). Epidemiology of obesity and hypertension. *International Journal of Obesity* **5**, Suppl. 1, 1–7.

Björntorp, P. (1984). Morphological classifications of obesity: what they tell us, what they don't. *International Journal of Obesity* **8**, 525–533.

Borkan, G. A., Gerzof, S. G., Robbins, A. H., Hults, D. E., Silbert, C. K. & Silbert, J. E. (1982). Assessment of abdominal fat content by computed tomography. *American Journal of Clinical Nutrition* **36**, 172–177.

Callaway, C. W., Chumlea, W. C., Bouchard, C., Himes, J. H., Lohman, T. G., Martin, A. D., Mitchell, C. D., Mueller, W. H., Roche, A. F. & Seefeldt, V. D. (1988). Circumferences. In *Anthropometric Standardization Reference Manual*, pp. 39–54. [T. G. Lohman, A. F. Roche and R. Martorel, editors]. Champaign, Illinois: Human Kinetics.

Castelli, W. P. (1984). Epidemiology of coronary heart disease: the Framingham study. *American Journal of Medicine* **76**, 4–12.

Després, J. P., Allard, C., Tremblay, A., Talbot, J. & Bouchard, C. (1985*a*). Evidence for a regional component of body fatness in the association with serum lipids in men and women. *Metabolism* **34**, 967–973.

Després, J. P., Bouchard, C., Tremblay, A., Savard, R. & Marcotte, M. (1985*b*). Effects of aerobic training on fat distribution in male subjects. *Medicine and Science in Sports and Exercise* **17**, 113–118.

Donahue, R. P., Abbot, R. D., Bloom, E., Reed, D. M. & Yano, K. (1987). Central obesity and coronary heart disease in men. *Lancet* **i**, 821–824.

Enzi, G., Gasparo, M., Biondetti, P. R., Fiore, D., Semisa, M. & Zurlo, F. (1986). Subcutaneous and visceral fat distribution according to sex, age, and overweight, evaluated by computed tomography. *American Journal of Clinical Nutrition* **44**, 739–746.

Fujioka, S., Matsuzawa, Y., Tokunaga, K. & Tarui, S. (1987). Contribution of intra-abdominal fat accumulation to the impairment of glucose and lipid metabolism in human obesity. *Metabolism* **36**, 54–59.

Grauer, W. O., Moss, A. A,. Cann, C. E. & Goldberg, H. I. (1984). Quantification of body fat distribution in the abdomen using computed tomography. *American Journal of Clinical Nutrition* **39**, 631–637.

Haines, A. P., Imeson, J. D. & Meade, T. W. (1987). Skinfold thickness and cardiovascular risk factor. *American Journal of Epidemiology* **126**, 86–94.

Harrison, G. G., Buskirk, E. R., Carter, J. E. L., Johnston, F. E., Lohman, T. G., Pollock, M. L. & Wilmore, J. (1988). Skinfold thicknesses and measurement technique. In *Anthropometric Standardization Reference Manual*, pp. 55–70 [T. G. Lohman, A. F. Roche and R. Martorel, editors]. Champaign, Illinois: Human Kinetics.

Hubert, H. B., Feinleib, M., McNamara, P. M. & Castelli, W. P. (1983). Obesity as an independent risk factor for cardiovascular disease: a 26-year follow-up of the participants in the Framingham heart study. *Circulation* **67**, 968–977.

Keys, A. (1980). Overweight, obesity, coronary heart disease and mortality. *Nutrition Reviews* **38**, 297–307.

Kissebah, A. H., Vydelingum, N., Murray, R., Evans, D. J., Hartz, A. J., Kalkhoff, R. K. & Adams, P. W. (1982). Relation of body fat distribution to metabolic complications of obesity. *Journal of Clinical Endocrinology and Metabolism* **54**, 254–260.

Krotkiewski, M., Björntorp, P., Sjöström, L. & Smith, U. (1983). Impact of obesity on metabolism in men and women. Importance of regional adipose tissue distribution. *Journal of Clinical Investigation* **72**, 1150–1162.

Kvist, H., Sjöström, L. & Tylén, U. (1986). Adipose tissue volume determinations in women by computed tomography: technical considerations. *International Journal of Obesity* **10**, 53–67.

Lapidus, L., Bengtsson, C., Larsson, B., Pennert, K., Rybo, E., & Sjöström, L. (1984). Distribution of adipose tissue and risk of cardiovascular disease and death: a 12-year follow-up of participants in the population of women in Gothenburg, Sweden. *British Medical Journal* **289**, 1257–1261.

Larsson, B., Björntorp, P. & Tibblin, G. (1981). The health consequences of moderate obesity. *International Journal of Obesity* **5**, 97–116.

Larsson, B., Svardsudd, K., Welin, L., Wilhelmsen, L., Björntorp, P. & Tibblin, G. (1984). Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13-year follow-up of participants in the study of men born in 1913. *British Medical Journal* **288**, 1401–1404.

Lew, E. A. & Garfinkel, L. (1979). Variations in mortality by weight among 750,000 men and women. *Journal of Chronic Diseases* **32**, 563–576.

Meneely, G. R. & Kaltreider, N. L. (1949). The volume of the lung determined by helium dilution. Description of the method and comparison with other procedures. *Journal of Clinical Investigation* **20**, 129–139.

Montenegro, M. R. & Solberg, L. (1968). Obesity, body weight, body length, and atherosclerosis. *Laboratory Investigation* 134–143.

Neter, J., Wasserman, W. & Kutner, M. (1985). *Applied Linear Statistical Models* 2nd ed., pp. 417–429. Homewood, Illinois: Richard D. Irwin Inc.

Royal College of Physicians (1983). Obesity. *Journal of the Royal College of Physicians, London* **17**, 5–65.

Seidell, J. C., Oosterlee, A., Thijssen, M. A. O., Burema, J., Deurenberg, P., Hautvast, J. G. A. J. & Ruijs, J. H. J. (1987). Assessment of intra-abodminal and subcutaneous abdominal fat: relation between anthropometry and computed tomography. *American Journal of Clinical Nutrition* **45**, 7–13.

Shuman, W. P., Newell Morris, L. L., Leonetti, D. L., Wahl, P. W., Moceri, V. M., Moss, A. A. & Fujimoto, W. Y. (1986). Abnormal body fat distribution detected by computed tomography in diabetic men. *Investigative Radiology* **21**, 483–487.

Siri, W. E. (1956). The gross composition of the body. *Advances in Biological and Medical Physics* **4**, 239–280.

Sjöström, L. (1988). Measurement of fat distribution. In *Fat Distribution During Growth and Later Health Outcomes*, pp. 43–61 [C. Bouchard and F. Johnston, editors]. New York: Alan R. Liss.

Sjöström, L., Kvist, H., Cederblad, A. & Tylén, U. (1986). Determination of total adipose tissue and body fat in women by computed tomography, ^{40}K, and tritium. *American Journal of Physiology* **250**, E736–E745.

Sjöström, L., Kvist, H. & Tylén, U. (1985). Methodological aspects of measurements of adipose tissue distribution. In *Metabolic Complications of Human Obesities*, pp. 13–19 [J. Vague, P. Bjorntorp, B. Guy-Grand, M. Rebuffé-Soive and P. Vague, editors]. Amsterdam: Elsevier Science Publishers.

Vague, J. (1947). La différenciation sexuelle: facteur déterminant des formes de l'obésité. *La Presse Médicale* **30**, 339–340.

Van Itallie, T. B. (1979). Obesity: adverse effects on health and longevity. *American Journal of Clinical Nutrition* **32**, 2723–2733.

Weinsier, R. L., Fuchs, R. J., Kay, T. D., Triebwasser, J. & Lancaster, M. C,. (1976). Body fat: its relationship to coronary heart disease, blood pressure, lipids and other risk factors measured in a large male population. *American Journal of Medicine* **61**, 815–823.

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