Site-specific differences in the fatty acid composition of abdominal adipose tissue in an obese population from a Mediterranean area: relation with dietary fatty acids, plasma lipid profile, serum insulin, and central obesity[1–3]

Marta Garaulet, Francisca Pérez-Llamas, Millán Pérez-Ayala, Pedro Martínez, Fermín Sánchez de Medina, Francisco J Tebar, and Salvador Zamora

ABSTRACT

Background: Abdominal obesity is associated with coronary risk, although causality is not well established.

Objective: In an obese Mediterranean population, we measured the fatty acid composition of adipose tissue, its relation with dietary fatty acids and central fat deposition, and its influence on plasma lipids and insulin.

Design: Adipose tissue samples were obtained from 84 obese patients (29 men, 55 women) aged 30–70 y (body mass index, in kg/m^2: 27–35). We measured concentrations of insulin and lipids in plasma and fatty acids in subcutaneous, omental, and perivisceral fat. Dietary fatty acid intake was assessed with a 7-d diet record.

Results: The population studied was normolipidemic and normoinsulinemic. There were important differences in fatty acid composition between tissue sites: saturated fatty acids were higher and monounsaturated fatty acids were lower in perivisceral than in subcutaneous fat ($P < 0.05$). Significant correlations were found for oleic, linoleic, α-linolenic, and total n−6 polyunsaturated fatty acids between the subject's habitual diet and adipose tissue composition. Oleic and n−3 fatty acids from adipose regions were negatively correlated with apolipoprotein B and triacylglycerols; adipose tissue 22:1n−9, 20:2n−6, stearic acid, and eicosapentaenoic acid were positively correlated with HDL and apolipoprotein A; and adipose tissue myristic acid was negatively correlated with apolipoprotein A ($P < 0.05$). Central obesity was positively associated with n−6 polyunsaturated fatty acids and inversely associated with monounsaturated fatty acids and n−3 polyunsaturated fatty acids in adipose tissue ($P < 0.05$).

Conclusion: The differences found in the composition and metabolism of perivisceral, omental, and subcutaneous fats may indicate that their atherogenic capacities also differ. *Am J Clin Nutr* 2001;74:585–91.

KEY WORDS Obesity, central obesity, cardiovascular risk, adipose tissue, body fat, dietary fatty acids, Mediterranean diet, heart disease, coronary artery disease, cardiovascular disease, atherosclerosis, dietary fat

INTRODUCTION

Cardiovascular disease accounts for a large proportion of deaths among adults in the Western world. Abdominal obesity, especially visceral obesity, is associated with coronary risk, although causality is not well established. The relation is not simply a function of overall obesity, because increased waist-to-hip ratio (WHR) is associated with increased coronary risk even in nonobese persons (1). This raises the question of why intraabdominal fat mass is so strongly related to several diseases and their risk factors. Insulin resistance may be a key factor in this link. Many studies have pointed to an association between insulin resistance and intraabdominal fat accumulation (2, 3).

Adipose tissue may play an important role in the development of atherosclerosis because adipose tissue fatty acids are in constant interchange with plasma (4), and plasma triacylglycerols are probably the major source of endogenous and exogenous fatty acids for the synthesis of complex lipids. Varying proportions of fatty acids from adipose tissue may be related to atherosclerosis and other diseases and might exert a direct influence on serum lipids that may differ depending on the adipose tissue region. It was suggested that intraabdominal fat has a higher turnover rate than does subcutaneous fat (5), and therefore the former may have a greater influence on the plasma lipid profile. There is conflicting information about differences between the fatty acid composition of subcutaneous and deep visceral adipose tissue. Some authors suggest that intraabdominal adipose tissue is enriched with saturated fatty acids and that this composition could contribute to the coronary risk associated with abdominal obesity (6).

The fatty acid composition of adipose tissue is partially dependent on dietary intake (7). Changing the nature of the fat consumed has a profound influence on the fatty acids available to the body. Therefore, modifying the sources of dietary fat may alter the composition of adipose tissue. On the other hand, the endogenous synthesis of nonessential fatty acids, predominantly

[1] From the Department of Physiology and Pharmacology, University of Murcia, Murcia, Spain; the Department of Biochemistry, University of Granada, Granada, Spain; and the Departments of Biochemistry and Endocrinology, Arrixaca Hospital, Murcia, Spain.

[2] Supported by a grant from the Official College of Pharmacists of Murcia.

[3] Address reprint requests to F Pérez-Llamas, Department of Physiology and Pharmacology, University of Murcia, 30100-Murcia, Spain. E-mail: frapella@um.es.

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in the form of saturated and monounsaturated fatty acids, may also be a contributing factor to human adipose tissue composition, although the significance of this contribution to the fatty acid pool in humans was questioned (8, 9).

Few studies have related the factors discussed above with consumption of a typical Mediterranean diet, even though it was established that diets high in olive oil, and consequently high in oleic acid, are strongly associated with the low cardiovascular disease mortality found in Spain and most other Mediterranean countries of Europe (10). The aim of the present study was to determine the fatty acid composition of intra- and extraabdominal adipose tissue, its relation with dietary fatty acids and central fat deposition, and its influence on plasma insulin and the lipid profile in an obese population of a Mediterranean area of southeast Spain.

SUBJECTS AND METHODS

Subjects

A total of 84 subjects (29 men and 55 women, aged 30–70 y) were selected from the outpatient clinics of the University Virgen de la Arrixaca, the General University, and the Morales Meseguer hospitals in Murcia, Spain. All the subjects were obese, with a body mass index (BMI; in kg/m^2) of 27–35, and were being admitted to the hospital for abdominal surgery or laparoscopy for gallbladder disease without icterus, ulcer, or umbilical hernia. Potential subjects were excluded from the study if they were following a special diet or taking steroid or thyroid medication, or they had diabetes mellitus, chronic renal failure, hepatic disease, or cancer. All subjects gave their written, informed consent, and the study was approved by the Ethics Committee of the Virgen de la Arrixaca Hospital.

Adipose tissue sample collection, anthropometrics, and body composition

Abdominal adipose tissue samples were obtained during surgery. Subcutaneous samples were taken from the periumbilical region and intraabdominal samples were taken from the perivisceral fat (surrounding the gallblader) and the omental fat. Depending on the type of surgery (laparotomy or laparoscopy) and the pathology (gallbladder, eventration, or ulcer), omental or perivisceral fat was obtained. Samples were stored at −70°C until analyzed. Body weight was measured to the nearest 0.1 kg while subjects were dressed in their underwear, and height was measured to the nearest centimeter. From these data, the BMI was calculated. Total body fat (%) was derived from the biceps, triceps, suprailiac, and subscapular skinfold-thickness measurements (11). All measurements were obtained on the right side, with the subject upright and relaxed. A Harpenden caliper (Holtain Ltd, Crymmych, United Kingdom) with a constant pressure of 10 g/mm^2 was used. Body fat distribution was assessed by measuring waist circumference at the level of the umbilicus and hip circumference over the widest part of the greater trocanters. Measurements were made 3 times by a single operator. The WHR and conicity index [waist circumference/(0.109 $\sqrt{(\text{weight/height})}$, where waist circumference and height are in m and weight is in kg] were calculated (12). Visceral and subcutaneous adipose tissue areas were measured with computed tomography on the basis of the recommendations of Sjöstrom (13) with a Toshiba CBTB007A scanner (Toshiba Corp, Shimoshiqui, Otowawara, Japan). A single 10-mm scan at the L4–L5 level (determined to the nearest 1 mm with a skeleton radiogram) was performed with a 512 × 512 matrix, a window size of 300 Hounsfield units, and a center of 40 Hounsfield units. The subcutaneous abdominal (SA) and visceral abdominal (VA) fat areas were determined from a tomodiagram section by image analysis with a MIP-Microm Image Processing System (Microm, Barcelona, Spain) on the basis of the IMCO 10 (Kontron, Eching, Germany). The ratio of VA to SA was then calculated (14). Note that VA includes both perivisceral and omental fat.

Adipose tissue fatty acid composition

To determine the fatty acid composition of adipose tissue, a direct transesterification procedure was carried out in methanol-benzene (4:1) with acetyl chloride (15). Fatty acids were identified as methyl esters on a Perkin-Elmer 84-10 gas chromatograph (Perkin-Elmer, Norwalk, CT) equipped with a 30 m × 0.25 mm fused-silica capillary column (SP-2380; Teknokroma, Barcelona, Spain). Detection was by flame ionization. The injector and detector temperatures were 210 and 280°C, respectively. Nitrogen was used as the carrier gas. Chromatography was performed with a temperature program that increased from 160 to 208°C by increments of 2°C/min and from 208 to 230°C by increments of 3°C/min. The column temperature was held at 230°C for 7 min. The instrument output was quantified with a Perkin-Elmer GP-100 integrator. The peaks were identified by comparison with standards (Supelco, Bellefonte, PA).

Plasma lipids and insulin

Venous blood samples were obtained after subjects fasted overnight. Plasma concentrations of triacylglycerols, total cholesterol, HDL, LDL, and apolipoprotein (apo) A and B were determined with commercial kits (Roche Diagnostics GmbH, Mannheim, Germany). Serum insulin concentrations were determined with a radioimmunoassay (MNIA, Serono, Italy).

Dietary data

Subjects recorded their dietary intakes for 7 d, after they had undergone surgery. The recorded intakes were typical of their usual diets. We calculated their nutrient intakes with a computer program (16) written on the basis of the Spanish food tables (17). The intakes of fatty acids were calculated from Spanish food-composition tables (18). For each subject, each nutrient intake was calculated as the mean daily intake for the 7 d. These calculations allowed us to estimate the intakes of the major saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs), including linoleic acid (18:2n−6), α-linolenic acid (18:3n−3), and n−3 fatty acids of marine origin.

Statistical analyses

Data are presented as means ± SDs. The Student's *t* test was performed to analyze differences between the sexes. To determine differences in the composition of the 3 adipose tissue regions studied, a two-way (type of fat and subject) analysis of variance (ANOVA) with a post hoc test of least significant difference with Bonferroni correction was used. Pearson's product-moment correlation coefficients were used to quantify the relations between adipose tissue composition, dietary fatty acids, and plasma lipids.

RESULTS

Subject characteristics including age, body weight, BMI, percentage body fat, and measures of body fat distribution (WHR,

TABLE 1
Subject characteristics[1]

	Men (n = 29)	Women (n = 55)
Age (y)	56 ± 15	55 ± 12
Weight (kg)	87.7 ± 13.9	77.2 ± 10.9[2]
Height (cm)	166 ± 9	154 ± 7[2]
Percentage body fat (%)	27.1 ± 2.6	40.2 ± 3.1[2]
BMI (kg/m^2)	24.7 ± 4.7	33.0 ± 3.9
Waist circumference (cm)	110 ± 10	108 ± 12
Hip circumference (cm)	106 ± 10	110 ± 9[3]
WHR	1.04 ± 0.10	0.97 ± 0.08[2]
CI	1.39 ± 0.07	1.40 ± 0.10
VA	200 ± 77	146 ± 75[4]
SA	226 ± 92	361 ± 104[2]
VA:SA	0.88 ± 0.50	0.46 ± 0.34[2]

[1] $\bar{x}$ ± SD. WHR, waist-to-hip ratio; CI, conicity index; VA, visceral abdominal fat area; SA, subcutaneous abdominal fat area.

[2–4] Significantly different from men (Student's t test): [2] $P < 0.001$, [3] $P < 0.05$, [4] $P < 0.01$.

conicity index, and VA:SA) are shown by sex in **Table 1**. There were no significant differences in age, BMI, or waist circumference between the sexes. Percentage body fat was greater in women, whereas the WHR and VA:SA were significantly higher in men. Fasting triacylglycerol, total cholesterol, LDL, HDL, apo A and B, insulin, and glucose concentrations are shown separately for men and women in **Table 2**.

The fatty acid composition of the adipose tissue regions and the subjects' habitual diets is shown in **Table 3**. Because there were no significant differences between the sexes in the proportions of fatty acids, the data are reported for the total subject population combined. The single fatty acid present in the greatest amount was oleic acid (18:1n−9), followed by palmitic acid (16:0) and 18:2n−6. The mean daily intake of dietary fat was 102 ± 41 g for the total subject population. When the fatty acid composition of the subjects' habitual diets was correlated with the composition of adipose tissue by using Pearson's product-moment correlations, significant correlations were found for n−6 PUFAs, 18:2n−6, 18:3n−3, and 18:1n−9 **(Table 4)**.

Differences in fatty acid composition between the 3 adipose tissue regions are shown in **Figure 1**. A two-way (type of fat and subject) ANOVA indicated that the perivisceral fat was the most saturated and contained less MUFA than did the other adipose regions.

Pearson's product-moment correlations between plasma lipid concentrations and the fatty acid contents of subcutaneous (n = 76), perivisceral (n = 57), and omental (n = 24) adipose tissue regions in this obese population were calculated. This indicated that the palmitoleic acid (16:1n−7) content of omental fat was inversely correlated with the total and LDL-cholesterol concentrations (r = −0.39 and −0.55, respectively; P = 0.05 for both). In addition, the n−3 fatty acid content of subcutaneous fat was inversely associated with the triacylglycerol concentration (r = −0.26, $P < 0.05$). The 18:1n−9 content of perivisceral fat was inversely correlated with the apo B concentration (r = −0.26, $P < 0.05$), whereas the stearic acid (18:0) and 22:1n−9 contents of omental fat and the eicosapentaenoic acid (20:5n−3) content of subcutaneous fat were positively correlated with the HDL concentration (r = 0.57, $P < 0.01$; r = 0.74, $P < 0.001$; and r = 0.25, $P < 0.05$, respectively). The 22:1n−9 content of omental fat and the 20:2n−6 content of subcutaneous fat were positively associated with the plasma apo A concentration (r = 0.60, $P < 0.01$, and r = 0.31, $P < 0.01$, respectively); however, in the latter case, 2 values much above the mean may have determined the correlation. In contrast, the vaccenic acid (18:1n−7) content of perivisceral fat was positively correlated with LDL (r = 0.47, $P < 0.01$) and the myristic acid (14:0) content of omental fat was inversely correlated with apo A concentrations (r = −0.41, $P < 0.05$). The 14:0 content of both intraabdominal fats tended to be positively correlated with apo B concentrations, although the correlations were not significant. In addition, the adipose tissue 18:2n−6 concentration tended to be correlated with the plasma LDL concentration (r = 0.22, P = 0.09). Of all the adipose tissue regions, omental fat showed the greatest number of correlations with the plasma lipid profile. There were no significant correlations between serum insulin values and the fatty acid compositions of the 3 adipose tissue regions or the n−3-to-n−6 ratio.

Correlations between degree of obesity (defined by BMI and percentage body fat), central distribution of fat (defined by WHR and VA), and the fatty acid contents of different adipose tissue regions in the total subject population are shown in **Table 5**. The degree of obesity and central distribution of body fat were positively correlated with the total n−6 PUFA content of adipose tissue (especially 18:2n−6 content) and negatively correlated with the MUFA and n−3 PUFA contents of adipose tissue. Serum insulin values were positively correlated with the degree of obesity (r = 0.29, $P < 0.01$ for BMI, and r = 0.28, $P < 0.05$ for percentage body fat) and with the amount of subcutaneous fat (r = 0.38, $P < 0.001$).

DISCUSSION

Visceral obesity has been defined as the condition in which the VA:SA is >0.4 (14). On the basis of this index, the subject population in this study can be defined as having the visceral type of obesity. In addition, the mean waist circumference of our subjects exceeded values established as being associated with cardiovascular disease risk (19). This suggests that our obese population might have high plasma lipid and insulin values. However, plasma lipids and insulin were within the normal ranges for subject age and sex.

The fatty acid composition of adipose tissue observed in this study is consistent with the results of other studies showing that oleic acid is the major component of adipose tissue; however, our values were higher than those found in other populations (20, 21).

TABLE 2
Fasting serum concentrations of lipids, insulin, and glucose[1]

	Men (n = 29)	Women (n = 55)
Triacylglycerols (mmol/L)	2.09 ± 1.18	1.75 ± 0.73
Cholesterol (mmol/L)	4.94 ± 1.12	5.71 ± 1.24[2]
HDL (mmol/L)	1.08 ± 0.38	1.33 ± 0.38[3]
LDL (mmol/L)	3.04 ± 0.88	3.51 ± 1.00
Apolipoprotein A (g/L)	1.15 ± 0.30	1.42 ± 0.50[3]
Apolipoprotein B (g/L)	0.98 ± 0.38	1.16 ± 0.39
Insulin (pmol/L)	94.56 ± 62.20	120.60 ± 5.45
Glucose (mmol/L)	6.88 ± 3.82	6.16 ± 2.72

[1] $\bar{x}$ ± SD.

[2,3] Significantly different from men (Student's t test): [2] $P < 0.0001$, [3] $P < 0.05$.

TABLE 3
Fatty acid composition of adipose tissue regions and habitual diets of the total subject population[1]

Fatty acid	Subcutaneous adipose tissue (n = 76)	Perivisceral adipose tissue (n = 57)	Omental adipose tissue (n = 24)	Diet (n = 76)
		%		
14:0	2.78 ± 1.18	3.09 ± 1.34	2.32 ± 0.79	1.90 ± 1.41
16:0	21.16 ± 3.63	23.30 ± 3.43	19.53 ± 3.33	17.37 ± 3.40
18:0	3.44 ± 1.20	4.33 ± 1.36	3.75 ± 0.89	6.81 ± 2.32
18:3n−3	0.58 ± 0.35	0.41 ± 0.05	0.59 ± 0.52	1.59 ± 1.63
20:5n−3	0.14 ± 0.24	0.09 ± 0.10	0.16 ± 0.23	0.18 ± 0.19
22:6n−3	0.27 ± 0.44	0.35 ± 0.32	0.25 ± 0.25	0.32 ± 0.29
18:2n−6	15.12 ± 5.20	14.82 ± 4.75	15.87 ± 3.95	17.20 ± 8.56
20:2n−6	0.40 ± 0.22	0.48 ± 0.18	0.32 ± 0.24	—
18:3n−6	0.29 ± 0.40	0.25 ± 0.27	0.40 ± 0.42	—
20:3n−6	0.33 ± 0.28	0.39 ± 0.37	0.23 ± 0.20	—
20:4n−6	0.44 ± 0.30	0.42 ± 0.37	0.37 ± 0.24	1.59 ± 1.63
22:4n−6	0.24 ± 0.31	0.18 ± 0.19	0.16 ± 0.17	—
16:1n−7	4.26 ± 1.59	3.42 ± 1.30	4.40 ± 1.55	2.01 ± 1.36
18:1n−7	1.42 ± 3.04	2.47 ± 3.49	2.55 ± 5.04	—
20:3n−7	0.20 ± 0.30	0.09 ± 0.12	0.20 ± 0.41	—
18:1n−9	48.10 ± 6.36	44.64 ± 6.41	48.17 ± 7.27	52.48 ± 9.94
20:1n−9	0.65 ± 0.46	0.77 ± 0.54	0.50 ± 0.55	—
22:1n−9	0.06 ± 0.16	0.05 ± 0.15	0.08 ± 0.19	—
24:1n−9	0.08 ± 0.17	0.16 ± 0.27	0.05 ± 0.10	—
SFA	27.38 ± 5.00	30.73 ± 5.27	25.84 ± 4.16	28.10 ± 8.16
MUFA	54.58 ± 6.40	51.48 ± 6.66	55.80 ± 4.98	53.37 ± 9.90
PUFA	18.03 ± 5.15	17.71 ± 5.31	18.35 ± 3.81	18.52 ± 8.55
n−3	1.01 ± 0.71	1.05 ± 0.59	0.98 ± 0.74	2.11 ± 1.73
n−6	16.38 ± 5.10	16.52 ± 5.02	17.17 ± 3.82	17.11 ± 8.38
n−9	48.37 ± 6.32	45.62 ± 6.32	49.01 ± 7.22	53.37 ± 9.90

[1] $\bar{x}$ ± SD. SFA, saturated fatty acids; PUFA, polyunsaturated fatty acids; MUFA, monounsaturated fatty acids. Perivisceral and omental adipose tissues are both part of the visceral abdominal fat area.

The PUFA values in this study were also higher, whereas SFA values were much lower than those observed in other countries (20, 21). Fat intake in the present study was also different from that recorded in other non-Mediterranean countries: MUFA intake was much higher and SFA intake was much lower in our subjects (22–24). These findings suggest that the population studied, despite being obese with a central distribution of fat, had a fatty acid profile (both in the diet and in adipose tissue) that might be considered protective against cardiovascular disease (25). This might also explain the normal plasma lipid and insulin concentrations observed.

The mean 18:1n−9 concentrations in the subcutaneous and perivisceral adipose tissue were positively associated with dietary intake of oleic acid in our subject population. This finding differs from conclusions reached by using the mathematical model of Beynen et al (26) and by other authors (24). The quantity of oleic acid consumed by our population was high (48.3 g/d), and several studies in animals suggested that the storage of different fatty acids varies with the quantity ingested (27, 28). However, our results agree with those found in a Greek population that also consumed a Mediterranean diet (29).

Our data indicate that there was a positive correlation between the fatty acid composition of the subjects' habitual diets and that of their adipose tissue for n−6 PUFAs, especially 18:2n−6, a finding consistent with Beynen's mathematical model (26). On the other hand, no general association between the 18:3n−3 content of adipose tissue and dietary estimates of 18:3n−3 intake was found; such an association was confined to the omental adipose tissue. This fatty acid, unlike 18:2n−6, was ingested in small amounts (1.59%). Furthermore, despite being an essential fatty acid, 18:3n−3 plays no important metabolic role other than acting as a precursor of other fatty acids of the n−3 family. It is rapidly converted into 20:5n−3 and docosahexaenoic acid (22:6n−3), and therefore is not stored in any appreciable quantities in the adipose tissue (30).

The results showed no associations between the concentrations of n−3 fatty acids or 20:5n−3 and 22:6n−3 in adipose tissue and those in the habitual diet, which contrasts with the findings of other authors who manipulated dietary fat (31, 32). There are several possible reasons such a relation was not evident in this study.

TABLE 4
Pearson's product-moment correlation coefficients (r values) between fatty acid contents of the diet and those of different adipose tissue regions[1]

Diet	Subcutaneous adipose tissue (n = 76)	Perivisceral adipose tissue (n = 57)	Omental adipose tissue (n = 24)
18:3n−3	NS	NS	0.43[2]
18:2n−6	0.44[3]	0.51[3]	0.55[2]
18:1n−9	0.27[2]	0.43[4]	NS
n−6	0.44[3]	0.50[3]	0.46[2]

[1] Perivisceral and omental adipose tissues are both part of the visceral abdominal fat area.
[2] $P < 0.05$.
[3] $P < 0.001$.
[4] $P < 0.01$.

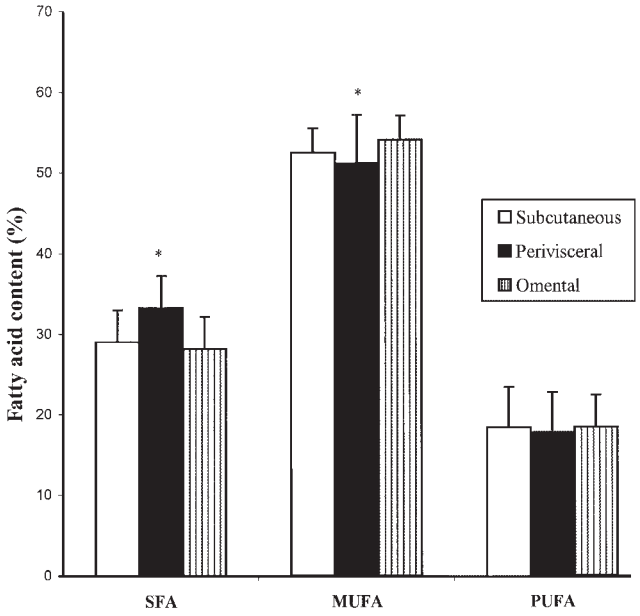

FIGURE 1. Mean (±SD) fatty acid content (%) of subcutaneous, perivisceral, and omental adipose tissue in the subject population (men and women combined). Note that perivisceral and omental adipose tissues are both part of the visceral abdominal fat area. Differences between the adipose tissue regions were tested with a two-way (type of fat and subject) ANOVA with a post hoc test of least significant difference and a Bonferroni correction. *Significantly different from the other 2 adipose tissue regions, $P < 0.05$. SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

First, in our study the intake of this type of fatty acid was low (eg, 0.25 g 22:6n−3/d), whereas intakes were up to 25 times greater (eg, 6 g/d) in intervention studies (33). Second, because of their metabolic importance and molecular structure, these fatty acids can easily move from the tissues in which they accumulate (34). Third, 20:5n−3 and 22:6n−3 can be synthesized endogenously from 18:3n−3.

The mean concentrations of some of the fatty acids were similar in body fat and the diet, although 14:0, 16:0, 16:1n−7 and arachidonic acid (20:4n−6) were present in greater amounts in adipose tissue, whereas concentrations of 18:1n−9 and 18:0 were significantly greater in the diet ($P < 0.05$). These results suggest that 18:1n−9 and 18:0 are preferentially used in the different metabolic pathways, oxidized for energy production, or desaturated or elongated to produce other fatty acids. The higher concentrations of 14:0, 16:0, and 16:1n−7 in the adipose tissue could be a result of their endogenous synthesis from carbohydrate. The low dietary consumption of arachinoic acid and the fact that it is synthesized endogenously from 18:2n−6 (35) might explain the significantly higher concentration found in adipose tissue than in the diet.

When the different adipose tissue sites were compared with each other to ascertain any site-specific differences in fatty acid composition, perivisceral fat was found to be the most saturated, whereas subcutaneous fat was much richer in MUFA. These results differ from those of studies that suggested a homogenous composition of fat throughout the body (36), but they agree with findings that the superficial or subcutaneous fat is softer than the deeper fat (37, 38).

There were no significant differences between the different adipose regions with regard to total PUFA content. These results are consistent with those of many studies (23, 38, 39). The essential fatty acids 18:2n−6 and 18:3n−3 and their metabolic products cannot be synthesized de novo, therefore the diet determines their concentrations in adipose tissue.

The different effects of dietary n−3 fatty acids on cardiovascular diseases have been described comprehensively (40). However, the influence of different adipose tissue concentrations of these fatty acids on plasma lipids is still not clear. The present findings suggest that n−3 fatty acids in subcutaneous adipose tissue are negatively correlated with triacylglycerols and positively correlated with HDL and apo A. These results agree with data obtained in epidemiologic studies from Scotland, Finland, and Italy (41). In our subjects, the degree of obesity (BMI) was negatively correlated with the concentration of n−3 fatty acids in omental fat. The accumulation of central fat (indicted by WHR), especially in the intraabdominal region (VA), was also associated with a lower n−3 fatty acid content in both intraabdominal fats.

Our data also show that the plasma concentrations of apo A decreased significantly as the concentration of 14:0 increased in perivisceral fat, whereas apo B concentrations increased. This suggests that 14:0 in the adipose tissue may play an atherogenic role in obese individuals.

It was suggested that 16:0 is one of the most atherogenic fatty acids in the diet (42). However, our findings showed no relation between the 16:0 contents of adipose tissue and plasma lipids, which is consistent with other studies (41). These results underline the differences between the fatty acids from dietary sources (exogenous) and those of an endogenous origin. When an excess

TABLE 5
Correlations (r) of degree of obesity, indicated by BMI and percentage body fat, and central distribution of fat, indicated by waist-to-hip ratio (WHR) and visceral abdominal fat area (VA), with the fatty acid contents of different adipose tissue regions[1]

Adipose tissue region	BMI	Percentage body fat	WHR	VA
Subcutaneous				
n−6	0.30[2]	0.23[2]	NS	0.29[2]
MUFA	−0.35[3]	−0.27[2]	NS	−0.24[2]
18:1n−9	−0.34[3]	−0.30[2]	NS	NS
18:2n−6	0.29[2]	NS	NS	0.27[2]
Perivisceral				
n−6	0.31[2]	0.39[3]	NS	NS
MUFA	NS	−0.34[2]	NS	NS
18:1n−9	NS	−0.30[2]	NS	NS
18:2n−6	0.29[2]	0.35[2]	NS	NS
20:4n−6	0.40[3]	0.29[2]	NS	NS
22:6n−3	NS	NS	NS	−0.45[3]
Omental				
n−6	0.41[2]	NS	NS	NS
18:1n−9	−0.60[3]	NS	NS	NS
18:2n−6	0.42[2]	NS	NS	NS
n−3	NS	NS	−0.43[2]	−0.63[3]
18:3n−3	−0.41[2]	NS	NS	NS
22:6n−3	NS	NS	−0.43[2]	−0.45[2]

[1] MUFA, monounsaturated fatty acids. Perivisceral and omental adipose tissues are both part of VA.
[2] $P < 0.05$.
[3] $P < 0.01$.

of carbohydrates is consumed, there is a rapid synthesis of 16:0, 18:0, and 18:1n−9, but no corresponding increase in plasma cholesterol concentrations (43).

Despite the fact that 18:0 is an SFA, its concentration in omental adipose tissue was positively correlated with plasma HDL concentrations, as was also found by Berry et al (7) and Hudgins et al (41). Emken (44) suggests that this results in part from the high capacity of the liver to desaturate this fatty acid.

In the present study, perivisceral 18:1n−9 was associated with low apo B concentrations in plasma. Omental 22:1n−9 was correlated with high HDL and apo A concentrations, whereas the 16:1n−7 of this adipose region was associated with low plasma concentrations of LDL and total cholesterol. If we consider that the degree of obesity (BMI and percentage body fat) and central fat distribution (VA) were inversely associated with MUFA concentrations, especially those of 18:1n−9 in every adipose tissue region studied, these data as a whole suggest a protective role of 18:1n−9 against cardiovascular diseases (45). Analyses of all the above data showed that omental fat was the region most strongly correlated with the plasma lipid profile. These findings could be explained by the higher degree of turnover characteristic of this adipose tissue region and could help explain the greater medical risk associated with central obesity.

Insulin values, although within the normal range, were positively correlated with degree of obesity and body fat distribution. Many studies have supported an association between insulin resistance and intraabdominal fat accumulation (2, 3). However, the data indicate that insulin values were positively correlated with subcutaneous fat accumulation. Subcutaneous fat probably plays a major role in determining systemic plasma fatty acid concentrations, which are relevant in determining insulin resistance (5). No correlations were found between insulin values and adipose tissue composition. These results differ from those of in vitro studies that suggested lipids may interact with insulin-stimulated glucose transport (46), but they agree with results of in vivo studies that show no association between the fatty acid profile and insulin sensitivity (47).

In summary, our data show that the studied population, despite being obese, apparently has normal plasma lipid concentrations. These lipid concentrations could be associated with the higher 18:1n−9 and PUFA contents and the lower SFA content found in the diet and adipose tissue compared with non-Mediterranean populations. The differences in composition and metabolism between perivisceral, omental, and subcutaneous abdominal fats indicate that the relations of these different adipose regions with plasma metabolites, and the atherogenic capacity of these adipose regions, also differ.

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