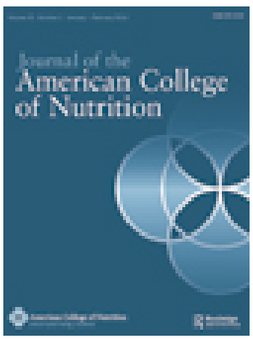

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Higher Waist Circumference Is Related to Lower Plasma Polyunsaturated Fatty Acids in Healthy Participants: Metabolic Implications

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ABSTRACT

Objective: We evaluated whether the relationship between waist circumference (WC) and cardiometabolic risk is related to usual diet and plasma fatty acid composition.

Methods: This cross-sectional study included 226 health professionals from 20 to 59 years old. Anthropometric features, oxidative stress, inflammatory markers, and plasma fatty acid profile were assessed. Dietary intake was evaluated with a semi-quantitative food frequency questionnaire, the quality of dietary habits by Healthy Eating Index, and insulin resistance by homeostasis model assessment–insulin resistance and triglyceride-glucose index.

Results: Higher WC was associated with lower concentrations of high-density lipoprotein cholesterol ($p = 0.000$) and adiponectin ($p = 0.000$) and higher uric acid levels ($p = 0.011$). Plasma polyunsaturated fatty acid (PUFA) levels were negatively associated with weight ($p = 0.046$), systolic blood pressure ($p = 0.035$), fasting glucose ($p = 0.000$), triglyceride-glucose index ($p = 0.023$), and IL-1β ($p = 0.037$). Individuals with elevated WC consumed more calories ($p = 0.002$), niacin ($p = 0.002$), and pyridoxine ($p = 0.017$), but less calcium ($p = 0.001$), phosphorus ($p = 0.016$), and vitamin B2 ($p = 0.011$). In addition, individuals with higher WC denoted lower PUFA concentrations ($p = 0.036$).

Conclusion: The results suggest that participants with higher WC have lower plasma PUFA concentrations and higher levels of saturated fatty acids. This could be related to metabolic and inflammatory changes that could trigger increased risk of metabolic syndrome and cardiovascular disease.

Abbreviations: BMI: body mass index; CVD: cardiovascular disease; DBP: diastolic blood pressure; DHA: docosahexaenoic acid; EPA: eicosapentaenoic acid; HDL-C: high-density lipoprotein cholesterol; HEI: Healthy Eating Index; HOMA-IR: homeostasis model assessment–insulin resistance; IL: interleukin; LDL-C: low-density lipoprotein cholesterol; MDA: malondialdehyde; MetS: metabolic syndrome; NCD: chronic noncommunicable disease; PUFA: polyunsaturated fatty acid; SBP: systolic blood pressure; SFA: saturated fatty acid; TC: total cholesterol; TNF: tumor necrosis factor; TyG: triglyceride-glucose; WC: waist circumference

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Abdominal obesity; metabolic syndrome; polyunsaturated fatty acids; habitual diet; inflammation

Introduction

The prevalence of chronic noncommunicable diseases (NCDs) has increased worldwide and this can be considered the leading cause of death (1). Thus, studies have been conducted to understand risk factors associated with NCDs as well as to propose prevention and treatment strategies (2). Among the NCDs, obesity has been widely investigated because it appears to be an important risk factor for other comorbidities (3).

Abdominal obesity is characterized by fat deposition in the abdominal region and is considered the greatest cardiovascular risk factor and a disturbance in glucose–insulin homeostasis (4). In this regard, the measure of waist circumference (WC) is recognized as a reliable indicator of abdominal adipose tissue amount. Moreover, WC measurement is a low-cost, feasible method (5). This application in clinical practices and scientific studies can be justified by its association with metabolic abnormalities (6). There are reports that subclinical inflammation may be the main association among obesity, insulin resistance, metabolic syndrome (MetS), and cardiovascular disease (CVD). In addition, there are evidences that NCDs are often concomitant with or resulting from previous inflammatory processes (7).

In this context, dietary interventions can assist in the course of subclinical inflammation. Researchers have pointed out that diet quality and quantity play a key prevention role in NCDs, with emphasis on the kind of fatty acids present in food, once the amount and composition of dietary fatty acids can reflect plasma fatty acid composition (8,9). Polyunsaturated fatty acid (PUFA)–rich diets have been shown to be effective in preventing CVD (10). A study conducted in 2012 with 2448 participants indicated that PUFA concentration in plasma is inversely associated with

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interleukin-6 (IL-6) and tumor necrosis factor (TNF) plasma concentration. However, the causal relationship between PUFA intake and inflammation remains unclear (11).

In this study, the participants were categorized by WC and evaluated for metabolic and inflammatory implications in order to verify the existing relationships. Therefore, the objective was to evaluate whether the relationship between WC and cardiometabolic risk is influenced by the usual diet and composition of plasma fatty acids.

Materials and methods

Participants

Health professionals or undergraduate students enrolled in the last two years of human health-related courses, ranging in age from 20 to 59 years, were invited to participate in this study. Those who used steroids or antibiotics, presented serious illness, had cancer (or have had it in the last three years), or were pregnant or lactating were excluded. Finally, 226 volunteers agreed to participate and completed the protocol. From this sample, a subsample of 106 individuals was randomly selected to study the concentration of plasma fatty acids. Data were collected between January 2012 and July 2013. The volunteers signed the consent form previously approved by the Ethics Committee on Human Research of the Federal University of Viçosa (Ref. No. 005/2011), according to Helsinki's Declaration principles.

Anthropometry and body fat composition

Body weight and height were measured according to routine standardized methods, while body fat content was determined by bioelectric impedance (Biodynamics 310®, Biodynamics Corporation). The values of body mass index (BMI; kg/m^2) and total body fat (%) were assessed as indicators of total adiposity. WC was measured at the midpoint between the last rib and the iliac crest, whilst waist–hip ratio (WHR) was measured as marker of central fat accumulation.

Dietary intake assessment and lifestyle features

Dietary intake was assessed in accordance with validated semi-quantitative food frequency questionnaire, validated for a Spanish population and adapted for Brazilian citizens, with 136 food items (12). Nutrient intake was estimated using ad hoc computer software specifically developed for this aim. In addition, the latest available information from Brazilian food composition tables was considered. Each nutrient was adjusted by 1000 kcal of energy intake for data standardization. The Healthy Eating Index (HEI), an indicator of diet quality that has been developed according to the current nutritional recommendations, was used with a specific adaptation (13) for a Brazilian population, according to Previdelli et al. (14). Volunteers were asked about smoking habits (yes or no answers). Former smokers were categorized as current smokers. Physical activity was assessed by International Physical Activity Questionnaire (long version) and participants with more than 150 minutes of exercise by week were categorized as physically active (15).

Blood pressure and biochemical assessments

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured, following World Health Organization criteria (16), using a digital HEM 142INT sphygmomanometer (OMROM Healthcare Co). Venous blood samples were drawn after a 12-hour overnight fast. Plasma ethylenediamine tetraacetic acid (EDTA) and serum were separated from whole blood by centrifugation at 3500 rpm at 4 °C for 10 minutes (Megafuge 11 R, Thermo Scientific). Then, samples were immediately frozen at −80 °C until assayed. Serum levels of triglycerides, total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), glucose, and insulin were measured by standard methods as previously described (17). Plasma low-density lipoprotein cholesterol (LDL-C) data were calculated by the Friedewald equation (18). Insulin resistance was estimated by homeostasis model assessment–insulin resistance (HOMA-IR), defined as fasting glucose (mmol/L) × fasting insulin (lU/mL)]/22.5 (19), and the triglyceride-glucose (TyG) index, calculated as Ln [(triglycerides (mg/dL)) × (glucose (mg/dL))/2] (20). Moreover, serum C3 complement was measured by the immunoturbidimetric method, and serum C-reactive protein concentrations were determined by enzyme-linked immunosorbent assay (ELISA) (Multiskan FC, Thermo Scientific) using the DSL-C-reactive protein ultra-sensitive kit (Ref. 10-42100, Linco Research Inc.). Uric acid was determined by an enzymatic colorimetric method in Cobas Mira Plus equipment (Roche Diagnostics). Plasma concentrations of different cytokines; TNF (Catalog number LHC3011); interleukins 1β, 6, and 10 (IL-6, IL-1β, IL-10; Catalog number LHC0061, LHC0011, and LHC0101, respectively); and adiponectin (Catalog number LHP0041) were determined by multiplex ELISA, utilizing a commercial kit (Biosource/Sellex). Plasminogen activator inhibitor-1 (PAI-1) plasma concentrations were determined by ELISA using a commercial kit (Invitrogen; Catalog number KHC3071).

The analysis of plasma fatty acid profile was determined by gas chromatography. Lipid fraction was obtained through the method described by Folch, Lees, and Stanley (1957) (21). After extraction, the lipids were subjected to saponification and esterification, in line with Hartman and Lago' methodology (1973) (22). Analysis was performed in a gas chromatograph (GC Solution, SHIMADZU), equipped with flame ionisation detector. Chromatograms were acquired and recorded by the GC Solution software. The compounds were identified and separated on a capillary column (30 m × 0.25 mm). For chromatographic separation, a 1-µL sample was injected with the aid of a 10-µL syringe (Hamilton®), split system = 5. Nitrogen gas was used as a carrier with linear speed scheduled at 43.2 cm/s. Furthermore, hydrogen and synthetic air gases formed the flame in the detector. The temperatures of injector and detector were isothermally controlled at both 200 °C and 220 °C. Initial column temperature was 100 °C (kept for 5 minutes), increasing 4 °C per minute until reaching 220 °C

Table 1. Sample characterization according to waist circumference median (77.15 cm).

Variables	Lower WC (≤77.15)	Higher WC (>77.15)	*p* values
Age (y)	26.87 ± 5.29	31.17 ± 8.83	**<0.001**
Weight (kg)	55.33 ± 5.76	72.48 ± 12.06	**<0.001**
WHR	0.75 ± 0.05	0.85 ± 0.06	**<0.001**
BMI (kg/m^2)	20.51 ± 1.64	24.86 ± 3.39	**<0.001**
BF (%)	27.58 ± 6.89	29.51 ± 10.10	0.222
SBP (mmHg)	103.15 ± 8.72	114.85 ± 12.71	**<0.001**
DBP (mmHg)	64.82 ± 6.38	69.59 ± 8.22	**<0.001**
TC (mg/dL)	183.40 ± 38.67	184.53 ± 34.16	0.818
HDL-C (mg/dL)	63.54 ± 13.81	55.10 ± 15.52	**<0.001**
LDL-C (mg/dL)	101.88 ± 31.60	109.73 ± 29.72	0.057
TG (mg/dL)	89.94 ± 36.90	100.11 ± 60.82	0.057
TC/HDL-C	2.92 ± 0.67	3.55 ± 1.05	**<0.001**
Glucose (mg/dL)	85.27 ± 8.29	89.52 ± 14.21	**0.007**
Insulin (mg/dL)	6.59 ± 2.82	7.97 ± 5.55	**0.021**
HOMA-IR	1.39 ± 0.63	1.87 ± 2.22	**0.031**
TyG index	8.17 ± 0.43	8.27 ± 0.50	0.093
Malondialdehyde (nmol/mL)	1.18 ± 1.25	1.35 ± 1.93	0.403
PAI-1 (pg/mL)	1258.75 ± 393.56	1305.19 ± 654.46	0.798
IL-10 (pg/mL)	1.76 ± 0.84	1.89 ± 0.94	0.270
IL-1β (pg/mL)	1.13 ± 0.26	1.13 ± 0.40	0.895
IL-6 (pg/mL)	1.43 ± 1.11	1.28 ± 0.67	0.232
TNF (pg/mL)	6.51 ± 2.69	6.85 ± 3.33	0.403
Adiponectin (mcg/mL)	17.44 ± 7.23	12.09 ± 8.07	**<0.001**
Uric acid (g/mL)	3.63 ± 1.03	4.11 ± 1.72	**0.011**
C3 complement (g/L)	97.59 ± 30.46	93.79 ± 39.53	0.419
CRP (mg/L)	1.97 ± 2.05	1.68 ± 2.01	0.279

Student *t* test. Data shown as mean ± SD. *N* (%). Data shown as frequencies. Test Chi-square.

*Bold values represent statistically significant *p* values (<0.05).

WC = waist circumference, WHR = waist-hip ratio, BMI = body mass index, BF = body fat, SBP = systolic blood pressure, DBP = diastolic blood pressure, TC = total cholesterol, HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol, TG = triglycerides, HOMA-IR = homeostasis model assessment–insulin resistance, TyG = triglyceride-glucose, PAI-1 = plasminogen activation inhibitor, IL = interleukin, TNF = tumor necrosis factor, CRP = C-reactive protein.

Table 2. Plasma fatty acid concentrations according to waist circumference median (77.15 cm).

Plasma Fatty Acids	Lower WC (≤ 77.15)	Higher WC (> 77.15)	*p* values
Total fatty acids	0.005 ± 0.017	0.003 ± 0.002	0.308
12:0	2.85 ± 2.57	3.48 ± 2.45	0.380
16:0	4.69 ± 2.95	3.94 ± 2.95	0.216
16:1n7	2.69 ± 2.49	3.32 ± 3.67	0.643
18:0	6.29 ± 1.44	6.45 ± 1.59	0.621
18:1n9c	4.99 ± 2.85	4.85 ± 2.70	0.785
18:2n6t	2.95 ± 2.16	2.04 ± 1,79	0.084
18:2n6c	17.62 ± 12.93	17.57 ± 11.84	0.983
18:3n3	1.85 ± 1.80	1.42 ± 1.25	0.192
18:3n6	1.88 ± 2.64	0.91 ± 1.31	0.325
20:0	1.45 ± 1.87	1.98 ± 2.68	0.357
20:1n9	3.60 ± 3.88	3.66 ± 4.83	0.973
20:2	5.93 ± 10.94	0.62 ± 0.30	0.403
20:3n3	1.33 ± 0.46	1.32 ± 0.66	0.930
20:3n6	1.01 ± 1.02	0.97 ± 1.27	0.921
20:5n3	4.95 ± 2.21	5.16 ± 1.99	0.704
21:0	6.97 ± 0.65	0.21 ± 0.64	0.075
22:0	0.95 ± 1.09	18.75 ± 0.56	**0.005**
22:1n9	5.08 ± 2.06	5.38 ± 1.76	0.434
22:2n6	3.01 ± 1.02	0.56 ± 0.53	**0.026**
22:6n3	2.39 ± 2.77	1.24 ± 1.40	0.052
23:0	4.73 ± 7.22	1.67 ± 1.15	0.459
24:0	0.74 ± 0.38	2.01 ± 2.48	**0.031**
24:1n9	0.80 ± 0.49	0.88 ± 0.65	0.841
SFA	10.24 ± 3.93	10.26 ± 3.64	0.978
MUFA	9.97 ± 4.11	10.71 ± 4.51	0.367
PUFA	7.84 ± 3.72	6.33 ± 3.70	**0.036**

Student *t* test. Data shown as mean ± *SD*.

WC = waist circumference, SFA = saturated fatty acid, MUFA = monounsaturated fatty acid, PUFA = polyunsaturated fatty acid.

*Bold values represent statistically significant *p* values (<0.05).

12:0–lauric acid; 16:0–palmitic acid; 16:1n-7–palmitoleic acid; 18:0–stearic acid; 18:1n-9c–oleic acid; 18:2n-6t–linoelaidic acid; 18:2n-6c–linoleic acid; 18:3n-3–linolenic acid; 18:3n-6–y-linolenic acid; 20:0–eicosanoic acid; 20:1n-9–gondoic acid; 20:2–8,11-eicosadienoic acid; 20:3n-3–eicosatrienoic acid; 20:3n-6–dihomo-y-linolenic acid; 20:5n-3–eicosapentaenoic acid; 21:0–heneicosanoic acid; 22:0–behenic acid; 22:1n-9–erucic acid; 22:2n-6–docosadienoic acid; 22:6n-3–docosahexaenoic acid; 23:0–tricosanoic acid; 24:0–tetracosanoic acid; 24:1n-9–nervonic acid.

(maintained for 20 minutes). Carrier gas flow in the column was settled as 1.0 mL/min. The PUFA group was obtained by adding the concentrations of linolenic fatty acid (C18:2n6), alpha-linolenic acid (C18:3n3), and linoelaidic acid (C18:2n6t).

Lipid oxidation products in plasma were assessed by malondialdehyde (MDA) concentrations. This was performed by determining the reaction product of thiobarbituric acid and aldehydes produced during lipid oxidation. The analysis of thiobarbituric acid reactive substances was performed through a protocol adapted from Buege and Aust (23). The results were expressed as MDA equivalents, in nmol, per mL of blood plasma.

Statistical analyses

Statistical analyses were performed using SPSS for Windows software, version 20.0. Participants were categorized by mean WC (77.15 cm). Variable normality was assessed by Kolmogorov–Smirnov test. Descriptive analyses of general features were expressed as mean values ± standard deviations whether normal distribution. On the other hand, those were articulated as median and interquartile range if non-normal distribution occurred. Pearson's chi-square test was performed to compare categorical variable ratios. Mean comparisons were obtained by Mann–Whitney test and the linear relationship between two continuous variables by Spearman's correlation. Multiple linear regression models were performed to analyze the prediction power of PUFA on glucose homeostasis features (insulin resistance, measured by TyG index and fasting plasma glucose), and since the sample consisted predominantly of women, the regression model was adjusted for gender and other confounding variables such as age, intake of calories, calcium, and alcohol/d. Those models were adjusted by age, gender, intake of calories, calcium, alcohol/d, and WC. A significance level of 5% was adopted in all statistical procedures.

Results

The focus of this study was not to identify alterations in individuals who already had abdominal obesity, but to elucidate that even those who are not considered to be high risk may exhibit changes in plasma PUFA concentrations. Participants were categorized by mean WC (77.15 cm).

Among 226 individuals included in the study, 74.3% were female and the mean age was 28 years. Participants with higher WC demonstrated elevated SBP and DBP, fasting glucose, and insulin resistance (evaluated by HOMA-IR), but lower HDL-C concentrations. Those participants also presented changes in inflammatory outcomes, with lower adiponectin concentrations and augmented plasma uric acid (Table 1). Of interest, participants with higher WC exhibited

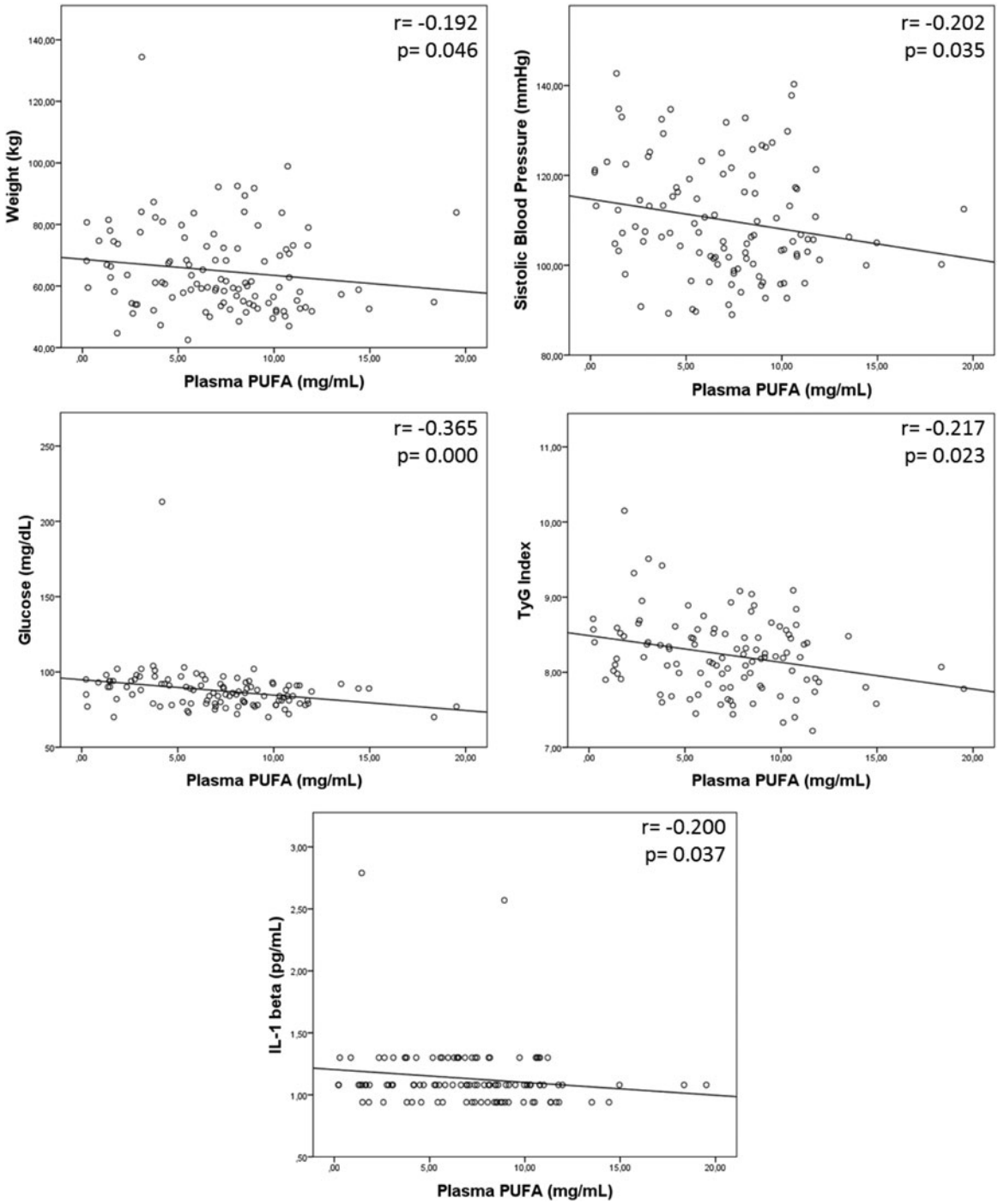

Figure 1. Correlations between plasma polyunsaturated fatty acid (PUFA) concentrations and metabolic and inflammatory features. PUFA plasma concentration was negatively associated to weight, systolic blood pressure, fasting glucose, triglyceride-glucose index, and interleukin-1β plasma.

minor plasma PUFA and docosadienoic acid concentrations and higher concentrations of saturated acids, such as behenic and tetrocosanoic acids, however without any altera tions in lipid oxidation (Table 2).

PUFA concentration in plasma was negatively associated with weight, SBP, fasting glucose, TyG index, and plasma IL-1β plasma (Figure 1). Higher PUFA/SFA ratio, reflecting an increased plasma PUFA concentration, was also correlated with lower serum triglyceride levels ($r = -0.210$, $p = 0.028$). Nonetheless, when evaluated separately, such fatty acids were correlated with neither any of the studied variables nor the consumption of dietary fatty acids (data not shown).

Participants with higher WC exhibited no differences in overall diet quality assessed by HEI. Nevertheless, they consumed more calories, niacin, pyridoxine, and alcohol in their usual diet. In contrast, less calcium, phosphorus, and vitamin B2 were absorbed per day (Table 3). WC was related neither to smoking status nor to physical activity (Table 4). Finally, it was observed that plasma PUFA concentration

Table 3. Nutrient intake (per day) by healthy participants according to waist circumference median (77.15 cm).

Nutrients	Lower WC (≤77.15)	Higher WC (>77.15)	*p* values
Calories (kcal)	2327.33 ± 668.66	2641.92 ± 790.46	**0.002**
Carbohydrates (g/1000 kcal)	131.16 ± 32.44	131.76 ± 34.89	0.893
Fatty acids (g/1000 kcal)	37.18 ± 11.32	35.32 ± 11.40	0.225
Protein (g/1000 kcal)	46.80 ± 15.67	43.58 ± 11.69	0.084
Dietary fiber (g/1000 kcal)	18.31 ± 10.70	17.61 ± 9.70	0.609
Cholesterol (mg/1000 kcal)	151.53 ± 101.26	143.80 ± 82.51	0.534
Sodium (mg/1000 kcal)	1021.91 ± 553.94	1000.58 ± 556.42	0.774
Potassium (mg/1000 kcal)	1473.74 ± 519.79	1494.05 ± 514.61	0.770
Calcium (mg/1000 kcal)	507.39 ± 411.53	349.26 ± 237.15	**0.001**
Magnesium (mg/1000 kcal)	164.94 ± 81.43	189.69 ± 171.35	0.170
Phosphorus (mg/1000 kcal)	678.19 ± 232.63	609.76 ± 182.91	**0.016**
Iron (mg/1000 kcal)	5.63 ± 2.38	5.26 ± 2.31	0.239
Copper (mg/1000 kcal)	0.85 ± 0.68	0.88 ± 0.64	0.804
Zinc (mg/1000 kcal)	5.35 ± 1.91	5.09 ± 2.14	0.352
Vitamin A (mg/1000 kcal)	353.01 ± 386.83	313.69 ± 344.28	0.434
Vitamin B1 (mg/1000 kcal)	0.75 ± 0.35	0.75 ± 0.56	0.972
Vitamin B2 (mg/1000 kcal)	0.85 ± 0.47	0.70 ± 0.39	**0.011**
Niacin (mg/1000 kcal)	11.85 ± 8.83	16.22 ± 11.94	**0.002**
Vitamin B6 (mg/1000 kcal)	0.67 ± 0.41	0.82 ± 0.49	**0.017**
Vitamin C (mg/1000 kcal)	77.15 ± 68.34	84.93 ± 71.91	0.410
Saturated fatty acids (g/1000 kcal)	14.05 ± 7.37	13.11 ± 6.14	0.299
Monounsaturated fatty acids (g/1000 kcal)	12.05 ± 5.14	11.78 ± 4.79	0.682
Polyunsaturated fatty acids (g/1000 kcal)	7.04 ± 4.55	7.27 ± 4.29	0.685
Alcohol (g/1000 kcal)	1.06 ± 1.71	2.06 ± 2.77	**0.004**
Healthy Eating Index	57.00 ± 8.48	55.15 ± 8.13	0.261

Student *t* test. Data shown as mean ± *SD*.
WC = waist circumference.
*Bold values represent statistically significant *p* values (<0.05).

Table 4. Associations between waist circumference and lifestyle features in healthy participants.

Variables	Lower WC (≤ 77.15)	Higher WC (> 77.15)	*p* values
Physical activity (yes)	99 (51.6)	93 (48.4)	0.329
Smoking habits (no)	102 (51.3)	97 (48.7)	0.162

Data are *n* (%); data shown as frequencies. Chi-square test.

Table 5. Multiple linear regression analyses showing the independent contributions of plasma polyunsaturated fatty acid concentrations on glucose homeostasis features.

Dependent variable	*β* coefficient	CI (95%)	R^2	*p* value
TyG index	−0.036	−0.060, −0.011	0.072	**0.005**
Adjusted[1]	−0.025	−0.072, 0.022	0.190	**<0.001**
Adjusted[2]	−0.010	−0.022, 0.003	0.088	**0.017**
Glucose	−1.020	−1.730, −0.301	0.069	**0.006**
Adjusted[1]	−0.806	−1.240, −0.372	0.176	**0.001**
Adjusted[2]	−0.807	−1.244, −0.370	0.166	**0.002**

CI = confidence interval, TyG = triglyceride-glucose.
*Bold values represent statistically significant *p* values (<0.05).
[1]Adjusted by age, gender, intake of calories, calcium, and alcohol/d.
[2]Adjusted by age, gender, intake of calories, calcium, alcohol/d, and waist circumference.

was negatively associated with TyG index and fasting blood glucose levels even after adjustments, the effect which was independent of WC itself (Table 5).

Discussion

Obesity is defined as excesso body fat and its association with MetS is even stronger if fat deposition is abdominal or central deposition (24). In this context, an innovative definition of MetS was published in 2006, in which central obesity, demarcated by the WC value, became essential for diagnosis (25). In the current study, we observed that participants with higher WC exhibited increased risk of MetS. It is already known that abdominal obesity, measured by WC, is directly linked to visceral fat. Moreover, WC is a great predictor of android-type obesity (26) and an indicator of several metabolic modifications as observed in this study, such as decreased HDL-C, increased blood pressure, and impaired glucose tolerance. Carvalho et al. (2015) (27) evaluated 968 students and found a decrease in HDL-C associated with elevated WC values in both men and women ($p = 0.0035$ and $p = 0.001$, respectively).

Researchers have reported that increased visceral adipose tissue is associated with higher plasma concentrations of inflammatory cytokines (28, 29). This fact can be explained by activated macrophages infiltration in the expanding adipose tissue, leading to secretion imbalance of proinflammatory and anti-inflammatory factors (30). This corroborates the results encountered in this study: Individuals with higher WC had lower concentrations of adiponectin and increased uric acid levels. It is already known that adiponectin has antilipolytic and anti-inflammatory action, and due to these effects, it can be considered an interesting marker of MetS risk (31). Research that evaluated 70 healthy individuals with an average age of 42 years highlighted that adiponectin concentration was negatively correlated with WC. The authors, however, concluded that the relationship between such factors is not clear (32).

Uric acid has been reported as a risk factor of CVD and MetS, becoming a distinguished cardiometabolic risk biomarker (33). Corroborating our findings, a study comprising 80 individuals found a positive association among uric acid concentrations, WC, BMI, and total body fat percentage, pointing out an increased proportion to the MetS

component numbers (34). The raised Uric acid concentrations found in this research may be due to its important role as a hydrophilic antioxidant in the body, which enhances the response to oxidative stress resulting from obesity (35).

The most interesting finding of this study was that participants with higher WC, although predominantly healthy, had lower concentrations of plasma PUFA and higher concentrations of different SFAs. Furthermore, another prominent finding was that the decrease in PUFA was associated with higher SBP, fasting glucose, and insulin resistance, assessed by TyG index. However, this diminishment was not related to HOMA-IR and IL-1β concentrations. Sethom et al. (2011) (36) evaluated 1975 adults with MetS, aged between 35 and 69 years, and found that WC had a positive correlation with both SFA ($p = 0.098$) and monounsaturated fatty acid ($p = 0.133$) concentrations, while a negative correlation could be perceived with PUFA concentrations ($p = -0.152$), suggesting that PUFAs have anti-inflammatory and anti-atherogenic potential. Klein-Platat et al. (2005) (37) reported that overweight adolescents had lower plasma PUFA concentrations than individuals with normal weight, indicating that PUFA concentrations are inversely associated with weight, which corroborates our findings. It is widely known that excessive adiposity affects lipid metabolism and inflammation due to the release of proinflammatory markers by adipocytes (38, 39). Abdominal adiposity, reflected by increased WC, appears to be positively associated with an altered fatty acid profile, a high SFA concentration, and a lower PUFA concentration (39). This may explain our findings since individuals with higher WC had lower concentrations of PUFA but greater SFA contents.

Regarding SBP, some mechanisms may elucidate the positive effects of PUFA on blood pressure, considering the fact that eicosapentaenoic acid (EPA) and docosahexaenoic (DHA) incorporation in phospholipids of cell membrane could influence physicochemical properties and blood flow. Therefore, this would favorably interfere with the synthesis of vasodilator prostaglandins, increasing systemic arterial compliance and improving endothelial function (40). The correlation found between plasma PUFA and fasting glycemia can be clarified by the study authored by Kiecolt-Glaser et al. (2011) (41), who reported a positive effect of PUFA, especially n-3, in the insulin signaling pathway, improving glucose homeostasis. Our outcomes denoted a negative correlation between plasma PUFA concentration and TyG index and glucose. TyG index is an interesting marker of insulin resistance, which shows valuable correlations with lipid components. Therefore, this index is incredibly useful for threat identification in the development of type 2 diabetes mellitus and CVD (42). Regarding IL-1β, alpha-linolenic acid, EPA, and DHA can affect inflammatory cytokines synthesis, which may inhibit IL-1β production (43). The relationship between PUFA and inflammation is already well defined, whereas PUFA-n6 and its metabolites generally behave as proinflammatory. On the other hand, PUFA-n3 acts more as an anti-inflammatory (44).

It was found that PUFA/SFA ratio was associated with lower triglyceride concentrations. Researchers reported that PUFA, especially the omega n-3 series, had a greater ability to decrease plasma triglyceride concentrations (45, 46). This effect may be a consequence of hepatic synthesis reduction of very-low-density lipoproteins (47). In our study, the positive effect of PUFA was not attributed to a specific fatty acid, but to the sum of all analyzed PUFA.

Although it would be expected that individuals with higher abdominal adiposity had increased oxidative stress (48), this outcome was not found here. However, it should be noted that changes in lipid oxidation tend to be enhanced due to the presence of double bonds in unsaturated fatty acids, especially PUFA, being more susceptible to oxidation and lipid peroxidation (49), which were reduced in these participants.

It was observed that participants featuring higher WC demonstrated no differences in overall diet quality. Dietary indices have been developed to provide a summary of key dietary characteristics, facilitating the evaluation of its quality (50). However, studies are still controversial concerning this association. Regarding diet components, participants with higher WC consumed more calories, niacin, pyridoxine, and alcohol, while they ingested less calcium, phosphorus, and vitamin B2. The clearer relationships regarding these associations are regarding calorie intake, alcohol, and calcium, the latter being described as an important nutrient in obesity etiology and insulin resistance (27).

In the present study, low calcium intake was associated with higher WC. It is already acknowledged that low calcium intake has been linked to obesity, due to the inverse relationship among dietary calcium, body weight, and body fat content (51). The mechanisms involved in this relationship are not yet completely elucidated. However, it has been reported that calcium interferes with fecal fat excretion by means of the formation of insoluble complexes in the intestine and by suppressing calcitriol concentrations. This leads to a lower accumulation of body fat by reducing the production of cortisol in adipose tissue, since calcitriol stimulates the expression of 11-hydroxysteroid dehydrogenase-1, which in turn catalyzes the conversion of cortisone to cortisol (involved in deposition of fat mainly in the abdominal region) in adipocytes. Moreover, it is reported that calcium does interfere in appetite regulation, but the occurrence procedure is not yet known (51–53). A study with young blood donors has reported a strong positive correlation between alcohol intake and WC, which is in agreement with our findings (54). These results can be observed in another study, in which the total alcohol intake exerts great influence on abdominal adiposity due to the high caloric density of alcohol (55).

Even though plasma PUFA concentration in these individuals has not been correlated to ingestion of fatty acids, this association had been previously described (56). Finally, it has been found that plasma concentrations of PUFA could be a feasible negative predictor of TyG index and fasting glucose, denoting an interesting marker in relation to glucose homeostasis.

The most important result of the present study was the relationship between high WC and low plasma PUFA concentrations. Although it is a cross-sectional study, it has remarkably relevant biological and clinical significance since it relates to cardiometabolic risk. In addition, recent studies involving PUFA and CVD also have a transverse nature, which reveals that studies of this nature are reliable and important for our literature (57–59).

The current research has some limitations, such as the fact that the studied population was predominantly female. It is known that estrogen, the female sex hormone, is related to ovulation control and the development of female characteristics. In addition, this hormone may be associated with body protection against dyslipidemia, and consequently atherosclerosis, since it plays an important role in the metabolism of fatty acids (60). The possible mechanism is that this hormone tends to increase HDL-C but decrease LDL-C concentrations. Thus, estrogen could improve endothelial function by the ability to reduce hepatic catabolism of lipase-dependent HDL-C particles, mechanisms which are still not well established (56).

It should be taken into account that the population of this study consists only of health professionals and students within the same area. Thus, results should be cautiously extrapolated and interpreted. Nonetheless, the fact that this population consists of apparently healthy individuals is also of great importance to determine changes that precede disease establishment. Therefore, the obtained outcomes could be used as early markers of cardiometabolic risk. Furthermore, it is a cross-sectional study and the cause/effect associations were not able to be determined, allowing merely suggested associations. This is important to guide and suggest either new intervention or case-control studies that could determine possible mechanisms involved in this field.

Conclusion

The results suggest that participants with higher WC have lower plasma PUFA concentrations and higher SFA contents. This could be related to metabolic and inflammatory changes that could trigger increased MetS and CVD risk. Intervention studies with PUFA-rich foods are interesting approaches to assess their plasmatic concentration and their possible protective effects on the development of cardiometabolic risk factors.

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Ethical Standards

The volunteers signed the consent form previously approved by the Ethics Committee on Human Research of the Federal University of Viçosa (Ref. No. 005/2011), according to Helsinki's Declaration principles.

Conflict of Interest

The authors declare no conflict of interest.

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