Abdominal diameters as indicators of visceral fat: comparison between magnetic resonance imaging and anthropometry

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The aim of the present study was to investigate the usefulness of abdominal diameters to indicate visceral fat, their relationship with serum lipids and their capability of detecting changes in visceral fat. Before and after weight loss, visceral and subcutaneous fat, and the sagittal and transverse diameters were assessed by magnetic resonance imaging (MRI) in forty-seven obese men and forty-seven premenopausal obese women with an initial body mass index of 31·0 (SD 2·4) kg/m². In a subsample (*n* 21), diameters, were also measured by anthropometry in the standing and supine positions. They were strongly correlated with the diameters derived from the MRI scans. Serum levels of total and HDL-cholesterol and triacylglycerol were measured before weight loss. In women the sagittal diameter correlated less strongly with visceral fat than anthropometrically-assessed waist circumference and waist:hip ratio (WHR). In men these associations were comparable. Changes in visceral fat with weight loss were more strongly correlated with changes in the sagittal diameter and sagittal:transverse diameter ratio (STR) than with changes in waist circumference or WHR in men. In women, changes in the anthropometric variables and the separate diameters (except STR) were not associated with visceral fat loss. In men, but not in women, both the sagittal diameter and the visceral fat area were related to serum lipids. It is concluded that the sagittal diameter and STR may have advantages over waist circumference and WHR in men, particularly in assessing changes in visceral fat, but this could not be demonstrated in women. The ability to predict visceral fat from circumferences and diameters or their ratios is, however, limited in obese men and women.

Magnetic resonance imaging: Anthropometry: Visceral fat: Obesity: Weight loss

Body fat distribution is an important variable to consider in the associations between obesity and cardiovascular disease (Björntorp, 1990; Després 1991) and between obesity and metabolic complications, such as insulin resistance, hyperinsulinaemia and diabetes mellitus (Björntorp, 1991). The amount of visceral fat plays a critical role in the relationships between regional fat distribution and metabolic complications (Fujioka *et al.* 1987; Björntorp, 1990, 1991; Després, 1991). Imaging techniques, like computed tomography (CT) and magnetic resonance imaging (MRI) allow a precise and reliable measurement of visceral fat (Borkan *et al.* 1982; Staten *et al.* 1989; Seidell *et al.* 1990). However, these imaging techniques are expensive, not generally available and, in the case of CT, expose subjects to ionizing radiation. Estimation of the amount of visceral fat from simple anthropometric variables would, therefore, be useful in clinical settings and also in epidemiological research studying the hazards of 'visceral obesity'.

A common and simple method for the assessment of fat distribution is the determination of the waist:hip ratio (WHR). This ratio is found to be more strongly related to visceral fat than to subcutaneous fat (Ashwell *et al.* 1985; Seidell *et al.* 1987). Nevertheless, WHR has limitations because it is not able to distinguish between subcutaneous and visceral abdominal fat (Baumgartner *et al.* 1988; Stallone *et al.* 1991), and its use to assess changes in visceral fat is controversial (Ross *et al.* 1991; Stallone *et al.* 1991). It has been suggested that the abdominal diameters, in particular the sagittal diameter, represent good predictors for the amount of visceral fat (Kvist *et al.* 1988). The aim of the present study was to investigate the usefulness of abdominal diameters as predictors for visceral fat in comparison with waist circumference and WHR in obese men and women. The relationships between abdominal diameters and serum lipids and the ability of the diameters to detect changes in visceral fat were also studied in this population.

SUBJECTS AND METHODS

Subjects and study design

Ninety-six obese subjects (forty-eight men and forty-eight premenopausal women), aged between 25 and 51 years, were selected for the study. The subjects were apparently healthy, as assessed by their medical history, a physical examination, blood screening and a urine test. They had a body mass index (BMI) between 28 and 38 kg/m^2. All volunteers gave their written informed consent to participate in the study that was approved by the Medical Ethical Committee of the Department of Human Nutrition.

Before the weight loss treatment, body composition and anthropometric measurements were performed in the same week that blood samples were taken. The MRI scans were made within 5 weeks after body composition was assessed. Body weight was stable during this 5-week period. Data from one man were missing due to illness and data from one woman could not be used because of technical problems with MRI scanning.

Weight loss was achieved by using a 4·2 MJ/d energy-deficient diet, comprising carbohydrate, 42% of energy (% E), protein, 25% E, and fat, 33% E for 13 weeks. The composition of the diet was calculated using the Dutch computerized food composition table (NEVO Foundation, 1985). Special slimming products and ordinary foodstuffs were combined in the diet. Individual energy deficits were based on estimated daily energy requirements calculated from resting metabolic rate, measured by a ventilated-hood system, in combination with the physical activity pattern (Weststrate & Hautvast, 1990). Throughout the study, compliance was checked by dietitians by means of interviews and body weight measurement every two weeks. After weight loss treatment the MRI scans and body composition and circumference measurements were repeated.

Seventy-eight of the subjects (forty women, thirty-eight men) completed all parts of the weight loss programme successfully. Seven subjects withdrew due to intercurrent illness unrelated to the intervention (one man, one woman) or for personal reasons (two men, three women). Results of two men were excluded because of suspicion of poor dietary compliance. In addition, in seven subjects (four men, three women) only the MRI scans before weight loss could be used because of measurement errors (see pp. 48–49).

MRI

MRI scans were performed with a whole-body scanner (GYROSCAN S15, Philips Medical Systems, Best, The Netherlands) using a 1·5 T magnetic field (64 MHz) and an inversion recovery pulse sequence (inversion time 300 ms, repetition time 820 ms, and echo time 20 ms) (Seidell *et al.* 1990). Slice thickness was 10 mm. The performance of one measurement took 10 min. One single transverse scan was taken halfway between the lower rib margin and the iliac crest with the subject lying supine. This site was determined by palpation and the location was about on the L4–L5 vertebra. During the experiments, however, it appeared that some subjects moved a little or that the site was misjudged. As a consequence, abdominal scans of seven subjects differed in location before compared with after weight loss. These subjects were excluded from statistical analysis to separate the effect of weight loss from measurement error. Image analyses to determine the abdominal fat areas were carried out as described by Seidell *et al.* (1990). The reproducibility of the fat-area determination was assessed by repeating the estimation of the visceral and subcutaneous fat areas in a random sample of thirty-seven abdominal scans before and forty-five abdominal scans after weight loss. The reproducibility, expressed as coefficient of variation (two-way analysis of variance), was 5·0 % for the visceral fat area before weight loss and 5·7 % after weight loss, and for the subcutaneous fat area 2·2 % before weight loss, and 2·0 % after weight loss. The sagittal and transverse diameters were obtained from the MRI scan as described by Kvist *et al.* (1988).

Body composition and anthropometry

Body weight was measured to the nearest 0·05 kg using a digital scale and height was measured to the nearest 0·1 cm using a wall-mounted stadiometer with the subjects wearing a swimming suit. BMI was calculated as weight (kg) divided by height (m). Waist circumference was measured midway between the lower rib margin and the iliac crest and hip circumference was measured at the level of the widest circumference over the great trochanters. Both circumferences were measured at the end of a gentle expiration while subjects were standing. The variability of duplicate measurements in a subsample of the population (*n* 46) of the waist and hip circumference was 1·4 and 0·7 % respectively. Whole-body density was determined by underwater weighing (Siri, 1961) with simultaneous measurement of the residual lung volume by a Helium dilution technique (Comroe *et al.* 1977). The measurements were done four times and the average density was used for the calculation of the percentage body fat (Siri, 1961). Percentage body fat of two women was determined from body weight and total body water as assessed by deuterium oxide dilution assuming 73·2 % of the fat-free mass to be water (Pace & Rathbun, 1945). These two women were afraid of complete immersion. Comparison between densitometry and the deuterium oxide dilution technique in this population showed good agreement (Van der Kooy *et al.* 1992). Three skinfold measurements (Harpenden skinfold caliper, Holtain Ltd Crymych, Dyfed) were taken: the supra-iliac and the subscapular (Durnin & Womersley, 1974) and the para-umbilicalis (Seidell *et al.* 1987). The variability of these skinfold measurements in a subsample of the population (*n* 39) was 6·6, 5·0 and 6·7 % respectively. The supra-iliac skinfold could not be measured in four subjects before weight loss because the skinfold thickness exceeded the width of the calliper ($>$ 45 mm). For the same reason subscapular skinfold thicknesses in four subjects were missing and para-umbilicalis skinfold thicknesses in eight subjects were missing. In a subsample of twenty-one subjects (ten men, eleven women) the abdominal diameters were also assessed by anthropometry in both a standing and supine position. The standing diameters and supine transverse diameter were measured by a calliper. The supine sagittal diameter was determined by a stadiometer as the distance between abdomen and back while lying on a couch. All diameters were assessed at the end of a gentle expiration at the same level at which the MRI scan was taken (halfway between the lower rib margin and the iliac crest) and this site was determined by palpation. Reproducibility of the anthropometric diameters was not assessed.

Serum lipids

Two blood samples were taken, with an interval of 2 d after an overnight fast. The mean value of the two samples was used in statistical analysis. HDL-cholesterol, after precipitation by dextran sulphate-Mg^{2+} (Warnick *et al.* 1982), and total serum cholesterol were determined using an enzymic method (Siedel *et al.* 1983). LDL-cholesterol was calculated using the equation of Friedewald *et al.* (1972). Serum triacylglycerol level was determined as described by Sullivan *et al.* (1985). The within run coefficient of variation of control sera was 1·4% for total cholesterol, 1·6% for HDL-cholesterol and 1·7% for triacylglycerols. Accuracy for total cholesterol and triacylglycerols was checked by analysis of serum pools of known value provided by the US Centers of Disease Control (Atlanta, GA, USA). The mean bias with regard to these target values was +0·13 mmol/l for total cholesterol and −0·02 mmol/l for triacylglycerols. Accuracy for HDL-cholesterol was checked by serum pools of known value produced by Solomon Park Research (Kirkland, WA, USA). The mean bias with regard to the target value was +0·08 mmol/l HDL-cholesterol (Leenen *et al.* 1992). Results of blood analyses of three subjects were excluded for statistical analysis because one man and one woman were diagnosed as having subclinical hyperthyroidism and another woman appeared subsequently to have hyperinsulinaemia (> 100 μU/ml).

Statistical analyses

Linear regression analysis and the method described by Bland & Altman (1986) were used to compare the agreement between the diameters assessed anthropometrically and those derived from the MRI scans. Differences between men and women were tested with the Student's *t* test. Pearson's product-moment correlation coefficients were used to quantify the relations between variables after checking the normality of the distributions of the variables. Logarithmic transformed values were used for triacylglycerols to achieve a normal distribution. Although the distribution of visceral fat area, visceral: subcutaneous fat ratio and changes in visceral fat and visceral: subcutaneous fat ratio with weight loss in women were slightly skewed, we do not present results with transformed variables as none of the transformations improved the strength and linearity of associations. Partial correlation coefficients were computed for associations between serum lipids and fat-distribution variables with age and fat mass as covariates. Effects of weight loss on variables were tested using a paired *t* test. Two-sided *P*-values were considered statistically significant at $P < 0.05$. The SAS statistical package (SAS Institute, Cary, NC, USA) was used to perform the analyses.

RESULTS

It was checked whether the diameters from the MRI scans were comparable to the anthropometrically-assessed abdominal diameters. Fig. 1(a) and 1(b) illustrate the relationships between the abdominal diameters measured in standing and supine positions, and the MRI diameters. No differences in relationships and deviations were found between the sexes, therefore the data of men and women were combined. The standing and supine anthropometric sagittal diameters differed systematically from the sagittal MRI diameter (MRI minus anthropometry; −1·4 cm (SE 0·3) and +1·6 cm (SE 0·3), $P < 0.001$ respectively) which is illustrated in Fig. 1(c) and 1(d). The standing and supine transverse anthropometric diameters were both smaller on average than the transverse MRI diameter (MRI minus anthropometry; +1·8 cm (SE 0·3) and +1·9 cm (SE 0·4), $P < 0.001$ respectively). In Fig. 1(c) it can be seen that the difference increased between the MRI and standing sagittal anthropometric diameters in subjects with large sagittal diameters. This was not found for the supine sagittal anthropometric diameter (Fig. 1(d)) and for the standing and supine transverse anthropometric diameters with their MRI equivalents (r 0·18, $P = 0.45$ and r 0·15, $P = 0.52$ respectively).

The characteristics of the subjects and fat distribution variables measured by MRI and anthropometry are presented in Table 1. Men had more visceral fat than women on average, both absolute and relative, expressed as visceral: subcutaneous fat ratio ($P < 0.001$).

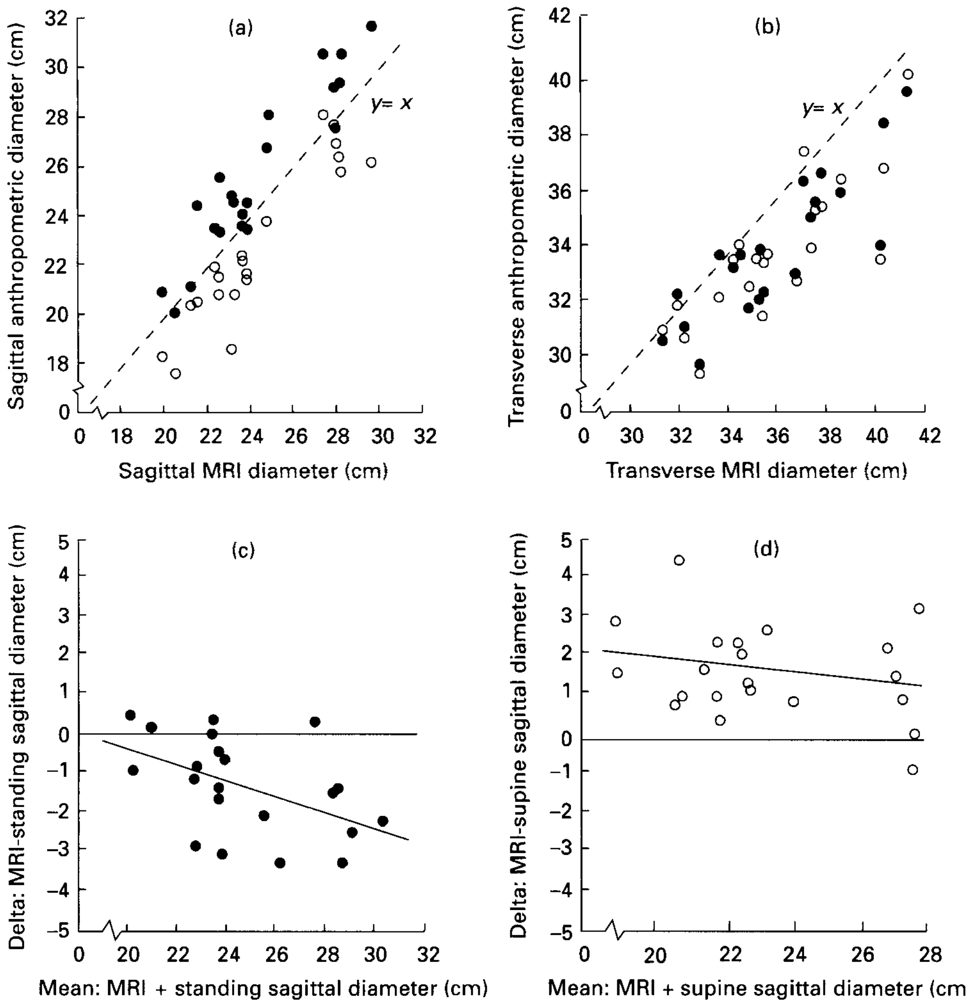

Fig. 1. The relationships between abdominal diameters ((a) sagittal, (b) transverse) derived from magnetic resonance imaging (MRI) and anthropometric diameters in standing (●) and supine (○) positions, and the relationships between the difference and mean of the anthropometrically assessed standing (c) and supine (d) sagittal diameters with the MRI-derived diameters in a subsample of twenty-one subjects. (a) Standing r 0·94, $P < 0·001$, supine r 0·93, $P < 0·001$; (b) standing r 0·85; $P < 0·001$, supine r 0·82, $P < 0·001$; (c) r −0·46, $P = 0·03$; (d) r −0·28, $P = 0·22$. For details of procedures, see pp. 48–49.

In Table 2 the relationships between abdominal fat areas, and the sagittal and transverse diameters, sagittal:transverse diameter ratio (STR), waist circumference and WHR are shown. In women, waist circumference and WHR showed the strongest correlations with visceral fat, with WHR differentiating the best between visceral and subcutaneous abdominal fat. In men, the sagittal diameter, waist circumference and WHR were comparably associated with visceral fat, but they were all also associated with subcutaneous fat. The relative amount of visceral fat (visceral:subcutaneous fat ratio) was weakly associated with STR and WHR only in women. Strong interrelationships were found between waist circumference and both diameters, sagittal and transverse (men, r 0·84 and

Table 1. *Descriptive characteristics of the subjects and body fat distribution variables measured by magnetic resonance imaging (MRI) and anthropometry*†

(Mean values with their standard deviations)

	Women (*n* 47)		Men (*n* 47)	
	Mean	SD	Mean	SD
Age (years)	39	6	40	6
Body wt (kg)	86·4	8·7	98·4*	8·7
Height (m)	1·66	0·06	1·79*	0·06
Body mass index (kg/m^2)	31·3	2·4	30·7	2·4
Fat mass (kg)	37·6	6·4	32·6*	6·3
Body fat distribution variable				
Visceral fat area‡ (cm^2)	108	47	156*	43
Subcutaneous fat area‡ (cm^2)	391	100	316*	78
Visceral:subcutaneous ratio	0·29	0·13	0·52*	0·17
Sagittal diameter‡ (cm)	23·5	2·2	25·0*	1·9
Transverse diameter‡ (cm)	36·2	3·1	36·0	2·0
Sagittal:transverse ratio	0·65	0·05	0·69*	0·04
Waist circumference§ (cm)	99·4	7·3	107·2*	6·8
Waist:hip ratio	0·87	0·07	0·98*	0·05

Statistical significance of difference between men and women: * $P < 0·001$, Student's *t* test.
† For details of procedures, see pp. 48–49.
‡ Derived from abdominal MRI scan.
§ Measured by anthropometry.

Table 2. *Correlations between abdominal fat areas and diameters, circumferences and their ratios*†

(Results shown as Pearson correlation coefficients)

	Abdominal fat areas					
	Women (*n* 47)			Men (*n* 47)		
	Visceral fat area‡ (cm^2)	Sub-cutaneous fat area‡ (cm^2)	Visceral: sub-cutaneous ratio	Visceral fat area‡ (cm^2)	Sub-cutaneous fat area‡ (cm^2)	Visceral: sub-cutaneous ratio
Sagittal diameter‡ (cm)	0·51***	0·68***	0·09	0·61***	0·65***	0·08
Transverse diameter‡ (cm)	0·27	0·89***	−0·18	0·45**	0·68***	−0·05
Sagittal:transverse ratio	0·35*	−0·14	0·32*	0·39**	0·22	0·15
Waist circumference§ (cm)	0·60***	0·55***	0·23	0·57***	0·73***	0·01
Waist:hip ratio	0·64***	0·16	0·42**	0·55***	0·30*	0·22

Statistical significance of Pearson correlation coefficients: * $P < 0·05$; ** $P < 0·01$; *** $P < 0·001$.
† For details of procedures, see pp. 48–49.
‡ Derived from abdominal magnetic resonance imaging scan.
§ Measured by anthropometry.

0·82; women, *r* 0·76 and 0·71 respectively; $P < 0·001$), but only weak interrelationships were found between STR and WHR (men, *r* 0·37, $P = 0·01$; women, *r* 0·23, $P = 0·11$).

The associations between visceral fat and the sagittal diameter improved as expected when adjustments were made for thickness of the subcutaneous abdominal fat layer, which

Table 3. *Serum lipid levels (mmol/l) and their relationship with body fat distribution variables adjusted for age and fat mass*†

	Lipid levels (mmol/l)		Visceral fat area‡ (cm^2)	Sagittal diameter‡ (cm)	Transverse diameter‡ (cm)	Sagittal: transverse ratio	Waist girth§ (cm)	Waist: hip ratio
	Mean	SD	Pearson correlation coefficients					
Women (*n* 45)								
Total cholesterol	5·59	0·88	0·01	0·14	0·08	0·07	0·03	−0·09
LDL-cholesterol	3·78	0·73	−0·05	0·15	0·14	0·03	0·05	−0·05
HDL-cholesterol	1·23	0·25	−0·33*	−0·23	−0·22	−0·03	−0·52***	−0·53***
Triacylglycerol	1·27	0·50	0·49***	0·28	0·07	0·21	0·54***	0·41**
Men (*n* 46)								
Total cholesterol	5·81	0·97	0·28	0·31*	−0·09	0·33*	0·11	0·20
LDL-cholesterol	4·01	0·84	0·26	0·25	−0·01	0·23	0·14	0·19
HDL-cholesterol	0·96	0·19	−0·08	−0·06	−0·06	−0·01	−0·09	−0·05
Triacylglycerol	1·86	0·71	0·21	0·31*	−0·27	0·44**	0·02	0·20

Statistical significance of Pearson correlation coefficients: * $P < 0·05$; ** $P < 0·01$; *** $P < 0·001$.
LDL, low density lipoprotein; HDL, high density lipoprotein.
† For details of procedures, see pp. 48–50.
‡ Derived from abdominal magnetic resonance imaging scan.
§ Measured by anthropometry.

could also be obtained from the MRI scan (men, *r* 0·72; women, *r* 0·86; $P < 0·001$). We attempted to adjust the diameters for this abdominal fat layer with the sum of trunk skinfolds (supra-iliac, subscapular and para-umbilicalis skinfold) and with the trunk skinfolds separately. The associations with visceral fat, however, did not improve (results not shown).

In both sexes, age and body fat mass contributed to the relationships between abdominal fat areas and anthropometric fat-distribution variables. Age was significantly correlated with visceral fat in both men (*r* 0·53, $P < 0·001$) and women (*r* 0·39, $P = 0·006$). Fat mass was related to visceral fat in men (*r* 0·52, $P < 0·001$), but only weakly in women (*r* 0·26, $P = 0·08$). When the relationships were adjusted for age and fat mass, WHR remained the best predictor for visceral fat in women (*r* 0·60, $P < 0·001$) and it did not show a significant correlation with subcutaneous fat (*r* 0·23, $P = 0·13$). In men, the sagittal diameter as well as STR were the strongest correlates of visceral fat (*r* 0·39, $P = 0·008$ and *r* 0·38, $P = 0·01$ respectively).

The associations of serum lipids with visceral fat and the potential visceral fat predictors are shown in Table 3. Adjustments for age and fat mass were made to evaluate the independent role of abdominal fat distribution in the lipid profile. In women, the correlates of HDL-cholesterol and triacylglycerol with sagittal diameter or STR were much weaker than the correlates found with visceral fat, waist circumference and WHR. In men, on the contrary, sagittal diameter and STR were positively related to total cholesterol and triacylglycerol levels while visceral fat showed only a weak correlation at borderline significance with total cholesterol ($P = 0·06$). Neither waist circumference nor WHR was significantly associated with any of the serum lipids in men, but WHR showed similar trends with the lipids as did visceral fat.

The weight-loss treatment resulted in a comparable mean weight reduction in men and women (13·3 kg (SD 3·0) and 12·6 kg (SD 3·9) respectively) of which an average of 82% was fat loss (10·3 kg in men and 10·9 kg in women). Table 4 shows the changes in body fat

Table 4. *Reductions in body fat distribution variables† with weight loss‡*

(Mean values with their standard deviations)

	Women (*n* 40)		Men (*n* 38)	
	Mean	SD	Mean	SD
Visceral fat area§ (cm^2)	37	29	61**	25
Subcutaneous fat area§ (cm^2)	118	56	110	45
Visceral:subcutaneous ratio	0·02‡	0·07	0·05	0·10
Sagittal diameters§ (cm)	3·3	1·6	4·4*	1·4
Transverse diameter§ (cm)	3·9	2·6	3·2	1·2
Sagittal:transverse ratio	0·02	0·04	0·07**	0·03
Waist circumference‖ (cm)	12·0	4·6	14·6*	3·8
Waist:hip ratio	0·04	0·04	0·08**	0·03

Statistical significance of difference between men and women: * $P < 0·01$, ** $P < 0·001$, Student's *t* test.

† For details of procedures, see pp. 48–50.

‡ Reductions in all variables were significant ($P < 0·001$) except for the change in visceral:subcutaneous ratio in women, which was not significant (paired *t* test).

§ Derived from abdominal magnetic resonance imaging scan.

‖ Measured by anthropometry.

Table 5. *Correlations between changes in abdominal fat areas, and changes in diameters, circumferences and their ratios†*

(Results shown as Pearson correlation coefficients)

	Changes in abdominal fat areas					
	Women (*n* 40)			Men (*n* 38)		
	Visceral fat area‡ (cm^2)	Sub-cutaneous fat area‡ (cm^2)	Visceral: sub-cutaneous ratio	Visceral fat area‡ (cm^2)	Sub-cutaneous fat area‡ (cm^2)	Visceral: sub-cutaneous ratio
Sagittal diameter‡ (cm^2)	0·10	0·76***	−0·29	0·56***	0·46**	0·16
Transverse diameter‡ (cm^2)	−0·18	0·71***	−0·39*	0·34*	0·43**	0·09
Sagittal:transverse ratio	0·32*	0·01	0·14	0·40*	0·27	0·09
Waist circumference§ (cm)	0·14	0·58***	−0·18	0·33*	0·63***	−0·10
Waist:hip ratio	0·21	0·23	0·01	0·18	0·37*	−0·12

Statistical significance of Pearson correlation coefficients: * $P < 0·05$; ** $P < 0·01$; ** $P < 0·001$.

† For details of procedures, see pp. 48–50.

‡ Derived from abdominal resonance imaging scan.

§ Measured by anthropometry.

distribution variables with weight loss. Men lost on average more visceral fat than women, but the change in visceral:subcutaneous fat ratio did not significantly differ between the sexes ($P = 0·22$).

Correlations between the reductions in abdominal fat areas and abdominal diameters, waist circumference and WHR are presented in Table 5. In women, only the change in STR was weakly correlated with the change in visceral fat, whereas the reductions in the separate diameters and waist circumference were highly correlated with changes in subcutaneous fat. In men, the changes in both abdominal diameters, in particular the sagittal diameter, and

Table 6. *Comparison between the visceral fat area derived from the abdominal magnetic resonance imaging scan*† *and visceral fat predicted from formulas reported in the literature*

	Comparison between measured and predicted visceral fat area									
	Women					Men				
		Measured – predicted area (cm^2)		Correlation measured with predicted area			Measured – predicted area (cm^2)		Correlation measured with predicted area	
Source	*n*	Mean	SE	*r*‡	CV%	*n*	Mean	SE	*r*‡	CV%
Seidell *et al.* (1987)	47	+16	5**	0·62	34	40§	+2	5	0·66	21
Kvist *et al.* (1988)	47	−9	6	0·51	37	47	−31	5***	0·61	22
Ferland *et al.* (1989)	43§	−46	5***	0·68	33		—			
Després *et al.* (1991)‖		—				47	+1	4	0·75	19
Després *et al.* (1991)¶		—				47	−8	5*	0·69	20
Ross *et al.* (1992)		—				47	+42	5***	0·52	23

Statistical significance of difference between measured and predicted area: * $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$, paired *t* test.
† For details of procedures, see pp. 48–50.
‡ Correlation coefficients were all statistically significant, $P < 0·001$.
§ The comparison was made with fewer subjects because of missing skinfolds.
‖ Prediction formula including the sagittal diameter.
¶ Prediction formula without the sagittal diameter.

the waist circumference were related to changes in visceral fat, however, they were also related to changes in subcutaneous fat. The change in the relative amount of visceral fat (visceral:subcutaneous ratio) was not correlated to change in STR and WHR, in either sex.

DISCUSSION

The comparison between anthropometrically assessed diameters and diameters derived from the MRI scans was important for the rationale of the present study in which only MRI diameters could be used. Since a good agreement was found between anthropometric and MRI diameters, further analyses with MRI-derived diameters were appropriate. Similar agreements between scan and anthropometric diameters have been reported by Kvist *et al.* (1988) and Després *et al.* (1991). The comparability of the diameters is also confirmed by the correlations found between the visceral fat area and the diameters in the subsample of twenty-one subjects. In women (*n* 11), the correlation between visceral fat and the sagittal MRI diameter was *r* 0·76 ($P = 0·007$), whereas the correlation between visceral fat and the anthropometrically assessed supine diameter was *r* 0·72 ($P = 0·01$). These relationships in men (*n* 10) were *r* 0·66 ($P = 0·04$) and *r* 0·61 ($P = 0·06$) respectively. A good comparison between the MRI and supine anthropometric abdominal diameters could be expected because the MRI diameters were also measured in the supine position. In the standing position with increasing obesity, gravity in combination with abdominal muscle strength and constitution of the abdominal adipose tissue mass may cause shifts in the abdominal fat mass (Baumgartner *et al.* 1988). Therefore, supine diameters were expected to be preferable over standing diameters. The present study showed, however, that this may be true for the standing sagittal diameter (Fig. 1(*c*)) but not for the standing transverse diameter and not, as reported by Ross *et al.* (1992), for waist circumference.

It has been suggested that in the supine position an increased accumulation of visceral fat would maintain the depth of the abdomen in a sagittal direction while subcutaneous abdominal fat would reduce the abdominal depth due to gravity (Sjöström, 1991). This was a reason to expect that the sagittal diameter and STR were useful indicators for visceral fat and why they were probably more specific than waist circumference and WHR. The results of the present study showed, however, that the sagittal diameter was comparable to waist circumference and WHR as an indicator of visceral fat in obese men. The changes in sagittal diameter and in the diameter ratio were, on the other hand, better in detecting changes in visceral fat than waist circumference and WHR. In women, waist circumference and WHR were superior to abdominal diameters in assessing visceral fat. The associations between visceral fat and abdominal diameters were also revealed by the relationships of the diameters with serum lipids in both sexes.

All the potential visceral fat predictors examined in the present study were only moderately associated with the amount of visceral fat. The present study was performed in obese subjects and this may partly explain why the correlations between visceral fat and anthropometric measures are relatively low compared to other studies. In previous studies the correlations between visceral fat and WHR ranged between 0·55 and 0·85 in women (Ashwell *et al.* 1985; Kvist *et al.* 1988; Ferland *et al.* 1989) and between 0·60 and 0·88 in men (Kvist *et al.* 1988; Seidell *et al.* 1989; Després *et al.* 1991; Ross *et al.* 1992). A wider range in age, body fatness or both compared with the present study may have enhanced the associations (Després *et al.* 1991).

The ability to predict the amount of visceral fat by abdominal diameters improves when appropriate adjustments are made for the subcutaneous abdominal fat layer. Skinfold thickness measurements for assessing the subcutaneous abdominal fat layer were shown not to be useful in this population, confirming the results of Hayes *et al.* (1988). Other techniques should be developed for this purpose.

Another phenomenon may have interfered with the strength of the associations presented here. In the present study the amount of visceral fat was assessed by an area of only one single scan. Although previous studies have shown that the visceral fat area of a single scan taken on the L4–L5 level is highly correlated to the volume of visceral fat estimated from multiple scans (Kvist *et al.* 1988; Ross *et al.* 1992), intestine volumes and partial volume effects (Seidell *et al.* 1990) may have caused errors in the visceral fat estimation from a single scan. Such errors in the visceral fat area may have lowered the associations in the present study. Associations between changes in visceral fat areas and anthropometric variables will be attenuated even more because of the possible errors in the visceral fat areas estimated before as well as after the weight change (Sjöström, 1991; Ross *et al.* 1992). Despite this limitation, the correlations between visceral fat loss and changes in both the sagittal diameter and STR in men and STR in women were superior to the correlations with waist circumference and WHR.

In the present study, no prediction formulas were generated for the assessment of visceral fat because of the population specificity of such formulas and the moderate associations we have found. In Table 6 a comparison is made between measured (MRI) and predicted amount of visceral fat in this study population, by using prediction equations reported in the literature. All formulas were generated by measuring abdominal fat areas or volumes by CT or MRI and choosing a set of anthropometric variables which resulted in the highest explained variance. Only the equation of Ferland *et al.* (1989) was generated for obese women, whereas the other formulas were generated for populations varying in age and body fatness. The correlations between measured and predicted visceral fat areas were moderate. Some equations predicted systematically larger and some smaller areas but the coefficients of variation for all formulas were large and comparable within a sex: in men around 20% and in women around 35%. The results confirm the conclusion of Després *et al.* (1991) that the ability to predict visceral fat from anthropometry is limited.

In summary, the sagittal diameter and the diameter ratio may have advantages over waist circumference and WHR in men, particularly in assessing changes in visceral fat. In women, waist circumference and WHR were superior to abdominal diameters. The results indicate that simple anthropometric measurements, which differ between the sexes, can only provide rough information about the amount of visceral fat.

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