Original Communication

Low intakes of vitamins C and A are associated with obesity in early adulthood

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Abstract: To evaluate the relationships between the intake of individual antioxidants as well as the dietary antioxidant quality score and obesity-related measures. A cross-sectional study was conducted on 562 young adults. Fat mass, fat-mass percentage, and fat-free mass were measured using a body composition analyzer. The intake of antioxidant nutrients including vitamins C, E, and A, selenium, zinc, and magnesium were calculated based on a 72-hour diet recall interview. We observed significant differences in the vitamin C (88.6 ± 72.6 mg/day vs. 70.7 ± 60.6 mg/day, p = 0.010), vitamin A (635.8 ± 519.8 μg/day vs. 492.6 ± 318.9 μg/day, p = 0.014), and selenium (135.3 ± 88.7 μg/day vs. 139.3 ± 79.3 μg/day, p = 0.034) intake between normal-weight and overweight or obese young adults. When the Dietary Antioxidant Quality Score (DAQS) was analyzed, there were no significant differences between normal-weight versus overweight or obese young adults after adjusting for confounders. Logistic regression analysis revealed that vitamin C intake (odds ratio (OR) 0.995, 95% CI 0.992–0.999, p = 0.013) and vitamin A intake (OR 0.999, 95% CI 0.999–1.000, p = 0.016) were independent predictors of overweight/obesity after adjusting for age, sex and energy intake. In contrast, a higher selenium intake was associated with an increased risk of overweight/obesity (OR 1.003, 95% CI 1.000–1.006, p = 0.034). Future longitudinal investigations of dietary antioxidant intake in relation to the development of obesity would be of interest to better understand the effect of dietary antioxidants on obesity.

Keywords: vitamin A, vitamin C, antioxidants, obesity, dietary intake

Introduction

Obesity, which is characterized by an increase in body weight that results in excessive body fat, has been recognized as a major public health concern associated with an increased risk of morbidity and mortality [1]. It has also been linked to several chronic conditions including cardiovascular disease [2], cancers [3], metabolic syndrome [4], fatty liver diseases [5], and diabetes mellitus [6]. Obesity rates are continuing to rise rapidly and it has been estimated that nearly a third of the world's population is classified as overweight or obese [7]. In Europe, the total direct and indirect costs attributable to excess weight and obesity were equivalent to 0.47–0.61% of the global burden of disease [8].

A chronic low-grade inflammatory condition is also thought to accompany obesity [9]: excess body fat is considered a source of pro-inflammatory cytokines including tumor necrosis factor-alpha (TNF-α), interleukin (IL)-1β, and IL-6, which all promote the increased generation of reactive oxygen species [10]. Compared to normal-weight individuals, overweight and obese subjects have been reported to have lower blood concentrations of antioxidants such as superoxide dismutase, glutathione peroxidase, and catalase, vitamins A, E, and C, and β-carotene [11, 12]. Additionally, adipose tissue is considered an active endocrine organ that releases adipokines including leptin (a key lipid metabolism regulator) whose pro-inflammatory effects induce oxidative stress [13].

Recent data show that antioxidant nutrients may exert protective effects in the context of obesity, [14] and indeed, Buijsse et al. indicated that the consumption of large amounts of fruit and vegetables might limit weight gain [15]. In this line, some authors have explored the relationship between obesity parameters and the intake of some antioxidant nutrients, albeit with inconsistent findings and conclusions [16–25]. Of note, most studies have focused on the effect of antioxidant status on body mass index (BMI). However, wide inter-individual variability in body fat percentages for the same BMI has been reported [26]. Thus, the analysis of body composition parameters such as fat mass and fat-free mass might lead to a better understanding of the potential effect of antioxidant intakes on obesity. Additionally, the majority of studies have been conducted in adults without stratifying the analyses by age [16, 17, 19, 20].

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On the other hand, most previous studies have investigated the relationship between single antioxidant intake and BMI [19, 21–23, 25]. Little is known regarding diet quality indexes of antioxidant intakes and their potential association with obesity. A Dietary Antioxidant Quality Score (DAQS), which sums up certain dietary antioxidants (vitamin C, vitamin E, vitamin A, selenium, zinc and magnesium) and assigns a score based on calculated quantity, was used to calculate antioxidant-nutrient intake [27]. This index has been previously proposed for assess the overall impact of antioxidants on health outcomes [27–30]. Interestingly, the DAQS was inversely associated with levels of IL-1 β, TNF-α, IL-6 and sTNF-R2 [31].

Considering the increasing trend towards excess weight and obesity among adolescents transitioning into adulthood [32], an exploration of nutritional strategies that might prevent obesity in early adulthood would be of special interest. This is especially relevant since health professionals have a main role in the implementation of community-based obesity prevention programs. Because of the limited and inconclusive evidence available, more research is needed to explore the relationships between antioxidant intake and obesity-related measures including BMI, fat-mass percentage, fat mass, and fat-free mass. Therefore, the objective of this study was to evaluate the relationships between individual antioxidant intakes such as vitamins A, C, E, zinc, selenium, and magnesium, the dietary antioxidant quality score (DAQs), and obesity parameters in a sample of young adults.

Methods

Design and study sample

A cross-sectional study was conducted on a convenience sample of 562 subjects aged 18–25 years (69.30% females and 30.60% males). The study participants were recruited from seven public education centers located in the main districts of Granada (Spain). A member of the research team visited the subjects in their academic centers and explained the objectives and characteristics of the study. Subject inclusion criteria comprised: good health (not undergoing medical treatment related to body weight management), and an age of between 18 and 25. Subjects with major acute or chronic conditions who had made significant lifestyle changes in the preceding months that could have affected body weight were excluded. Migrants who might have diets that reflect their country of origins did not participate in this study. Exclusion criteria was a BMI < 18.5 kg/m^2. Written informed consent was obtained from all participants, and the study was approved by the local ethics committee at the University of Granada and conducted in accordance with the Declaration of Helsinki.

Body composition measurements

Body weight, fat mass, percentage of fat mass and fat-free mass were measured twice (without shoes and in light clothes) to the nearest 0.1 kg using a body composition analyser (TANITA BC-418MA®). Pietrobelli et al. (2004) validated the BC-418 Tanita device against DXA in a population of 6–64 years healthy US Americans of both sexes and different weight classes, reporting a good accuracy [33]. There were good correlations between BC-418 and DXA regional %fat estimates, ranging from r = 0.79 to 0.85. Measurements were taken in the morning after a 12 hr fast with no consumption of food or beverages, as well as a 24 hr abstention from exercise, under resting conditions. Days before the measurements, subjects were informed of these restrictions. A Harpenden stadiometer (Holtain 602VR®) was used to take height measurements. Each participant was asked to stand erect with their back, buttocks, and heels in continuous contact with the vertical height rod of the stadiometer, and their head orientated in the Frankfurt plane. The horizontal headpiece was then placed on top of the participant's head to measure their height. Height was measured twice (without shoes) to the nearest 0.5 cm. The average of the two values from each measurement was used in the analysis. BMI was calculated by dividing body weight (kg) by the square of body height (m^2). BMI value was classified according to the recommendations of the World Health Organization (WHO Expert Consultation 2004) (normal weight: BMI 18.5–24.9 kg/m^2 and overweight/obese: BMI > 25.0 kg/m^2). The same trained research assistant performed all the measurements and the same device was used for all of the measurements. The body composition analyzer was calibrated daily according to the manufacturer's guidelines.

Physical activity

A self-administered questionnaire was used to assess physical activity (PA) (the International Physical Activity Questionnaire – IPAQ). The questionnaire has proven to be a valid and reliable instrument for measuring PA in the European adult population [34]. It was used to calculate the minutes hours of vigorous PA, moderate PA and walking over the last 7 days. A MET-min was derived by multiplying the respective total minutes by the Metabolic Equivalent of Task (MET) value for vigorous PA (MET = 8.0), moderate PA (4.0) and walking (3.3), and then adding all three [34]. MVPA (MET-min) was calculated by summing vigorous PA and moderate PA while total PA (MET-min) was

Table 1. Basic characteristics of the study population

	Total (n = 562)	Females (n = 390)	Males (n = 172)	P value
Age (years)	20.39 ± 2.69	20.37 ± 2.71	20.44 ± 2.65	0.767
Weight (Kg)	63.66 ± 12.40	59.54 ± 9.78	72.98 ± 12.71	<0.001
Height (m)	1.67 ± 0.08	1.63 ± 0.06	1.75 ± 0.07	<0.001
BMI (kg/m^2)	22.65 ± 3.61	22.19 ± 3.50	23.71 ± 3.64	<0.001
Fat mass percent (%)	22.08 ± 7.70	24.52 ± 6.93	15.30 ± 5.35	<0.001
Fat mass (Kg)	14.24 ± 7.38	15.32 ± 7.24	11.78 ± 7.14	<0.001
Fat free mass (Kg)	49.44 ± 9.18	44.31 ± 3.44	61.08 ± 7.31	<0.001
Total physical activity (MET-min)	2868.75 (0-56640)	2459.08 (0-56640)	3779.12 (0–23184)	<0.001
MVPA (MET-min)	1610 (0-21600)	1124.76 (0-12000)	2705.00 (0–21600)	<0.001
Sedentary time (min/day)	418.71 (0-1440)	432.14 (0-1440)	388.65 (0–1200)	0.020
Dietary intake				
Energy intake (kcal/day)	1987.75 ± 663.69	1911.33 ± 620.93	2161.05 ± 724.23	<0.001
Vitamin C (mg/day)	84.76 ± 69.95	80.73 ± 65.97	93.84 ± 77.65	0.055
Vitamin E (mg/day)	5.50 ± 3.50	5.38 ± 3.37	5.78 ± 3.78	0.233
Vitamin A (μg/day)	604.58 ± 478.99	592.70 ± 491.90	631.43 ± 448.67	0.361
Zinc (mg/day)	9.19 ± 4.06	8.87 ± 3.89	9.93 ± 4.35	0.006
Selenium (μg/day)	137.30 ± 86.70	133.35 ± 89.62	146.22 ± 79.22	0.090
Magnesium (mg/day)	310.51 ± 185.26	307.44 ± 193.12	317.46 ± 166.45	0.532

BMI: body mass index; MVPA: moderate-to-vigorous physical activity; MET: metabolic equivalent of task, representing energy expenditure per day. Data are expressed as the mean ± standard deviation for normal distribution and median [interquartile range] for non-normal distribution. Total physical activity, MVPA (moderate-to-vigorous physical activity) and sedentary time variables data are expressed as median (interquartile range).

calculated by summing vigorous PA, moderate PA and walking. Sedentary time (min/day), excluding sleep, was also estimated.

Antioxidant nutrient intakes

Antioxidant nutrients intakes including vitamin C, vitamin E, vitamin A, selenium, zinc and magnesium as well as energy intake were assessed using a 72-hour diet recall interview considering intakes on Thursday, Friday and Saturday to capture weekly variations across weekdays and the weekend. In a face-to-face interview with trained investigators, individuals were asked to recall all food consumed in the preceding 72 hours, including nutritional supplements, multivitamins and beverages. Standard household measures and picture food models were employed during the interviews to define amounts when requested. The completed food records were analysed using a computerised nutrient analysis program (Nutriber 1.1.5).

Dietary Antioxidant Quality Score (DAQS)

DAQs calculate the antioxidant capacity of the nutrient intake by assessing the consumption of vitamin C, vitamin E, vitamin A, selenium and zinc [35]. Daily nutrient intake was compared to that of the Daily Recommended Intake for Spanish population (RDI) [36]. The intakes of the five antioxidant nutrients were assessed separately by assigning a value of 0 or 1 to each nutrient: 0 was assigned when the intake of the nutrient was below two thirds of the RDI and 1 was assigned when this intake level was equaled or exceeded. Thus, after computing total DAQs, the scores ranged from 0 (very poor quality) to 5 (high quality).

Statistical analysis

The Kolmogorov-Smirnov statistic was applied to verify data distribution normality. The data were expressed as the mean ± standard deviation for normal distribution, and the median for non-normal distribution. The independent two-sample t-test, or Mann-Whitney U-test, was used to compare the variables with normal or non-normal distribution, respectively, between the groups. Differences in antioxidants intakes and DAQs in relation to the overweight/obesity prevalence were calculated by means of an analysis of variance (ANOVA) adjusting by age, sex and energy intake in the total sample and by age and energy intake in females and males. Logistic regression models were used to estimate odds ratios for overweight/obesity after adjusting for covariates. Multiple regression analysis were used to analyze the association between antioxidants nutrients, DAQs and obesity measures after adjusting for age, sex and energy intake. Multiple regression analysis were also performed separately by gender after adjusting for age, and energy intake. SPSS Statistics version 21.0 (SPSS. Chicago. IL. USA) was used for all the analyses. P values < 0.05 were considered to be statistically significant.

Table 2. Comparison of antioxidants nutrients and DAQs between normal weight and overweight/obese young adults

	Females (n = 355)[a]			Males (n = 166)[a]			Overall (n = 521)[b]		
	Normal (n = 296)	Overweight/ obese (n = 59)		Normal (n = 117)	Overweight/ obese (n = 49)		Normal (n = 413)	Overweight/ obese (n = 108)	
	Mean ± sd	Mean ± sd	p value	Mean ± sd	Mean ± sd	p value	Mean ± sd	Mean ± sd	p value
Vitamin C (mg/day)	82.27 ± 67.82	71.51 ± 59.18	0.245	104.80 ± 81.73	69.92 ± 62.96	0.037	88.69 ± 72.67	70.79 ± 60.64	0.010
Vitamin E (mg/day)	5.38 ± 3.39	5.20 ± 3.45	0.909	6.12 ± 4.06	4.97 ± 2.86	0.618	5.59 ± 3.60	5.10 ± 3.19	0.615
Vitamin A (µg/day)	621.10 ± 535.98	468.39 ± 259.25	0.038	673.18 ± 476.75	521.86 ± 379.33	0.301	635.89 ± 519.80	492.65 ± 318.90	0.014
Zinc (mg/day)	8.93 ± 3.97	8.44 ± 3.63	0.761	10.40 ± 4.60	8.74 ± 3.61	0.415	9.34 ± 4.21	8.57 ± 3.61	0.777
Selenium (µg/day)	130.40 ± 91.18	140.24 ± 84.39	0.158	147.89 ± 81.18	138.32 ± 73.76	0.183	135.37 ± 88.71	139.37 ± 79.39	0.034
Magnesium (mg/day)	309.65 ± 202.19	282.81 ± 140.88	0.557	328.66 ± 176.51	281.65 ± 138.47	0.725	315.05 ± 195.22	282.28 ± 139.14	0.969
DAQs	2.73 ± 1.12	2.12 ± 0.80	0.157	2.46 ± 1.11	2.20 ± 0.94	0.168	–	–	–

[a]Analysis of variance (ANOVA) models were adjusted for age and energy intake in females and males.
[b]ANOVA models were adjusted age, sex and energy intake in the overall population.
p-values were obtained by an ANOVA adjusting by age, sex and energy intake in the total sample and by age and energy intake in females and males. The DAQS score refers to the intake of selenium, zinc, vitamin A, vitamin C and vitamin. Daily nutrient intake of each micronutrients was compared to that of the daily recommended intake for Spanish people (DRI). Since the daily recommended intake for vitamin A is different in women and men, it is recommended that the index be calculated separately for females and males. For this reason, analysis were only showed separately for females and males but no for the overall population.

Results

This work included 390 females and 172 males, with an overall mean age of 20.3 ± 2.6 years; the characteristics of the participants are summarized separately by sex in Table 1. The average BMI was 22.1 ± 3.5 kg/m^2 for the females and significantly higher for the males at 23.7 ± 3.6 kg/m^2 ($p < 0.001$). The mean BMI for both sexes was within the normal range and so most individuals (73.8%) in this study were a normal weight (68.0% male and 76.3% female). The prevalence of excess weight or obesity in this sample was significantly higher in males (28.5%) than in females (15.2%; $p = 0.001$). Furthermore, significant differences were observed between males and females with respect to height, weight, fat mass, fat-free mass, and visceral fat ($p < 0.001$). The reported energy intake was significantly higher in males (2,161.0 ± 724.2 kcal) than in females (1,911.3 ± 620.9 kcal; $p < 0.001$), and males consumed significantly more zinc than females ($p = 0.006$). Finally, males had significantly higher reported levels of total physical activity and MVPA than women (p < 0.001). They also reported lower levels of sedentary time than women (p = 0.020).

Table 2 shows the comparison of antioxidant nutrients and DAQs by normal-weight and overweight or obese individuals. No significant differences were found between normal-weight and overweight subjects with respect to age (females: normal-weight 20.40 ± 2.69 years versus overweight or obese 20.63 ± 2.97 years, $p = 0.591$; males: normal-weight 20.21 ± 2.43 years versus overweight or obese 21.02 ± 3.11 years, $p = 0.110$). As can be observed in Figure 1, after adjusting for age, sex, and energy intake in the whole sample there were significant differences between normal-weight versus overweight or obese young adults in vitamin C (88.6 ± 72.6 mg/day vs. 70.7 ± 60.6 mg/day; $p = 0.010$), vitamin A (635.8 ± 519.8 µg/day vs. 492.6 ± 318.9 µg/day; $p = 0.014$), and selenium (135.3 ± 88.7 µg/day vs. 139.3 ± 79.3 µg/day; $p = 0.034$) intake. Moreover, we also observed significant differences in normal-weight versus overweight or obese individuals for vitamin A consumption in females (621.1 ± 535.9 µg/day vs. 468.3 ± 259.2 µg/day; $p = 0.038$) and vitamin C intake in males (104.8 ± 81.7 mg/day vs. 69.9 ± 62.9 mg/day; $p = 0.037$) when adjusted for age and energy intake (Figure 1).

Logistic regression analysis of antioxidants nutrients and DAQs in young adults with normal weight and overweight/obese are shown in Table 3. Vitamin C intake (odds ratio (OR) 0.995, 95% CI 0.992–0.999, p = 0.013) and vitamin A intake (OR 0.999, 95% CI 0.999–1.000, p = 0.016) in the overall population were independent predictors of overweight/obesity after adjusting for age, sex and energy intake. In addition, males who have a higher vitamin C intake (OR 0.994, 95% CI 0.988–0.999, p = 0.024) and

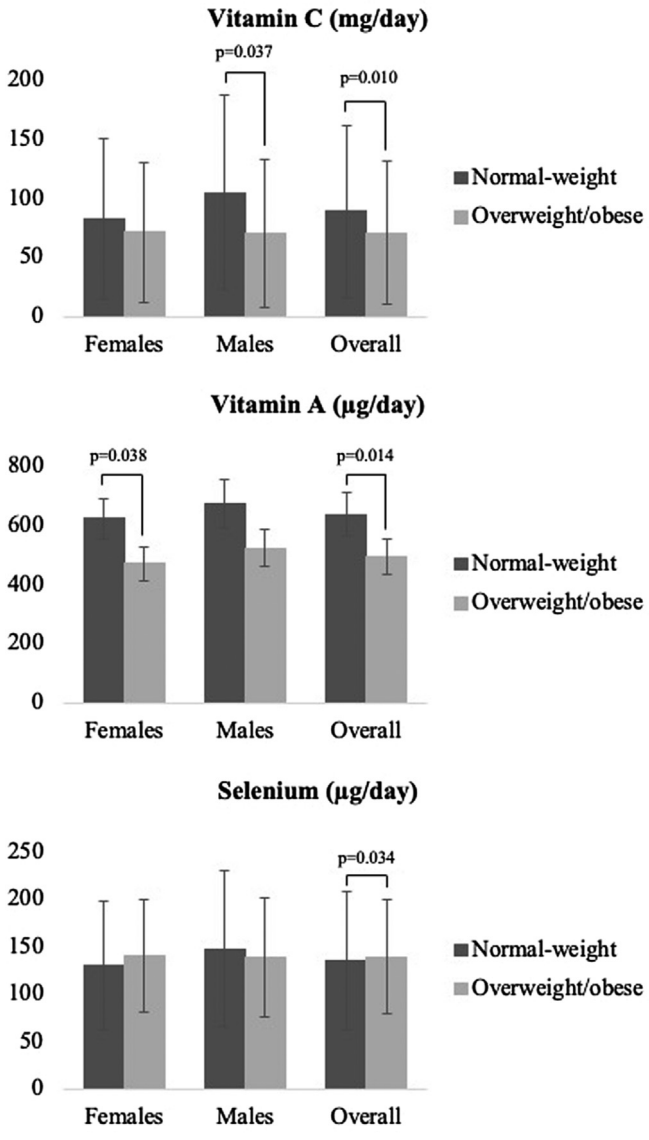

Figure 1. Comparison of vitamin C, vitamin A and selenium intakes by normal-weight and overweight or obese individuals.

women who have a higher vitamin A intake (OR 0.999, 95% CI 0.998–1.000, p = 0.040) were at decreased risk of overweight/obesity. In contrast, a higher selenium intake was associated with an increased risk of overweight/obesity (OR 1.003, 95% CI 1.000–1.006, p = 0.034) after adjusting for covariates in the overall population.

The association between antioxidant nutrient intake and obesity-related measures in the overall sample after adjusting for age, sex, and energy intake is shown in Table 4. Linear regression analysis revealed significant inverse associations between weight and vitamin C ($\beta = -0.014$; 95% CI [− 0.026, −0.001]; $p = 0.032$) and between fat mass and vitamin A ($\beta = -0.002$; 95% CI [− 0.003, −0.001]; $p = 0.002$). In addition, BMI was inversely associated with vitamin C ($\beta = -0.005$; 95% CI [− 0.009, −0.001]; $p = 0.016$) and vitamin A ($\beta = -0.001$; 95% CI [− 0.001, 0.000]; $p = 0.036$) intake.

Table 5 presents our analysis of the association between antioxidant nutrients, DAQs, and obesity parameters for males and females, adjusted for age and energy intake. There were significant inverse associations between vitamin C intake and weight ($\beta = -0.028$; 95% CI [− 0.051, 0.004]; $p = 0.021$) and fat mass ($\beta = -0.015$; 95% CI [− 0.028, −0.003]; $p = 0.018$) in males. Vitamin A consumption was inversely associated with BMI ($\beta = -0.001$; 95% CI [− 0.001, 0.000]; $p = 0.049$) and fat mass ($\beta = -0.002$; 95% CI [0.004, 0.001]; $p = 0.003$) in females.

Discussion

The aim of this study was to investigate possible associations between dietary intakes of individual antioxidants

Table 3. Logistic regression analysis of antioxidants nutrients and DAQs in young adults with normal weight and overweight/obese

	Females (n = 355)[a]			Males (n = 166)[a]			Overall (n = 521)[b]		
	Odds Ratio	95% CI	p value	Odds Ratio	95% CI	p value	Odds Ratio	95% CI	p value
Vitamin C (mg/day)	0.997	0.992, 1.002	0.246	0.994	0.988, 0.999	0.024	0.995	0.992, 0.999	0.013
Vitamin E (mg/day)	0.995	0.910, 1.087	0.907	0.973	0.863, 1.096	0.647	0.983	0.915, 1.055	0.628
Vitamin A (μg/day)	0.999	0.998, 1.000	0.040	0.999	0.998, 1.000	0.257	0.999	0.999, 1.000	0.016
Zinc (mg/day)	0.984	0.889, 1.090	0.760	1.059	0.934, 1.200	0.372	1.013	0.938, 1.095	0.740
Selenium (μg/day)	1.002	0.999, 1.005	0.166	1.004	0.999, 1.010	0.127	1.003	1.000, 1.006	0.034
Magnesium (mg/day)	0.999	0.997, 1.001	0.544	1.000	0.998, 1.003	0.756	1.000	0.998, 1.001	0.917
DAQs	0.814	0.606, 1.092	0.170	0.739	0.480, 1.138	0.170	–	–	–

[a]Logistic regression models were adjusted for age and energy intake in females and males.
[b]Logistic regression models were adjusted age, sex and energy intake in the overall population.
The DAQS score refers to the intake of selenium, zinc, vitamin A, vitamin C and vitamin. Daily nutrient intake of each micronutrients was compared to that of the daily recommended intake for Spanish people (DRI). Since the daily recommended intake for vitamin A is different in women and men, it is recommended that the index be calculated separately for females and males. For this reason, analysis were only showed separately for females and males but no for the overall population.

and DAQs and obesity-related measures by assessing BMI, fat-mass percentage, fat mass, and fat-free mass in a sample of 560 young adults. Our data revealed that overweight and obese young adults have significantly lower intakes of vitamin C and vitamin A and so the intake of low amounts of these antioxidant nutrients is associated with higher BMIs in this population subset. In addition, fat mass was inversely associated with vitamin A, and BMI was inversely associated with vitamin C and vitamin A intake in the whole population sample. These findings support a possible link between low antioxidant nutrient intakes and an increased risk of obesity in early adulthood and correlate with the results from a National Health and Nutrition Examination Survey that reported a high prevalence of inadequate intakes of micronutrients in obese versus normal-weight adults [21].

Vitamin A is a fat-soluble vitamin that participates in adipocyte metabolism [37]. It is obtained through diet from animal sources such as meat, dairy products, and fish and from colorful fruits and vegetables [38].We showed that overweight and obese young adults have significantly lower vitamin A intakes compared to their normal-weight counterparts and that vitamin A intake is inversely associated with BMI and fat mass. In agreement with these findings, a previous study conducted in 61 healthy young adults showed a negative correlation between vitamin A intake and anthropometrical measurements including weight, BMI, waist circumference and waist-to-hip ratio [23], and a small study by Damms et al. also reported insufficient intakes of several micronutrients including retinol in obese adults [22]. Together, these data all suggest that vitamin A may play an important role in body-weight regulation. This hypothesis fits with other data showing that all-trans retinoic acid (a vitamin A metabolite) stimulates lipolysis [39] and that vitamin A may downregulate adipose tissue and blood leptin levels thus, ameliorating its oxidative stress and pro-inflammatory effects [40].

We also saw a negative association between Vitamin C and BMI and fat mass which agrees with previous studies showing a similar association between serum vitamin C levels and obesity in adult populations [11, 22, 41, 42] as well as with other population studies analyzing a wide range of ages. For instance, in a population of adults aged 20–65, inadequate vitamin C intake was more prevalent among individuals with higher BMIs [19]. Similarly, BMI was inversely correlated with ascorbic acid concentrations in a large population aged 18–74 years in the National Health and Nutrition Examination Survey II [42] and findings from the European Prospective Investigation into Cancer and Nutrition Norfolk cohort study also provided evidence that plasma ascorbic acid levels were inversely associated with fat distribution [11]. Taken together, all this evidence suggests that vitamin C intake, which is derived from fruits (citrus fruit, kiwi or mango) and vegetables (broccoli, tomatoes or peppers) [43], may be implicated in the mechanisms avoiding to obesity, which may be linked to its reported role in modulating adipocyte lipolysis and the inhibition of glucose metabolism and adipocyte leptin secretion in vitro [44].

On the other hand, we found that selenium intake in young overweight and obese adults was higher than in individuals with normal BMI ranges. In line with our findings, higher dietary selenium intake correlated with higher levels of insulin resistance [45], a pathology which can be caused by obesity and can contribute to its development. Moreover, a recent systematic review and meta-analysis concluded that selenium may increase the risk of type 2 diabetes across a wide range of exposure levels [46]. Similarly, observational studies added support to the role of high dietary selenium in the incidence of diabetes [47, 48]. In contrast, Wang et al. found that obesity itself, as well as its severity, were associated with low dietary selenium content in a general adult cohort [25]. Therefore, due the inconsistency in direction of association reported in previous research, the role of

Table 4. Multiple regression analysis for the association between antioxidants nutrients and obesity measures in the overall population

	Weight (Kg)		BMI		Fat mass percent (%)		Fat mass (Kg)		Fat free mass (Kg)	
	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value
Vitamin C (mg/day)	−0.014 (−0.026, −0.001)	0.032	−0.005 (−0.009, −0.001)	0.016	−0.010 (−0.021, 0.000)	0.058	−0.008 (−0.017, 0.000)	0.053	−0.005 (−0.011, 0.000)	0.067
Vitamin E (mg/day)	0.096 (−0.165, 0.357)	0.469	0.000 (−0.086, 0.085)	0.995	0.002 (−0.253, 0.257)	0.988	0.036 (−0.138, 0.210)	0.684	0.041 (−0.081, 0.164)	0.510
Vitamin A (μg/day)	−0.001 (−0.003, 0.001)	0.173	−0.001 (−0.001, 0.000)	0.036	−0.001 (−0.002, 0.001)	0.415	−0.002 (−0.003, −0.001)	0.002	0.001 (0.000, 0.001)	0.225
Zinc (mg/day)	0.115 (−0.186, 0.416)	0.452	0.044 (−0.055, 0.142)	0.385	0.135 (−0.139, 0.409)	0.331	0.055 (−0.146, 0.255)	0.594	0.057 (−0.084, 0.198)	0.431
Selenium (μg/day)	0.005 (−0.007, 0.017)	0.397	0.001 (−0.002, 0.005)	0.443	0.006 (−0.003, 0.016)	0.170	0.003 (−0.005, 0.010)	0.511	0.002 (−0.003, 0.008)	0.435
Magnesium (mg/day)	0.002 (−0.033, 0.008)	0.421	0.001 (−0.001, 0.002)	0.493	0.001 (−0.007, 0.009)	0.781	0.002 (−0.002, 0.006)	0.268	0.000 (−0.003, 0.002)	0.796

Multiple regression models were adjusted for age, sex and energy intake.

Table 5. Multiple regression analysis for the association between antioxidants nutrients, DAQs and obesity measures separately for females and males

	Weight (Kg)				BMI				Fat mass percent (%)				Fat mass (Kg)				Fat free mass (Kg)			
	Females		Males		Females		Males		Females		Males		Females		Males		Females		Males	
	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value	β (95% CI)	P value
Vitamin C (mg/day)	−0.004 (−0.019, 0.011)	0.590	−0.028 (−0.051, −0.004)	0.021	−0.004 (−0.009, 0.002)	0.175	−0.007 (−0.03, 0.000)	0.051	−0.009 (−0.023, 0.006)	0.226	−0.013 (−0.027, 0.001)	0.070	−0.003 (−0.014, 0.008)	0.594	−0.015 (−0.028, −0.003)	0.018	−0.001 (−0.006, 0.005)	0.838	−0.013 (−0.027, 0.001)	0.065
Vitamin E (mg/day)	0.104 (−0.195, 0.402)	0.495	0.101 (−0.410, 0.613)	0.696	0.005 (−0.102, 0.112)	0.921	−0.004 (−0.147, 0.138)	0.954	0.027 (−0.274, 0.328)	0.859	−0.105 (−0.597, 0.387)	0.672	0.068 (−0.153, 0.288)	0.546	−0.011 (−0.291, 0.270)	0.940	0.034 (−0.072, 0.140)	0.529	0.060 (−0.247, 0.366)	0.701
Vitamin A (μg/day)	−0.002 (−0.004, 0.000)	0.093	0.000 (−0.004, 0.004)	0.949	−0.001 (−0.001. 0.000)	0.049	0.000 (−0.002, 0.001)	0.568	−0.001 (−0.003, 0.001)	0.209	0.001 (−0.002, 0.004)	0.372	−0.002 (−0.004, −0.001)	0.003	−0.001 (−0.003, 0.001)	0.438	0.000 (0.000, 0.001)	0.290	0.001 (−0.002, 0.004)	0.430
Zinc (mg/day)	0.016 (−0.324, 0.357)	0.925	0.309 (−0.289, 0.907)	0.309	0.027 (−0.095, 0.149)	0.666	0.074 (−0.093, 0.240)	0.383	0.068 (−0.286, 0.421)	0.706	0.281 (−0.117, 0.679)	0.163	0.059 (−0.194, 0.311)	0.648	0.041 (−0.288, 0.369)	0.808	−0.045 (−0.167, 0.076)	0.461	0.262 (−0.095, 0.619)	0.149
Selenium (μg/day)	0.004 (−0.009, 0.016)	0.562	0.004 (−0.022, 0.031)	0.743	0.001 (−0.003, 0.006)	0.601	0.001 (−0.007, 0.008)	0.863	0.005 (−0.006, 0.016)	0.355	0.014 (−0.004, 0.033)	0.128	0.002 (−0.007, 0.011)	0.662	0.001 (−0.014, 0.016)	0.887	0.001 (−0.004, 0.005)	0.813	0.006 (−0.010, 0.022)	0.480
Magnesium (mg/day)	0.003 (−0.003, 0.009)	0.386	−0.001 (−0.015, 0.012	0.850	0.000 (−0.002, 0.002)	0.838	0.001 (−0.003, 0.005)	0.559	0.002 (−0.007, 0.011)	0.610	−0.006 (−0.023, 0.012)	0.499	0.002 (−0.003, 0.006)	0.454	0.002 (−0.005, 0.009)	0.596	0.000 (−0.002, 0.002)	0.725	−0.004 (−0.011, 0.004)	0.378
DAQs	0.686 (−1.695, 0.323)	0.182	−0.704 (−2.739, 1.330)	0.495	−0.304 (−0.666, 0.057)	0.099	−0.384 (−0.949, 0.180)	0.181	−0.929 (−1.900, 0.042)	0.061	−0.367 (−1.913, 1.178)	0.637	−0.684 (−1.430, 0.062)	0.072	−0.882 (−1.991, 0.228)	0.118	0.000 (−0.359, 0.359)	0.999	0.090 (−1.131, 1.311)	0.885

Multiple regression models were adjusted for age and energy intake.

selenium on obesity warrant further examination. It should be highlight that selenium seems to have bimodal roles as an antioxidant and a pro-oxidant, exerting beneficial and harmful effects under different circumstances [49]. Nevertheless, the preventive effect of selenium is considered to be due to the antioxidant function of selenoproteins [50].

The results of previous studies assessing the link between vitamin E, zinc, or magnesium intakes and BMI status have been inconsistent [14, 16–19, 21] but in our own work, we found no associations between these antioxidants and obesity parameters. These previous inconclusive results may because of differences in the samples sizes, population characteristics, study designs, or dietary assessments used in each case. Also of note, some associations between antioxidant nutrient intakes in our study did not remain significant when analyzed separately by sex. This may be because the reduced sample sizes of these separate groups had less statistical power to discern these associations and therefore, studies including larger sample sizes will be required in the future.

Our findings may have clinical applications because they suggest that the consumption of antioxidant-rich food maybe helps to prevent obesity in early adulthood. Nevertheless, we cannot completely discard that other lifestyle and dietary factors covariating with intake of the antioxidant nutrients investigated may have been responsible of the association detected in the study. Thus, further studies are required to validate our preliminary results. The elaboration of interventional studies investigating the effect of antioxidant-rich diets for improving BMI and adiposity may also be very useful.

Finally, it is important to note the potential limitations of this study. First, its cross-sectional design prevented the determination of cause and effect. Second, we did not explore the relationships between dietary intake of antioxidants and DAQs and their corresponding plasma concentrations. Thus, future research should investigate these relationships in order to provide a more physiological approach. Thirdly, it should be noted that our results may have been confounded by the fact that we did not exclude individuals taking multivitamins. Additionally, subjects who were on a special diet (e.g., plant-based, vegetarian, vegan, etc.) were not excluded. This is a potential limitation since special diets can significantly affect dietary intake of antioxidants. Regarding the difference in the number of men and women, it should be noted that the proportion of women versus men was higher in the educational centers that participated in the study. Also, we cannot discard that, since students were informed that participation was voluntary and there was no penalty for not participating, women had higher motivation to be involved in obesity and diet research than men. Thus, further studies with a larger sample size of males would be necessary to support our preliminary findings. Finally, given the higher number of statistical interactions that have been tested, we have not eliminated the possibility that multiple testing could play a role in our results. Conversely, the strengths of this study include its assessment of body composition parameters in addition to BMI to avoid the problems associated with relying only on BMI to assess obesity status. We also assessed dietary intake using a 72-hour recall interview which is thought to provide better data on individual average diets. The literature supports the use of 72-hour diet recall as a valid method for assessing nutrient intake since it collects more accurate data on the typical or average diet [51]. In addition, these surveys were conducted by well-trained investigators to try to avoid problems of food intake underreporting in self-administered questionnaires [52] and pictorial food models were used to improve the accuracy of the meal descriptions. Also, to the best of our knowledge, this is the first study to explore the association between antioxidant nutrients, DAQs, and obesity-related measures including body composition parameters in a specific cohort of young adults.

In conclusion, vitamin A and C intakes are negatively associated with obesity-related measures including fat mass and BMI in healthy young adults. Additionally, overweight and obese young adults consume significantly less vitamin C and A. Future longitudinal investigations of dietary antioxidant intake in relation to the development of obesity may help to elucidate the effect of dietary antioxidants on obesity.

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