Computed Axial Tomographic Scan Measurement of Abdominal Fat Distribution and Its Correlation With Anthropometry and Insulin Secretion in Healthy Asian Indians

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Asian Indians have high insulin resistance, hyperinsulinemia, a high prevalence of diabetes, and a high waist to hip ratio (WHR), although the rate of obesity is low. WHR and visceral fat (VF) are highly correlated, and both are associated with insulin resistance. This study was performed to determine the normal ranges of abdominal fat distribution (subcutaneous [SF] and VF) in nondiabetic South Indians and also to study its correlations with WHR, plasma insulin, and metabolic profiles. Fat areas were measured by computed axial tomographic scan at the L_4 to L_5 level. Mean areas of SF and VF in men and women in this study were similar to the values in white populations. Women had significantly less VF than men. Gender differences were observed in the contribution of fat areas to anthropometric, hormonal, and metabolic variables. In general, in men, total fat (TF) area showed significant independent correlation with body mass index (BMI), WHR, and total cholesterol, and VF correlated with insulin secretion. In women, TF and BMI were correlated and SF showed a correlation with total cholesterol. Insulin secretion in women did not show a correlation with fat areas.

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SERIAL EPIDEMIOLOGIC STUDIES in urban South Indians have shown that they have a high prevalence of diabetes, and it is increasing.[1-4] Although the study group has a low prevalence of obesity measured as the body mass index (BMI), an increase in BMI even in the non-obese range has been noted to be a risk factor for diabetes.[2,3] Moreover, despite the low BMI, they have high upper-body adiposity, measured as the waist to hip ratio (WHR). WHR also was an additional risk factor for diabetes.[2,3] Several reports have shown that for a given BMI, Asian Indians have a higher WHR compared with whites.[5-7] WHR and visceral fat (VF) were highly correlated, and both were associated with insulin resistance; the risk associated with high WHR was considered to be due to VF.[8-10] Hitherto, there have been no studies on the direct measurement of abdominal fat distribution in Indians. In this study, we measured the distribution of abdominal fat in the subcutaneous (SF) and VF areas by computed axial tomographic scan in normal healthy Indian men and women. The correlation of fat areas with the insulin secretory response was also studied.

SUBJECTS AND METHODS

All persons in this study underwent a standard oral glucose tolerance test (OGTT) with 75 g glucose, and glucose tolerance was classified according to World Health Organization criteria.[11] Forty healthy controls (aged 36 ± 10 years; male to female ratio, 21:19) with normal glucose tolerance and no known family history of diabetes were selected for the study. All of them provided written consent for the study. All women in this study were of premenopausal age.

Anthropometric measurements including height, weight, and waist and hip girth were made by standard procedures described previously.[2,3] BMI and WHR were calculated. Systolic (SBP) and diastolic (DBP) blood pressure were also measured.

The mean intake of calories in the study group was 1,400 to 2,250 kcal/d. All of them were habituated to a high-carbohydrate, cereal-based diet with an approximate composition of 60% carbohydrate, 20% protein, and 20% fat, and had no changes in the routine diet pattern at least 1 week before the OGTT. None of them had a change in body weight recently. During the OGTT, plasma samples were collected for glucose, fasting lipid (total cholesterol, high-density lipoprotein cholesterol [HDL-C], low-density lipoprotein cholesterol [LDL-C], very-low-density lipoprotein cholesterol, and triglycerides [TG]), serum insulin, and C-peptide (CP) measurements.

Plasma glucose level was measured by the glucose oxidase method and lipid levels by enzymatic procedures using Boehringer Mannheim (Mannheim, Germany) reagents and a Hitachi 704 autoanalyzer. Serum IRI was determined by a radioimmunoassay procedure using a kit supplied by the Bhabha Atomic Research Centre (Bombay, India). A modified procedure of Herbert et al[12] with a double antibody and PEG precipitation was used. The lowest detection limit was 2 μU/mL, and intraassay and interassay coefficients of variation (CV) were less than 5% and less than 7%, respectively. The CP level was measured using radioimmunoassay reagents from Diagnostic Systems Laboratories (Texas). The intraassay CV was 5.5%, interassay CV less than 4.8%, and lowest detection limit 0.003 pmol/mL. Areas under the curves were calculated using Thai's formula.[13] Ratios of insulin to glucose areas were calculated and represented as I/G. The incremental area of insulin at 30 minutes (30-minute value − fasting value) was divided by the glucose concentration at 30 minutes (IRI in picomoles and glucose in millimoles) and represented as ΔI/G for evaluating β-cell secretion.[14,15]

Fat measurements were made using a Hitachi W.450 x-ray CT system. The details of test procedures were as follows: exposure time, 2.8 seconds; slice thickness, 10 mm; exposure factors, 90 mA, 120 kV, Filter 2°, attenuation values: mesenteric fat, −90 to −110; retroperitoneal fat, −120 to −130; and SF, −130 to −145. Measurements were taken at the L_4 to L_5 level. Areas of fat were expressed as centimeters squared. Mesenteric and retroperitoneal fat areas were added to obtain the VF area. VF by SF ratios (V/S ratios) were calculated.[16] VF and SF areas were added to obtain total fat area (TF).

Statistical Analysis

Values are given as the mean ± SD. Intergroup variations were tested by ANOVA or *t* test as relevant. Multiple linear regression analyses were performed to determine the correlation of various fat areas to anthropometry and lipid and hormonal variables. Fat areas, insulin area, and CP area were logarithmically transformed for regression analysis. The SPSS package (Version 4.01; SPSS, Chicago, IL) was used for the calculations. Pearson's correlations between the various parameters were also determined. Data on fat measurements were tested separately in men and women due to the differences in fat distribution.

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Table 1. Anthropometric Data and Fat Areas in Men and Women

Variable	Men (n = 21)	Women (n = 19)
Age (yr)	37 ± 10.8	36 ± 9.7
BMI (kg/m²)	26.8 ± 4.1	25.3 ± 3.1
Waist girth (cm)	86.8 ± 10.8	78.8 ± 7.9
WHR	0.9 ± 0.06	0.86 ± 0.07
Fat area (cm²)		
TF	316 ± 124	330 ± 99
SF	218 ± 81	273 ± 86
VF	98 ± 51	57 ± 22*
V/S ratio	0.45 ± 0.15	0.22 ± 0.1*

NOTE. Values are the mean ± SD.
*$P < .05$ *v* men by ANOVA.

RESULTS

There were 21 men (aged 21 to 55 years; BMI, 21.2 to 37.7 kg/m²) and 19 women (aged 23 to 53 years; BMI, 21.3 to 31.0 kg/m²) in the study. Table 1 shows the anthropometric data and fat areas in men and women. TF areas were similar in men and women, but men had a higher VF area and V/S ratio than women ($P < .05$).

Table 2 shows the biochemical data in men and women. Women had higher HDL-C and lower TG than men ($P < .05$). Fasting CP was also lower in women ($P < .05$).

Table 3 shows the correlations for fat areas with anthropometric data and BP. As expected, fat areas were interrelated significantly. In men, age showed a positive correlation with TF and VF, but this correlation was absent in women. In men, TF, SF, and VF showed significant correlation with BMI and waist girth. In women, only TF and SF showed significant correlation with BMI, and TF, SF, and VF showed significant correlations with waist girth. WHR correlated with all fractions of fat in men, but only with VF in women. The V/S ratio was correlated with DBP in men, and VF and the V/S ratio were correlated with SBP in women.

Table 4 shows the correlation of fat areas with the plasma lipid parameters studied. Total cholesterol and LDL-C were significantly correlated with all the fat areas studied in men and women. HDL-C was correlated with TF and SF in men, but it was negatively correlated with the V/S ratio in women. TG did not show a correlation with any of the fat areas in both sexes.

Table 2. Biochemical Data in the Study Group (mean ± SD)

Variable	Men (n = 21)	Women (n = 19)
Plasma glucose (mg/dL)		
Fasting	100 ± 8.0	97 ± 7.0
2-hour	101 ± 16	110 ± 15
Cholesterol (mg/dL)		
Total	185 ± 33	174 ± 24
LDL	113 ± 27	110 ± 19
HDL	40 ± 7.0	45 ± 6.7*
TG	138 ± 48	94 ± 23*
Plasma insulin (μU/mL)		
Fasting	20 ± 14	16 ± 7
2-hour	68 ± 50	78 ± 39
Plasma CP (pmol/mL)		
Fasting	0.72 ± 0.21	0.49 ± 0.15*
2-hour	1.61 ± 0.67	1.71 ± 0.81

*$P < .05$ *v* men by ANOVA.

Table 3. Correlations (*r*) of Fat Areas with Anthropometric Data and BP in Controls

	Men				Women			
	TF	SF	VF	V/S Ratio	TF	SF	VF	V/S Ratio
TF	—	.956‡	.890‡	.293	—	.978‡	.693‡	.049
SF	.956‡	—	.718‡	.015	.978‡	—	.527*	−.147
VF	.890‡	.718‡	—	.674‡	.693‡	.527*	—	.715‡
Age	.41*	.250	.575†	.575†	.323	.277	.358	.177
BMI	.936‡	.897‡	.830‡	.230	.703‡	.719‡	.379	−.046
Waist girth	.960‡	.938‡	.832‡	.262	.525*	.466*	.560†	.312
WHR	.682‡	.690‡	.548†	.160	.286	.210	.436*	.245
DBP	.061	−.034	.200	.427*	−.051	−.100	.140	.369
SBP	.235	.168	.297	.327	.178	.080	.449*	.526*

*$P < .05$.
†$P < .01$.
‡$P < .001$.

Table 5 shows correlations between the fat areas with blood glucose and hormonal parameters. In men, 2-hour insulin, insulin area, and fasting CP were correlated with VF and the V/S ratio. TF was also correlated with insulin area, fasting CP, and I/G. In women, 2-hour CP and CP area showed a correlation with the V/S ratio. ΔI/G showed an inverse correlation with TF and SF only in women.

Table 6 presents the results of multiple linear regression analyses in men and women showing the independent contributions of the fat areas to the anthropometric data, plasma glucose, and lipid parameters studied. TF area contributed significantly to BMI in men and women. In men, TF contributed significantly to the waist girth ($R^2 = 91\%$), whereas in women the contribution was only 20% from TF and 36.4% from age. WHR was mainly related to TF in men, but in women it showed an independent correlation only with age. In men, glucose responses were not directly correlated with fat areas. In women, TF was related to fasting plasma glucose. Total cholesterol showed a correlation with TF in men and SF in women. None of the other lipid parameters were related to fat areas in men and women. VF showed a significant correlation with fasting CP and insulin area in men, whereas in women no correlation between fat areas and CP or insulin was seen (Table 7).

DISCUSSION

Several studies have evaluated the relation between visceral adiposity and metabolic profiles, but most of them have been in

Table 4. Correlations (*r*) of Fat Areas With Lipid Profiles in Controls

	Men				Women			
	TF	SF	VF	V/S Ratio	TF	SF	VF	V/S Ratio
Total cholesterol	.538†	.534†	.449*	.199	.559†	.527*	.454*	.089
LDL-C	.570*	.495*	.442*	.203	.549*	.466*	.624†	.340
HDL-C	.387*	.370*	.344	.169	.275	.354	−.103	−.470*
TG	.240	.262	.163	.050	.341	.383	.064	−.177

*$P < .05$.
†$P < .01$.

Table 5. Pearson Correlation Coefficients Between Fat Areas and Hormonal Profile in Controls

	Men				Women			
	TF	SF	VF	V/S Ratio	TF	SF	VF	V/S Ratio
2-hour glucose	.035	.011	.065	.062	−.006	.021	−.098	.041
Insulin								
Fasting	.229	.268	.127	−.066	−.149	−.138	−.127	−.049
2-hour	.291	.138	.476*	.617†	−.319	−.350	−.089	.295
Area	.395*	.248	.553†	.601†	−.282	−.326	−.023	.293
CP								
Fasting	.457*	.350	.544†	.463*	.307	.287	.257	.077
2-hour	.251	.200	.285	.187	−.245	−.302	.050	.446*
Area	.060	−.007	.152	.257	−.089	−.152	.163	.446*
ΔI/G	−.108	−.150	−.023	.181	−.436*	−.450*	−.218	.233
I/G	.362*	.236	.495*	.541†	−.325	−.364	−.062	.246

*$P < .05$.
†$P < .01$.

European populations[8,10,17-21] and in Japanese-Americans.[9,22-24] This is the first study on visceral adiposity in Asian Indians. Asian Indians as an ethnic group have a high risk of diabetes and coronary heart disease.[5]

Age and BMI were similar in men and women in this study. TF areas were also similar. Women had more SF and significantly less VF than men. These are well-known differences in fat distribution attributed to differences in body shape in the two genders. In South Indian men, both BMI and WHR were significantly correlated with SF and VF and therefore with TF areas. Waist girth also showed strong correlations with these fat areas. Interestingly, women showed a different pattern. VF in women did not correlate with BMI, but was correlated with WHR. In women, waist girth correlated with all three fat measurements, but to a lesser degree than in men. Our previous epidemiologic studies have shown a strong association of WHR with the risk of diabetes in both sexes.[2,3] The fact that VF correlated with WHR in men and women indirectly indicates the specific association of VF with the risk of diabetes. Multiple regression analysis showed that the variance in WHR in men was explained to the extent of 53% by TF, thus showing no independent association of VF and WHR. In women, age contributed 43.5% of the variance in WHR, and the effect of VF was nullified.

Although gender differences were noted in the effect of VF on DBP and SBP, generally, only VF or the V/S ratio correlated with BP. In a study of a large number of nondiabetic Japanese-Americans, Boyko et al[22] have shown a strong correlation of intraabdominal fat with BP.

Abdominal fat areas did not show a correlation with 2-hour plasma glucose in men and women. Despres et al[18] showed a significant association of glucose area during the OGTT with the area of deep abdominal fat in obese women. Sparrow et al[21] and Fujioka et al[24] also found a similar correlation with 2-hour plasma glucose and VF area in men, but diabetic subjects were not excluded from these studies. Seidell et al, [17] studying healthy men, found that those with a larger VF area showed a higher plasma glucose area compared with men having less VF. One of the reasons for the disparity in the results of our study versus prior studies may be the inclusion of only normoglycemic individuals with a narrow range of plasma glucose values.

Total cholesterol and LDL-C were correlated with all fat

Table 6. Results of Multiple Linear Regression Analyses

	Significant Variables									
		Men					Women			
Dependent Variable		R^2 (%)	β	SEB	*P*		R^2 (%)	β	SEB	*P*
1. BMI*	TF	78.6	9.36	1.12	.0000	TF	54.0	7.75	1.74	.0003
2. Waist girth*	TF	91.0	0.0008	0.00006	.0000	Age	36.4	0.447	0.1370	.0049
						TF	20.0	0.00036	0.00013	.00154
3. WHR*	TF	52.9	0.104	0.022	.0002	Age	43.5	0.0048	0.0013	.0021
4. Fasting glucose†			None			TF	21.0	10.11	4.76	.048
5. 2-hour glucose†	FCP	20.1	44.9	10.8	.0007	2-hour Ins	41.4	0.223	0.069	.0053
	2-hour CP	30.7	12.42	3.29	.0015					
	2-hour Ins	18.3	0.148	0.047	.0056					
6. Total cholesterol‡	TF	41.0	54.5	15.0	.0018	SF	26.2	38.82	15.8	.025
7. HDL-Chol‡			None					None		
8. TG‡			None					None		

NOTE. Fat areas and insulin areas were logarithmically transformed. Variables: *age, TF, SF, VF, V/S ratio; †age, BMI, WHR, TF, SF, and VF; ‡2-hour plasma glucose, BMI, WHR, fat areas, age.

Table 7. Results of Multiple Linear Regression Analyses–Hormonal Parameters

Dependent Variable	Significant Variables									
	Men					Women				
		R^2 (%)	β	SEB	*P*		R^2 (%)	β	SEB	*P*
CP										
Fasting	VF	23.4	0.195	0.081	.0264			None		
2-hour	2-hour Glu	30.7	0.024	0.0081	.0091	2-hour Glu	27.0	0.028	0.0112	.0225
Area	Age	24.1	0.019	0.0076	.024	Area Glu	42.8	0.0029	0.0008	.0024
Insulin										
Fasting			None					None		
2-hour	V/S ratio	36.7	188.8	53.1	.0023			None		
	2-hour Glu	13.9	1.18	0.52	.037	2-hour Glu	41.4	1.86	0.57	.0053
Area	Area Glu	41.3	0.0024	0.0001	.016			None		
	VF	12.1	0.308	0.142	.044			None		

NOTE. Variables included age, BMI, WHR, TF, SF, VF, V/S ratio, plasma glucose.

areas in both sexes. On multiple regression analysis, total cholesterol had an independent correlation with TF area in men and only with SF in women. HDL-C, which showed a negative correlation with the V/S ratio, failed to show an independent correlation with any of the fat areas tested in multivariate analysis. Despres et al[18] had shown that in non-obese premenopausal women, SF and abdominal fat cell hypertrophy were related to changes in plasma lipoproteins, whereas the WHR and deep abdominal fat had little association with these metabolic profiles. Their results had shown that obesity is a prerequisite for a significant association between intraabdominal fat and lipid profiles in women, but not necessarily in men.

In men, VF and the V/S ratio appeared to contribute to insulin secretion, as shown by the independent contribution to fasting CP and insulin and the insulin area in plasma. These results indicate an association of VF with hyperinsulinemia in men. Seidell et al[17] showed a significant positive association between male abdominal adiposity and insulin and CP levels, both during fasting and in response to oral glucose in Swedish men. In our study, women showed no independent association of VF with insulin or CP responses.

This study was made to establish the ranges for abdominal fat areas in normoglycemic men and women, and also to assess their contribution to the anthropometric measurements and metabolic profiles. Gender differences were present in the contribution to the parameters studied. These varied differences could be related to the interplay of sex hormones, which influence both fat distribution and metabolism.[19,25] In general, in men, TF area had a significant correlation with BMI, WHR, and total cholesterol. In men, VF was correlated with insulin secretion. Women showed a correlation of TF and BMI, and SF was correlated with total cholesterol. None of the fat areas studied showed an independent correlation with insulin secretion in women.

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