Preventive Medicine 125 (2019) 40–48

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Dietary share of ultra-processed foods and metabolic syndrome in the US adult population

Eurídice Martínez Steele[a,b,*], Filippa Juul[c], Daniela Neri[a,b], Fernanda Rauber[a,b], Carlos A. Monteiro[a,b]

[a] Department of Nutrition, School of Public Health, University of São Paulo, São Paulo, Brazil
[b] Center for Epidemiological Studies in Health and Nutrition, University of São Paulo, São Paulo, Brazil
[c] College of Global Public Health, New York University, New York, NY 10012, USA

ARTICLE INFO

Keywords:
NHANES
Ultra-processed foods
Metabolic syndrome
HDL-C
Waist circumference
Blood pressure
Triglycerides
Hyperglycemia

ABSTRACT

This study sought to examine the relationship between dietary share of ultra-processed foods and metabolic syndrome among US adults. We studied 6, 385 participants from the cross-sectional National Health and Nutrition Examination Survey 2009–2014, aged 20+ years, with blood tests under fasting conditions and at least one 24-hour dietary recall. Food items were classified according to the extent and purpose of industrial food processing. Ultra-processed foods (UPF) are formulations of many ingredients, mostly of exclusive industrial use, that result from a sequence of industrial processes (hence ultra-processed). Metabolic Syndrome (MetS) was defined according to the 2009 Joint Scientific Statement as meeting three or more of the following criteria: (1) elevated waist circumference (2) elevated fasting plasma glucose (3) elevated blood pressure (4) elevated triglycerides (5) reduced high-density lipoprotein (HDL-C). Poisson regression models with robust variance adjusted for age, sex, race/ethnicity, family income, education, physical activity and smoking showed significant linear association between the dietary contribution of UPF and the prevalence of MetS (a 10% increase in contribution was associated with a 4% prevalence increase) (prevalence ratio -PR- = 1.04; 95% CI 1.02, 1.07). A dietary UPF contribution of > 71% (5th population quintile) was associated with 28% higher prevalence of MetS compared to a contribution below 40% (1st population quintile) (PR = 1.28; 95% CI 1.09, 1.50). The association was stronger in young adults (PR between upper and lower quintiles = 1.94; 95% CI 1.39, 2.72) and decreased with age. These findings add to the growing evidence that UPF consumption is associated with diet-related non-communicable diseases.

1. Introduction

Metabolic syndrome (MetS) is a complex of multiple, interrelated risk factors for cardiovascular disease (CVD) and diabetes which occur more often together than by chance alone and for which the cause is often uncertain (Alberti et al., 2009). MetS is not an absolute risk indicator, as it does not contain many of the factors that determine absolute risk, such as age, sex, cigarette smoking, and low-density lipoprotein cholesterol levels (Alberti et al., 2009). However, evidence exists that people affected by MetS are at twice the risk of developing CVD over the next 5 to 10 years and have a 5-fold risk of type 2 diabetes mellitus compared to unaffected individuals (Alberti et al., 2009).

In the last decades, worldwide prevalence of MetS has risen dramatically, presumably due to increasing obesity and lifestyle risk factors (Alberti et al., 2009), including poor diet (Martínez-González and Martín-Calvo, 2013). Still, the most appropriate diet for prevention and treatment of MetS remains uncertain (Pérez-Martínez et al., 2017). Recent studies suggest that using overall dietary patterns rather than isolated nutrients may better appraise the association between diet and MetS (Martínez-González and Martín-Calvo, 2013). In this sense, evidence is supportive of a beneficial effect on MetS of the adherence to "a priori defined" Mediterranean dietary pattern (Martínez-González and Martín-Calvo, 2013; Pérez-Martínez et al., 2017; Kastorini et al., 2011; Gouveri and Diamantopoulos, 2015; Babio et al., 2014) and also, though studies are scarce (Pérez-Martínez et al., 2017), to the DASH diet or Northern Europe dietary pattern (Calton et al., 2014; Azadbakht

Abbreviations: Body mass index, (BMI); Confidence interval, (CI); High density lipoprotein, (HDL); Metabolic syndrome, (MetS); Metabolic equivalent of task, (MET); Mobile examination center, (MEC); National Health and Nutrition Examination Survey, (NHANES); Prevalence ratio, (PR); Ultra-processed foods, (UPF)

* Corresponding author at: Departamento de Nutrição, Faculdade de Saúde Pública, Universidade de São Paulo, Av. Dr. Arnaldo, 715, São Paulo 01246-907, Brazil.
E-mail address: emar_steele@hotmail.com (E. Martínez Steele).

https://doi.org/10.1016/j.ypmed.2019.05.004
Received 19 December 2018; Received in revised form 6 May 2019; Accepted 7 May 2019
Available online 09 May 2019
0091-7435/

et al., 2005; Adamsson et al., 2012). Conversely, other studies including two recent meta-analyses (Martínez-González and Martín-Calvo, 2013; Rodríguez-Monforte et al., 2017; Shab-Bidar et al., 2018; Agodi et al., 2018; Esmaillzadeh et al., 2007; Heidemann et al., 2011) have confirmed that greater adherence to "a posteriori-defined" Western dietary pattern is associated with an increased risk for MetS, while prudent/traditional dietary patterns are associated with a lower prevalence of MetS.

Highly present in Western dietary patterns, ultra-processed foods (UPF) are formulations of many ingredients, mostly of exclusive industrial use, that result from a sequence of industrial processes (hence ultra-processed) (Monteiro et al., 2019). Evidence exists that global food supplies are increasingly dominated by UPF (Moodie et al., 2013; *Ultra-processed food and drink products in Latin America: Trends, impact on obesity, policy implications*, 2015; Stuckler et al., 2012; Monteiro and Cannon, 2012; Monteiro et al., 2013). Nationally representative studies carried out in the US (Martínez Steele et al., 2017; Martínez Steele and Monteiro, 2017; Martinez Steele et al., 2016), Canada (Moubarac et al., 2017; Moubarac et al., 2012) and other countries (Rauber et al., 2018; Julia et al., 2018; Cediel et al., 2018; Latasa et al., 2017; Louzada et al., 2015a, 2015b, 2018; Monteiro et al., 2010) have shown that high dietary contribution of UPF renders nutritionally unbalanced diets. Large, population-based cross-sectional and cohort studies support that the consumption of these foods is associated with overweight and obesity (Julia et al., 2018; Juul et al., 2018; Mendonça et al., 2016; Louzada et al., 2015; Canella et al., 2014), dyslipidemia (Rauber et al., 2015), hypertension (Mendonça et al., 2017) and abdominal obesity (Juul et al., 2018). Two small cross-sectional studies found an association between UPF consumption and MetS in Brazilian adolescents (Tavares et al., 2012) and among Indigenous Cree (Eeyouch) from northern Québec (Lavigne-Robichaud et al., 2018).

The aim of the current study was to examine whether a relationship exists between the dietary share of UPF and MetS among a representative sample of US adults.

2. Subjects and methods

2.1. Data source, population and sampling

We used nationally representative data from *National Health and Nutrition Examination Survey* (NHANES, n.d.) 2009–2014 (three 2-year cycles). NHANES is a continuous, nationally representative, cross-sectional survey of the non-institutionalized, civilian US residents conducted by The Centers for Disease Control and Prevention (Johnson et al., n.d.). Participants were recruited using a four-stage sample design based on the selection of counties, blocks, households, and the number of people within households.

The survey included an interview conducted in the home and a subsequent health examination performed at a mobile examination center (MEC), including blood collection. All NHANES examinees were eligible for two 24-hour dietary recall interviews: the first one collected in-person in the MEC (NHANES, 2009a) and the second by telephone, 3 to 10 days later (NHANES, 2009b). Dietary interviews were conducted by trained interviewers using the validated (Moshfegh et al., 2008; Blanton et al., 2006; Rumpler et al., 2008) *US Department of Agriculture Automated Multiple-Pass Method* (Agriculture Research Service, n.d.).

Our analytical sample comprised non-pregnant and non-breast-feeding individuals aged 20 years or above who fasted for at least 8 h and had complete information on all variables of interest, resulting in a final sample size of 6385 individuals (Table 1). Nonresponse analysis indicated no systematic bias due to socio-demographic characteristics (OSM Table 1).

NHANES underwent institutional review board approval and included written informed consent.

2.2. Definition of outcome

Metabolic Syndrome (MetS) was defined based on the Joint Scientific Statement definition (Alberti et al., 2009) as meeting three or more of the following criteria: (1) elevated waist circumference (2) elevated fasting plasma glucose (3) elevated blood pressure (4) elevated triglycerides (5) reduced high-density lipoprotein (HDL-C) (Table 2).

2.3. Definition of exposure

We classified all recorded food items (Food Codes) for NHANES cycles 2009–2014 according to NOVA, a four-group food classification based on the extent and purpose of industrial food processing including unprocessed or minimally processed foods, processed culinary ingredients, processed foods and ultra-processed foods (Monteiro et al., 2019; Martinez Steele et al., 2016). This study focused on the NOVA group of UPF further described in OSM 2. Details of how food item classification was accomplished are further explained in previously published papers (Martinez Steele et al., 2016; Juul et al., 2018) and in OSM 2. We used the dietary contribution of UPFs (as a percentage of total energy intake), both categorized into quintiles and continuous, as our exposure variables.

2.4. Assessing energy and nutrient intakes

USDA's Food and Nutrient Database for Dietary Studies 5.0, 2011–2012 and 2013–2014 (US Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory, 2016) were used to code dietary intake data and calculate Food Code energy intakes, and also saturated and total fat dietary contributions (% of total energy). For handmade recipes, we calculated the underlying ingredient (SR Code) energy values using variables from both *FNDDS 5.0, 2011–2012* and *2013–2014* (U.S. Department of Agriculture, Agricultural Research Service, n.d.) and *USDA National Nutrient Database for Standard Reference, Release 24, 26 and 28* (US Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory, 2016).

Data on added sugars per Food Code were obtained by merging the Food Patterns Equivalents Database (FPED) 2009–2010, 2011–2012 and 2013–2014 (Bowman et al., 2013).

2.5. Covariates

Socio-demographic covariates included age, gender, race, family income, and education. Age was used both as a continuous variable and grouped into three categories (20–39 years, 40–59 years, and 60 years of age and over) (Johnson et al., n.d.). Race/ethnicity was categorized as Mexican-American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black and Other Races including Multi-Racial. With respect to family income, ratio of family income to poverty was established and categorized based on Supplemental Nutrition Assistance Program (SNAP) eligibility as 0.00–1.30, > 1.30–3.50, and 3.50 and above (Johnson et al., n.d.). Education reflected the highest grade completed by the participant and was categorized as < 12 years (middle and elementary school), 12 years (high school) and > 12 years (college and graduate School).

BMI was calculated by dividing weight by height squared (kg/m^2) and used as a continuous covariate.

Physical activity was categorized into three intensity levels – light (< 150 min per week of moderate intensity equivalent activity), moderate (150 to 300 min per week of moderate-intensity equivalent activity) and vigorous (> 300 min per week of moderate- intensity equivalent activity) (U.S. Department of Health and Human Services, 2008). Smoking status was categorized as current smoker and non-smoker. The covariate "Following special diet" (yes/no) was defined as having tried to lose weight or not gain weight through diet modification

Table 1
Study flowchart.

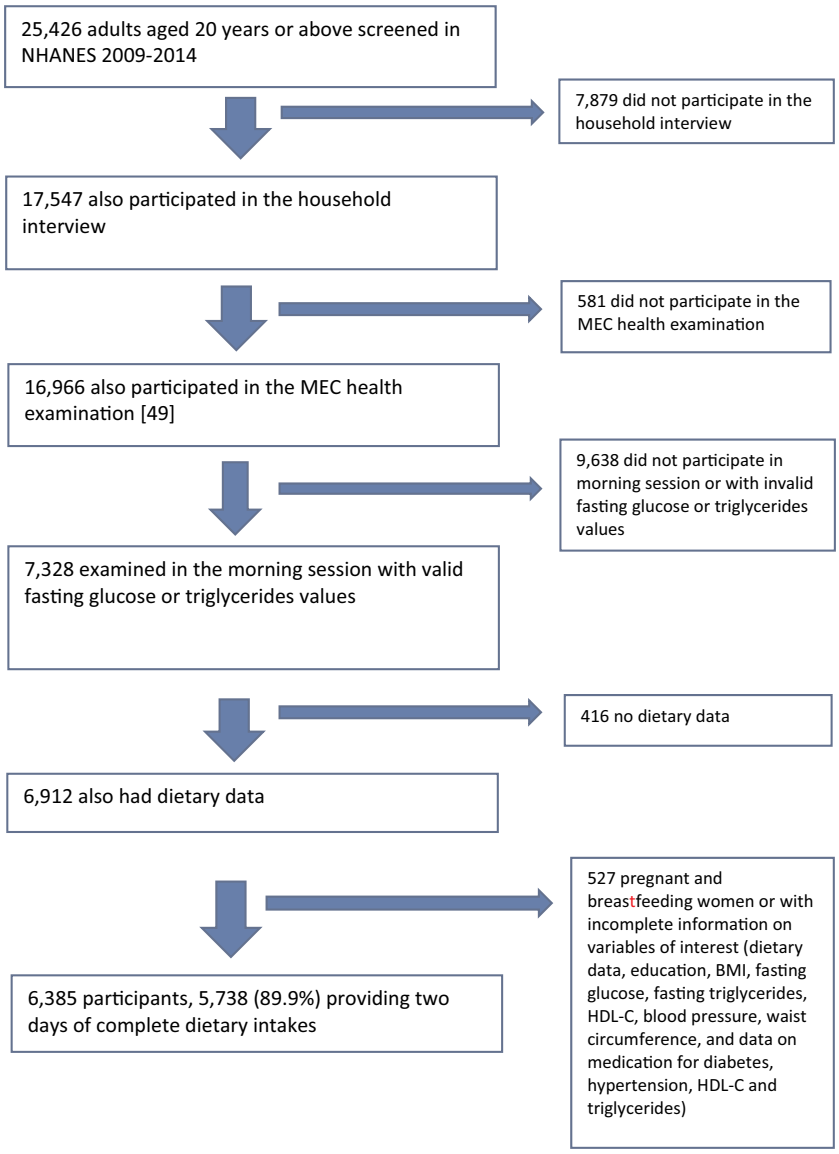

Table 2
Criteria for the definition of metabolic syndrome[d] (Joint Scientific Statement definition (Alberti et al., 2009)) and standardized techniques.

Component	Cut-points
Elevated waist circumference[a]	≥ 102 cm in males or ≥ 88 cm in females
Elevated fasting serum triglycerides[b]	≥ 150 mg/dL (or current prescription treatment for dyslipidemia)
Reduced high-density lipoprotein (HDL) cholesterol[b]	< 40 mg/dL in men or < 50 mg/dL in women (or current prescription treatment for dyslipidemia)
Elevated blood pressure[c]	Systolic blood pressure ≥ 130 mmHg and/or diastolic blood pressure ≥ 85 mmHg (or currently taking antihypertensive medication)
Elevated fasting plasma glucose[b]	≥ 100 mg/dL (or currently taking insulin or an oral hypoglycemic medication)

[a] Height, weight, and waist circumference were measured by trained personnel in the MEC using standardized techniques and calibrated equipment. Waist circumference was measured at the high point of the iliac crest at the end of normal expiration to the nearest 0.1 cm (Centers for Disease Control and Prevention, n.d.-a).

[b] For the lipid and glucose assays, fasting morning blood samples were drawn from the participants' arm by certified phlebotomists (Centers for Disease Control and Prevention, n.d.-b).

[c] Standardized techniques were used to obtain the blood pressure measurements. Up to four attempts were made to collect three blood pressure readings. The average of up to three brachial systolic and diastolic blood pressure readings were used for the systolic and diastolic blood pressure values, following the integrated survey information system averaging rules (Centers for Disease Control and Prevention. National Center for Health Statistics. National Health and Nutrition Examination Survey, n.d.).

[d] Metabolic syndrome was defined as meeting three or more of the following criteria.

Table 3
Dietary contribution of ultra-processed foods and prevalence (%) of metabolic syndrome according to characteristics of respondents. US population aged 20 and above under fasting conditions (NHANES 2009–2014).

			Dietary contribution of ultra-processed foods (% total energy)	Prevalence of metabolic syndrome
		n	Mean (SE)[a]	% (SE)[a]
Gender	Men	3144	55.9 (0.6)	41.9 (1.4)
	Women	3241	55.0 (0.5)	41.5 (1.4)
	P value		0.123	0.845
Age groups (years)[b]	20 to 39	2126	58.9^{A} (0.6)	20.1^{A} (1.1)
	40 to 59	2239	54.6^{B} (0.8)	44.5^{B} (1.4)
	60 or above	2020	52.2^{C} (0.6)	67.9^{C} (1.5)
	P for trend		< 0.001	< 0.001
Race/ethnicity[b]	Mexican American	951	53.6^{C} (0.5)	40.0^{ABC} (1.9)
	Other Hispanic	665	47.6^{A} (1.0)	35.0^{AB} (2.0)
	Non-Hispanic white	2867	57.2^{B} (0.5)	43.8^{C} (1.3)
	Non-Hispanic black	1197	57.3^{B} (0.8)	40.4^{BC} (1.5)
	Other race (including multi-racial)	705	45.1^{A} (1.4)	30.5^{A} (2.5)
	P value		< 0.001	< 0.001
Income to poverty[b]	0.00–1.30	1985	57.9^{A} (0.7)	40.9^{A} (1.5)
	> 1.30–3.50	2133	56.9^{A} (0.7)	43.4^{A} (1.2)
	> 3.50 and above	1775	53.3^{B} (0.6)	40.2^{A} (1.7)
	Missing	492	52.5^{B} (1.3)	44.4^{A} (2.9)
	P value		< 0.001	0.182
Educational attainment[b]	< 12 years	1542	55.9^{A} (0.9)	49.3^{A} (1.8)
	12 years	1381	59.6^{B} (0.8)	46.5^{A} (1.6)
	> 12 years	3462	54.0^{A} (0.5)	38.0^{B} (1.4)
	P for trend		< 0.001	< 0.001
Physical activity[b]	Low	2471	56.4^{B} (0.6)	52.6^{A} (1.3)
	Medium	863	53.9^{A} (0.9)	42.4^{B} (2.1)
	High	3051	55.3^{AB} (0.5)	33.9^{C} (1.5)
	P for trend		0.109	< 0.001
Current smoker	No	5109	54.5 (0.5)	42.2 (1.1)
	Yes	1276	59.5 (0.7)	39.7 (2.1)
	P value		< 0.001	0.277
Special diet	No	4031	56.2 (0.6)	36.5 (1.2)
	Yes	2354	54.4 (0.6)	49.6 (1.7)
	P value		0.032	< 0.001
Total		6385	55.5 (0.5)	41.7 (1.1)

[a] Pairwise differences across categories of selected covariates were tested using Wald test (with Bonferroni inequality adjustment for multiple comparisons).

[b] In covariates with > 2 categories, values sharing a letter in the superscript are not statistically significantly different at the $p < 0.05$ level.

or having sought help to lose weight from a dietitian or nutritionist in the past year.

2.6. Data analysis

We utilized all available dietary intake data for each participant, using means of both recall days when available (89% of participants) and one day otherwise.

First, we evaluated the mean dietary contribution of UPF (% of total energy) overall and across socio-demographic and life-style characteristics and MetS status of respondents using linear regression. Thereafter, we estimated the prevalence of MetS overall and across strata, using Poisson regression with robust variance, as odds ratios may overestimate prevalence ratios for common outcomes (Barros and Hirakata, 2003). Test of linear trend was performed for ordinal variables and Wald test with Bonferroni inequality adjustment for multiple comparisons was used for non-ordinal categorical variables or in the absence of a statistically significant linear trend.

We used Poisson regression with robust variance to estimate the association between quintiles of dietary contribution of UPF and prevalence of MetS. We estimated crude prevalence ratios (PRs), as well as (1) age–adjusted PRs, (2) socio-demographic multivariable adjusted PRs (including age, sex, race/ethnicity, income-to-poverty and educational attainment), and (3) multivariable socio-demographic and life-style adjusted PRs (including model 2 covariates, smoking status and physical activity level). We also examined the prevalence increase in MetS associated with a 10% increase in the proportion of UPF consumption (continuous variable).

As secondary analysis, we also evaluated whether the prevalence of each MetS defining condition varied across quintiles of UPF consumption.

Effect modification by sex, age (continuous) and age group were tested by including a multiplicative interaction term (tested as continuous and/or dummy variable) in the multivariable socio-demographic and life-style adjusted model. Analyses were stratified according to statistically significant interaction variables.

To test the robustness of the associations, we conducted sensitivity analyses (using the multivariable socio-demographic and life-style adjusted model) excluding individuals: 1) on special diets to control or minimize the effect of reverse causality; 2) with extreme energy intake values (< 600 or > 4500 kcal for men and < 500 or > 3500 kcal for women); 3) underweight (BMI < 18.5 kg/m2); and 4) older than 64 years old. While the Joint Scientific Statement classifies use of medication as an equal criterion for meeting the definition of specific components, NHANES does not collect information on the therapeutic indication for self-reported use of lipid-modifying agents which may be used for increasing HDL-C and/or lowering triglyceride levels (National Cholesterol Education Program (U.S.)., 2002; *JAMA*, 2001) and may therefore lead to overestimation of MetS and related conditions (Beltrán-Sánchez et al., 2013). For this reason, we conducted an additional sensitivity analysis using a more conservative definition for MetS that does not consider treatment for triglycerides or HDL cholesterol.

Given that total energy intake, added sugars (% energy intake), total fat (% energy intake), saturated fat (% energy intake) and BMI are plausible mediators and/or confounders of the association between UPF consumption and MetS, adjusting for these factors could attenuate the effect. We therefore conducted sensitivity analysis further controlling for each of these five variables independently (in multivariable socio-demographic and life-style models). These analyses were performed after confirming the association between each dietary indicator/BMI and exposure and outcome variables, respectively, using linear regression. Tests of linear trend were performed in all models by treating quintiles of UPF consumption as an ordinal continuous variable.

NHANES survey sample weights were used in all analyses to account for differential probabilities of selection for the individual domains, nonresponse to survey instruments, and differences between the final sample and the total US population. The Taylor series linearization variance approximation procedure was used for variance estimation in all analyses to account for the complex sample design and the sample weights (Johnson et al., n.d.).

Statistical hypotheses were tested using a two-tailed $p \leq 0.05$ level of significance. All analyses were conducted with Stata statistical software package version 14.

3. Results

3.1. UPF consumption and prevalence of metabolic syndrome according to sociodemographic and life-style variables

Among US adults aged 20 years or above who met the eligibility criteria (n = 6385), the mean dietary contribution of UPF was 55.5% (95% CI 54.6, 56.4) of total energy intake and decreased with age (p for

linear trend < 0.001) (Table 3). UPF consumption was lowest among Other Hispanic and Other race, intermediate among Mexican American, and highest among Non-Hispanic White and Black (p < 0.05). Individuals with income-to-poverty ratio < 3.5 and 12 years of education presented the highest UPF consumption (p < 0.05). Participants with low physical activity consumed more UPF than individuals with medium physical activity level (p < 0.05). Current smokers (p < 0.001) and individuals who were not following a special diet (p = 0.032) also consumed more UPF.

The unadjusted prevalence of MetS was 41.7% (95% CI 39.6, 43.9) (Table 3). Consistent with previously reported values (Aguilar et al., 2015), the prevalence dropped to 35.4% (95% CI 33.4, 37.3) when using a definition for MetS that does not consider current prescription for triglycerides or HDL cholesterol. The unadjusted prevalence increased with age and decreased with higher physical activity level (p for linear trend < 0.001). Prevalence of MetS varied according to race/ethnicity (p < 0.05) and was lower among individuals with higher level of education (p for linear trend < 0.001) and not following a special diet (p < 0.001). Even though unadjusted mean UPF consumption did not differ between individuals with and without MetS (55.9% kcal; 95% CI 54.6, 57.1 vs. 55.3% kcal; 95% CI 54.1, 56.4, respectively), adjusted means by potential confounding factors did differ.

3.2. Association between UPF consumption and metabolic syndrome

As shown in Table 4, though the crude association between UPF consumption and MetS was not statistically significant, the age-adjusted model, as well as models taking in to account other potential confounding factors, all showed significant positive associations. In the fully adjusted model, the highest UPF consumption (5th quintile with dietary contribution of UPF > 71% kcal) was associated with 28% higher prevalence of MetS compared to the lowest consumption (1st quintile with UPF consumption < 40% kcal) (PR = 1.28; 95% CI 1.09, 1.50). In the fully adjusted model, a 10% increase in the consumption of UPF was associated with a 4% increase in the prevalence of MetS (PR = 1.04; 95% CI 1.02, 1.07).

A significant interaction was observed between dietary contribution of UPF and age (Wald test p < 0.01, interaction term using age as continuous). When comparing the highest and lowest quintiles, the association between UPF consumption and MetS was stronger among 20–39 y (PR = 1.94; 95% CI 1.39, 2.72), than among 60 y + (PR = 1.16; 95% CI 0.99, 1.34) (Table 5). While a 10% increase in UPF consumption was associated with a 12% increase in prevalence of MetS among the 20–39 y (continuous PR = 1.12; 95% CI 1.06, 1.18), the strength of the association dropped to a third among 40–59 y (continuous PR = 1.04; 95% CI 0.99, 1.09). No interaction was observed for sex (Wald test p = 0.28, interaction term included as continuous).

Sensitivity analyses confirmed the robustness of the results, as the association between quintiles of UPF consumption and MetS did not substantially change in any of the alternative scenarios (OSM Table 3). The association grew slightly stronger after excluding people older than 64 years (PR between extreme quintiles = 1.41; 95% CI 1.14, 1.75) and when using a more conservative definition of MetS (PR = 1.33; 95% CI 1.11, 1.59).

A positive association was observed between quintiles of UPF consumption and total energy intake, added sugars, total fats, saturated fats and BMI (p for linear trend ≤ 0.001 in all cases). Participants with MetS had lower mean energy intake (p ≤ 0.001), higher mean total fat intake (p ≤ 0.001) and higher mean BMI (p ≤ 0.001) (OSM Table 4). Still, the association between quintiles of UPF consumption and MetS remained unchanged after further adjustment for intake of energy, and total and saturated fat (Table 6). The association remained significant but was weaker when adjusting for added sugars (PR between extreme quintiles = 1.23; 95% CI 1.08, 1.40) and BMI (PR = 1.20; 95% CI 1.07, 1.35).

A statistically significant association was also observed between quintiles of UPF consumption and elevated waist circumference (PR between extreme quintiles = 1.26; 95% CI 1.13, 1.39), reduced HDL-C (PR = 1.34; 95% CI 1.19, 1.49) and elevated blood pressure (PR = 1.19; 95% CI 1.03, 1.38), in multivariable adjusted models (OSM Table 5).

4. Discussion

Findings from this nationally representative study of US adults show that higher dietary contribution of UPF is associated with higher prevalence of MetS. The association was especially strong among young adults (between 20 and 39 years) and grew weaker with age.

A positive association between UPF consumption and MetS has been reported in small studies carried out in Brazil (Tavares et al., 2012) and Canada (Lavigne-Robichaud et al., 2018). Our results are also consistent with evidence linking "a priori" Mediterranean, DASH and Northern Europe dietary patterns (Martínez-González and Martín-Calvo, 2013; Pérez-Martínez et al., 2017; Kastorini et al., 2011; Gouveri and

Table 4
Prevalence (%) of metabolic syndrome according to quintiles of dietary contribution of ultra-processed foods. US population aged 20 and above under fasting conditions (NHANES 2009–2014) (N = 6385).

Dietary contribution of ultra-processed foods (% of total energy intake)		Metabolic syndrome				
		%	PR unadj (95% CI)	PR adj[a] (95% CI)	PR adj[b] (95% CI)	PR adj[c] (95% CI)
Quintiles	Mean (range)					
1st (n = 1489)	29.4 (0 to 39.7)	37.5	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
2nd (n = 1357)	45.9 (39.7 to 51.6)	43.6	1.16 (1.01, 1.33)	1.18 (1.04, 1.34)	1.16 (1.02, 1.33)	1.16 (1.02, 1.32)
3rd (n = 1201)	56.3 (51.6 to 60.9)	44.6	1.19 (1.05, 1.34)	1.23 (1.11, 1.37)	1.21 (1.09, 1.35)	1.20 (1.08, 1.34)
4th (n = 1197)	65.6 (60.9 to 71.1)	42.5	1.13 (0.99, 1.29)	1.24 (1.09, 1.41)	1.22 (1.07, 1.39)	1.21 (1.07, 1.37)
5th (n = 1141)	80.3 (71.1 to 100)	40.4	1.08 (0.91, 1.27)	1.34 (1.15, 1.56)	1.31 (1.12, 1.53)	1.28 (1.09, 1.50)
P for trend	_	_	0.544	< 0.001	0.001	0.003
Continuous[d]	_	_	1.01 (0.99, 1.03)	1.05 (1.03, 1.08)	1.05 (1.02, 1.07)	1.04 (1.02, 1.07)
P value	_	_	0.414	< 0.001	< 0.001	0.001

[a] Prevalence ratio (using Poisson model with robust variance) adjusted for age (years).
[b] Prevalence ratio adjusted for sex, age (years), race/ethnicity (Mexican-American, other Hispanic, non-Hispanic white, non-Hispanic black and other race - including multi-racial-), ratio of family income to poverty (SNAP < 1.30, > 1.30–3.50, > 3.50 and over, missing) and educational attainment (< 12, 12 years and > 12 years).
[c] Prevalence ratio adjusted for sex, age (years), race/ethnicity, ratio of family income to poverty and educational attainment + current smoking status (yes, no) + physical activity (low, medium, high).
[d] PR for a 10% increase in the dietary contribution of ultra-processed foods.

Table 5
Prevalence (%) of metabolic syndrome according to quintiles of dietary contribution of ultra-processed foods stratified by age group. US population aged 20 and above under fasting conditions (NHANES 2009–2014).

Dietary contribution of ultra-processed foods (% of total energy intake)	Age group (years)								
	20–39			40–59			≥60		
	(n = 2126)			(n = 2239)			(n = 2020)		
	%	PR unadj (95% CI)	PR adj[a] (95% CI)	%	PR unadj (95% CI)	PR adj[a] (95% CI)	%	PR unadj (95% CI)	PR adj[a] (95% CI)
Quintiles									
1st	13.4	1 (ref.)	1 (ref.)	34.6	1 (ref.)	1 (ref.)	60.2	1 (ref.)	1 (ref.)
2nd	18.4	1.38 (0.92, 2.06)	1.37 (0.94, 2.01)	44.2	1.28 (1.02, 1.59)	1.23 (0.98, 1.54)	70.2	1.17 (1.02, 1.33)	1.18 (1.03, 1.34)
3rd	21.7	1.62 (1.06, 2.48)	1.59 (1.04, 2.41)	49.9	1.44 (1.15, 1.81)	1.37 (1.09, 1.72)	68.9	1.14 (1.00, 1.27)	1.14 (1.01, 1.28)
4th	22.1	1.66 (1.11, 2.46)	1.72 (1.17, 2.54)	48.3	1.39 (1.15, 1.68)	1.33 (1.09, 1.61)	69.4	1.15 (0.99, 1.35)	1.15 (0.99, 1.34)
5th	24.7	1.85 (1.32, 2.58)	1.94 (1.39, 2.72)	45.5	1.31 (0.98, 1.75)	1.24 (0.90, 1.69)	70.7	1.17 (1.01, 1.36)	1.16 (0.99, 1.34)
p for trend	_	< 0.001	< 0.001	_	0.032	0.113	_	0.075	0.127
Continuous[b]	_	1.11 (1.05, 1.16)	1.12 (1.06, 1.18)	_	1.05 (1.01, 1.10)	1.04 (0.99, 1.09)	_	1.02 (0.99, 1.05)	1.02 (0.99, 1.05)
P value	_	< 0.001	< 0.001	_	0.016	0.078	_	0.088	0.168

Mean (min max range) dietary contribution of ultra-processed foods per quintile - **20 to 39 y**: 1st = 31.9 (0 to 42.8), 2nd = 49.4 (42.9 to 55.2), 3rd = 60.1 (55.3 to 64.6), 4th = 69.6 (64.6 to 75.1), 5th = 83.8 (75.2 to 100); **40 to 59 y**: 1st = 28.6 (0 to 39.3), 2nd = 45.3 (39.3 to 50.7), 3rd = 55.3 (50.7 to 60.2), 4th = 64.5 (60.2 to 69.7), 5th = 79.3 (69.8 to 99.8); **+60 y**: 1st = 28.0 (0 to 36.9), 2nd = 42.8 (36.9 to 48.5), 3rd = 53.0 (48.5 to 57.4), 4th = 61.8 (57.4 to 66.6), 5th = 75.1 (66.6 to 100).

[a] PR = prevalence ratio (using Poisson model with robust variance) adjusted for sex, age (years), race/ethnicity, ratio of family income to poverty and educational attainment + current smoking status (yes, no) + physical activity (low, medium, high).

[b] PR for a 10% increase in the dietary contribution of ultra-processed foods.

Table 6
Prevalence (%) of metabolic syndrome according to quintiles of dietary contribution of ultra-processed foods, adjusted for all socio-demographic, lifestyle and energy intake, added sugars, saturated fat or BMI. US population aged 20 and above under fasting conditions (NHANES 2009–2014) (N = 6385).

Dietary contribution of ultra-processed foods (% of total energy intake)	Metabolic syndrome				
	PRadj[a] (95% CI)	PRadj[b] (95% CI)	PRadj[c] (95% CI)	PRadj[d] (95% CI)	PRadj[e] (95% CI)
Quintiles					
1st	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
2nd	1.16 (1.04, 1.29)	1.15 (1.03, 1.28)	1.16 (1.04, 1.29)	1.16 (1.04, 1.29)	1.15 (1.03, 1.27)
3rd	1.20 (1.08, 1.34)	1.18 (1.06, 1.32)	1.19 (1.07, 1.34)	1.20 (1.08, 1.34)	1.13 (1.02, 1.26)
4th	1.20 (1.07, 1.35)	1.18 (1.05, 1.32)	1.20 (1.07, 1.34)	1.21 (1.08, 1.35)	1.15 (1.03, 1.28)
5th	1.28 (1.13, 1.44)	1.23 (1.08, 1.40)	1.28 (1.13, 1.44)	1.28 (1.13, 1.45)	1.20 (1.07, 1.35)
p for trend	< 0.001	0.002	< 0.001	< 0.001	0.004
Continuous[f]	1.04 (1.02, 1.07)	1.04 (1.01, 1.06)	1.04 (1.02, 1.06)	1.04 (1.02, 1.07)	1.03 (1.01, 1.05)
P value	< 0.001	0.002	< 0.001	< 0.001	0.003

[a] Prevalence ratio (using Poisson model with robust variance) adjusted for sex, age group, race/ethnicity, ratio of family income to poverty and educational attainment + smoking status + physical activity + total daily energy intake (kcal).

[b] Prevalence ratio adjusted for sex, age group, race/ethnicity, ratio of family income to poverty and educational attainment + smoking status + physical activity + added sugars (% total energy).

[c] Prevalence ratio adjusted for sex, age group, race/ethnicity, ratio of family income to poverty and educational attainment + smoking status + physical activity + total fat (% total energy).

[d] Prevalence ratio adjusted for sex, age group, race/ethnicity, ratio of family income to poverty and educational attainment + smoking status + physical activity + saturated fat (% total energy).

[e] Prevalence ratio adjusted for sex, age group, race/ethnicity, ratio of family income to poverty and educational attainment + smoking status + physical activity + BMI (continuous).

[f] PR for a 10% increase in the dietary contribution of ultra-processed foods.

Diamantopoulos, 2015; Babio et al., 2014; Calton et al., 2014; Azadbakht et al., 2005; Adamsson et al., 2012) and "a posteriori" western and prudent/traditional dietary patterns (Martínez-González and Martín-Calvo, 2013; Rodríguez-Monforte et al., 2017; Shab-Bidar et al., 2018; Agodi et al., 2018; Esmaillzadeh et al., 2007; Heidemann et al., 2011) with MetS. Indeed, dietary patterns rich in UPF share common features with Western dietary patterns (Rodríguez-Monforte et al., 2017) and also tend to be poor in minimally-processed foods (Martínez Steele et al., 2017; Moubarac et al., 2012; Rauber et al., 2018; Louzada et al., 2015a). Conversely, dietary patterns based on minimally processed foods share common traits with the Mediterranean dietary pattern (Calton et al., 2014), DASH diet (Azadbakht et al., 2005), the Northern Europe dietary pattern (Adamsson et al., 2012) and prudent dietary patterns.

Given that the association of UPF food intake with MetS remained significant when adjusted for total energy, added sugars intake, fat and saturated fat intakes and BMI, dietary patterns based on UPF may contribute to MetS through various intermediate pathways not only

based on their nutrient profile but also on other characteristics related to the foods and/or by displacing minimally processed foods from the diet.

At the nutrient level, studies have shown that UPF and diets based on UPF tend to be rich in saturated fats, added/free sugars and sodium, and poor in fiber and micronutrients (Martínez Steele et al., 2017; Martínez Steele and Monteiro, 2017; Martinez Steele et al., 2016; Moubarac et al., 2017; Moubarac et al., 2012; Rauber et al., 2018; Julia et al., 2018; Louzada et al., 2018; Cediel et al., 2018; Latasa et al., 2017; Louzada et al., 2015a, 2015b; Monteiro et al., 2010). In turn, saturated fatty acids, free sugars and sodium have been associated with increased risk of MetS (Martínez-González and Martín-Calvo, 2013) while monounsaturated fatty acids, polyunsaturated fatty acids and dietary fiber have been associated with reduced risk of MetS (Pérez-Martínez et al., 2017; Calton et al., 2014; Djousse et al., 2010).

Beyond nutrient composition, other food characteristics may be important in the association of UPF and MetS. Food processing is largely associated with loss of physical and structural characteristics of the food matrix and has been linked with lower satiety potential and higher glycemic response, with potential important implications for individuals with diabetes (Fardet, 2016). It has also been postulated that UPF may promote inflammation-related diseases through diet–microbiome–host interactions. The presence of emulsifiers, additives and large amounts of readily accessible acellular nutrients in UPF may create an environment in the gut that favors the selection of microbes that boost inflammation-related disease (Zinöcker and Lindseth, 2018). This may in turn promote the clinical progression of MetS in obese people (Boulange et al., 2016).

At the food level, dietary patterns based on UPF may also be important. Dietary patterns based on UPF have been inversely associated with consumption of selected minimally processed foods including legumes, vegetables, fruits, fish and nuts (Martínez Steele et al., 2017; Moubarac et al., 2012; Rauber et al., 2018; Louzada et al., 2015a) whose intake has been associated with the prevention of MetS (Pérez-Martínez et al., 2017; Calton et al., 2014; Rodríguez-Monforte et al., 2017; Djousse et al., 2010).

We observed that the strength of the association between UPF consumption and prevalence of MetS decreased with age. A plausible explanation for these findings could be that as age increases, the rise in prevalence of other risk factors such as sedentary lifestyle, obesity, or other age-related disorders (associated or not with UPF consumption) compete with diet as triggers for disease, leading to a drop in the strength of association among the elderly. An alternative explanation, under the assumption that MetS is not fully reversible, could be that the chances that individuals change their diet in response to disease diagnosis increase with age (partly because of longer exposure to disease), thereby resulting in increased reverse causality.

UPF consumption may also increase the risk of MetS by influencing any or all of its defining conditions or by promoting overweight/obesity. Confirming our results, previous studies have reported an association between UPF consumption and hypertension (Mendonça et al., 2017), elevated waist circumference (Juul et al., 2018) and overweight/obesity (Julia et al., 2018; Juul et al., 2018; Mendonça et al., 2016; Louzada et al., 2015; Canella et al., 2014). One study found that UPF consumption at preschool age was a significant predictor of increased total and LDL cholesterol concentrations during childhood (Rauber et al., 2015), but not of reduced HDL as in our study.

Our study has several strengths. We studied a large, nationally representative sample of the US population, increasing external validity of results. Also, the ability to disaggregate recipes into underlying ingredients enabled the calculation of more precise estimates of dietary contribution of UPF.

Potential limitations should be considered. As with most population measures, dietary data obtained by 24-hour recalls is imperfect (Subar et al., 2015). However, 24-hour recalls are the least-biased self-report instrument available (Prentice et al., 2011). Also, the standardized methods of NHANES have been shown to produce accurate intake estimates (Moshfegh et al., 2008; Blanton et al., 2006; Rumpler et al., 2008) and are therefore suitable for assessing population averages. Although NHANES collects limited information indicative of food processing level (i.e. place of meals, product brands), these data are not consistently determined for all food items and may also not provide updated, market representative nutrient information (Slining et al., 2015). The potential misclassification, which could lead to modest over or underestimation of the dietary contribution of UPF, is more likely to be non-differential and would therefore bias the association between UPF and MetS towards the null. Previous studies suggest that people with obesity may underreport consumption of foods with caloric sweeteners (Bingham et al., 2007) such as desserts and sweet baked goods (Lafay et al., 2000; Pryer et al., 1997). This social desirability bias may lead to underestimation of the dietary contribution of UPF or dilution of the association between UPF consumption and MetS. The fact that NHANES does not collect information on self-reported use of lipid medication may lead to overestimation of MetS (Beltrán-Sánchez et al., 2013). However, using a MetS definition that does not consider treatment for triglycerides or HDL cholesterol did not alter the studied association. Because common lifestyle risk factors tend to cluster (Schuit et al., 2002), higher levels of UPF consumption could be a proxy of an overall unhealthy diet or lifestyle, and subsequent residual confounding could overestimate the strength of the studied association.

The cross-sectional nature of our findings cannot infer causality. This is especially true if we consider that MetS is a condition that likely develops over years and may not be fully reversible. In this sense, reverse causality could lead to underestimation of the studied association should people change their diet and consume less UPF after diagnosis. Yet, the association remained largely unchanged after excluding individuals following any sort of diet.

In conclusion, this cross-sectional study found an association between dietary share of UPF and metabolic syndrome in a nationally representative sample of the US adult population, thereby confirming previous findings from small studies in Brazil and Canada. Furthermore, it adds to the growing evidence of cross-sectional and longitudinal associations between UPF consumption and several diet-related noncommunicable diseases.

Acknowledgments

Not applicable.

Author contributions

EMS and CAM conceived and designed the study including statistical analysis; EMS performed the statistical analyses; EMS and CAM analyzed and interpreted the data; EMS took the lead in writing the manuscript; FJ, FR, DN and CAM revised the manuscript for important intellectual content. All authors approved the final manuscript and take full responsibility for the final content.

Funding

This work was supported by the CNPq [Processo CNPq n° 150888/2017-1] and the Sao Paulo Research Foundation (FAPESP) [Processo 2018/17972-9; 2016/25853-4; 2016/14302-7; 2015/14900-9].

Declaration of competing interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.05.004.

References

Adamsson, V., Reumark, A., Cederholm, T., Vessby, B., Risérus, U., Johansson, G., 2012. What is a healthy Nordic diet? Foods and nutrients in the NORDIET study. Food Nutr. Res. 278, 542–544.

Agodi, A., Maugeri, A., Kunzova, S., Sochor, O., Bauerova, H., Kiacova, N., Barchitta, M., Vinciguerra, M., 2018. Association of dietary patterns with metabolic syndrome: results from the Kardiovize Brno 2030 study. Nutrients 10 (7). https://doi.org/10.3390/nu10070898. pii: E898. Jul 13.

Automated Multiple-Pass Method. United States Department of Agriculture. Agriculture Research Servicehttp://www.ars.usda.gov/ba/bhnrc/fsrg, Accessed date: August 2015.

Aguilar, M., Bhuket, T., Torres, S., Liu, B., Wong, R.J., 2015. Prevalence of the metabolic syndrome in the United States, 2003-2012. JAMA 313 (19), 1973–1974. https://doi.org/10.1001/jama.2015.4260. May 19.

Alberti, K.G., Eckel, R.H., Grundy, S.M., et al., 2009. Harmonizing the metabolic syndrome: a joint interim statement of the international diabetes federation task force on epidemiology and prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation 120, 1640–1645.

Azadbakht, L., Mirmiran, P., Esmaillzadeh, A., Azizi, T., Azizi, F., 2005. Beneficial effects of a dietary approaches to stop hypertension eating plan on features of the metabolic syndrome. Diabetes Care 28, 2823–2831.

Babio, N., Toledo, E., Estruch, R., Ros, E., Martínez-González, M.A., Castañer, O., et al., 2014. Mediterranean diets and metabolic syndrome status in the PREDIMED randomized trial. CMAJ 186, E649–E657.

Barros, A.J., Hirakata, V.N., 2003. Alternatives for logistic regression in cross-sectional studies: an empirical comparison of models that directly estimate the prevalence ratio. BMC Med. Res. Methodol. 3, 21.

Beltrán-Sánchez, H., Harhay, M.O., Harhay, M.M., McElligott, S., 2013. Prevalence and trends of metabolic syndrome in the adult US population, 1999–2010. J. Am. Coll. Cardiol. 62 (8), 697–703. https://doi.org/10.1016/j.jacc.2013.05.064. August 20.

Bingham, S., Luben, R., Welch, A., et al., 2007. Epidemiologic assessment of sugars consumption using biomarkers: comparisons of obese and non-obese individuals in the European Prospective Investigation of Cancer Norfolk. Cancer Epidemiol. Biomark. Prev. 16 (8), 1651–1654.

Blanton, C.A., Moshfegh, A.J., Baer, D.J., Kretsch, M.J., 2006. The USDA automated multiple-pass method accurately estimates group total energy and nutrient intake. J. Nutr. 136 (10), 2594–2599 Oct.

Boulange, C.L., Neves, A.L., Chilloux, J., et al., 2016. Impact of the gut microbiota on inflammation, obesity, and metabolic disease. Genome Med. 8, 42.

Bowman, S.A., Clemens, J.C., Thoerig, R.C., et al., 2013. Food patterns equivalents database 2009–10; 2011-2012; 2013-2014: methodology and user guide [online]. Food surveys research group, beltsville human nutrition research center, agricultural research service. Department of Agriculture, US Beltsville, Marylandhttp://www.ars.usda.gov/ba/bhnrc/fsrg, Accessed date: June 2013.

Calton, E.K., James, A.P., Pannu, P.K., Soares, M.J., 2014. Certain dietary patterns are beneficial for the metabolic syndrome: reviewing the evidence. Nutr. Res. 34, 559–568.

Canella, D.S., Levy, R.B., Martins, A.P., Claro, R.M., Moubarac, J.C., Baraldi, L.G., Cannon, G., Monteiro, C.A., 2014 Mar 25. Ultra-processed food products and obesity in Brazilian households (2008-2009). PLoS One 9 (3), e92752. https://doi.org/10.1371/journal.pone.0092752. (eCollection 2014).

Cediel, G., Reyes, M., da Costa Louzada, M.L., Martinez Steele, E., Monteiro, C.A., Corvalán, C., Uauy, R., 2018. Ultra-processed foods and added sugars in the Chilean diet (2010). Public Health Nutr. 21 (1), 125–133. https://doi.org/10.1017/S1368980017001161. Jan. (Epub 2017 Jun 19).

Centers for Disease Control and Prevention. National Center for Health Statistics. National Health and Nutrition Examination Survey. Anthropometry Procedures Manuals: 2009–2010; 2011–2012; 2013–2014.

Centers for Disease Control and Prevention. National Center for Health Statistics. National Health and Nutrition Examination Survey. Laboratory Procedures Manuals: 2009–2010; 2011–2012; 2013–2014.

Centers for Disease Control and Prevention. National Center for Health Statistics. National Health and Nutrition Examination Survey. Physician Examination Procedures Manual: 2009–2010; 2011–2012; 2013–2014.

Djousse, L., Padilla, H., Nelson, T.L., Gaziano, J.M., Mukamal, K.J., 2010. Diet and metabolic syndrome. Endocr Metab Immune Disord Drug Targets 10, 124–137.

Esmaillzadeh, A., Kimiagar, M., Mehrabi, Y., Azadbakht, L., Hu, F.B., Willett, W.C., 2007. Dietary patterns, insulin resistance, and prevalence of the metabolic syndrome in women. Am. J. Clin. Nutr. 85, 910–918.

Fardet, A., 2016. Minimally processed foods are more satiating and less hyperglycemic than ultra-processed foods: a preliminary study with 98 ready-to-eat foods. Food Funct. 7, 2338–2346.

Gouveri E, and Diamantopoulos EJ. The Mediterranean diet and metabolic syndrome (chapter 29) in The Mediterranean Diet. An Evidence-Based Approach. Elsevier 2015. Edited by: Victor R. Preedy and Ronald Ross Watson.

Heidemann, C., Scheidt-Nave, C., Richter, A., Mensink, G.B., 2011. Dietary patterns are associated with cardiometabolic risk factors in a representative study population of German adults. Br. J. Nutr. 106, 1253–1262.

Executive summary of the third report of the National Cholesterol Education Program (NCEP) expert panel on detection, evaluation and treatment of high blood cholesterol in adults (adult treatment panel III). JAMA 285, 2486–2497 (PubMed: 11368702).

Johnson CL, Paulose-Ram R, Ogden CL, et al. National Health and Nutrition Examination Survey: Analytic Guidelines, 1999–2010, 2011–2012. National Center for Health Statistics.

Julia, C., Martinez, L., Allès, B., Touvier, M., Hercberg, S., Méjean, C., Kesse-Guyot, E., 2018 Jan. Contribution of ultra-processed foods in the diet of adults from the French NutriNet-Santé study. Public Health Nutr. 21 (1), 27–37. https://doi.org/10.1017/S1368980017001367. (Epub 2017 Jul 13).

Juul, F., Martinez-Steele, E., Parekh, N., Monteiro, C.A., Chang, V.W., 2018. Ultra-processed food consumption and excess weight among US adults. Br. J. Nutr. 120 (1), 90–100. https://doi.org/10.1017/S0007114518001046. Jul. (Epub 2018 May 6).

Kastorini, C.M., Milionis, H.J., Esposito, K., Giugliano, D., Goudevenos, J., Panagiotakos, D.B., 2011. The effect of Mediterranean diet on metabolic syndrome and its components: a meta-analysis of 50 studies and 534,906 individuals. J. Am. Coll. Cardiol. 57, 1299–1313.

Lafay, L., Mennen, L., Basdevant, A., et al., 2000. Does energy intake underreporting involve all kinds of food or only specific food items? Results from the Fleurbaix Laventie Ville Sante (FLVS) study. Int. J. Obes. Relat. Metab. Disord. 24, 1500–1506.

Latasa, P., Louzada, M.L.D.C., Martinez Steele, E., Monteiro, C.A., 2017. Added sugars and ultra-processed foods in Spanish households (1990-2010). Eur. J. Clin. Nutr. https://doi.org/10.1038/s41430-017-0039-0. Dec 26.

Lavigne-Robichaud, M., Moubarac, J.-C., Lantagne-Lopez, S., Johnson-Down, L., Batal, M., Laouan Sidi, E., Lucas, M., 2018. Diet quality indices in relation to metabolic syndrome in an indigenous Cree (Eeyouch) population in northern Québec, Canada. Public Health Nutr. 21 (1), 172–180. https://doi.org/10.1017/S136898001700115X.

Louzada, M.L., Baraldi, L.G., Steele, E.M., Martins, A.P., Canella, D.S., Moubarac, J.C., Levy, R.B., Cannon, G., Afshin, A., Imamura, F., Mozaffarian, D., Monteiro, C.A., 2015 Dec. Consumption of ultra-processed foods and obesity in Brazilian adolescents and adults. Prev. Med. 81, 9–15. https://doi.org/10.1016/j.ypmed.2015.07.018. (Epub 2015 Jul 29).

Louzada, M.L., Martins, A.P., Canella, D.S., Baraldi, L.G., Bertazzi, R.L., Claro, R.M., Moubarac, J.C., Cannon, G., Monteiro, C.A., 2015a. Ultra-processed foods and the nutritional dietary profile in Brazil. Rev. Saude Publica 49, 38. https://doi.org/10.1590/S0034-8910.2015049006132.

Louzada, M.L., Martins, A.P., Canella, D.S., Baraldi, L.G., Bertazzi, R.L., Claro, R.M., Moubarac, J.C., Cannon, G., Monteiro, C.A., 2015b. Impact of ultra-processed foods on micronutrient content in the Brazilian diet. Rev. Saude Publica 49, 45. https://doi.org/10.1590/S0034-8910.2015049006211.

Louzada, M.L.D.C., Ricardo, C.Z., Steele, E.M., Levy, R.B., Cannon, G., Monteiro, C.A., 2018. The share of ultra-processed foods determines the overall nutritional quality of diets in Brazil. Public Health Nutr. 21 (1), 94–102.

Martínez Steele, E., Monteiro, C.A., 2017. Association between dietary share of ultra-processed foods and urinary concentrations of phytoestrogens in the US. Nutrients 9 (3), 209. https://doi.org/10.3390/nu9030209.

Martinez Steele, E., Baraldi, L.G., Louzada, M.L., Moubarac, J.C., Mozaffarian, D., Monteiro, C.A., 2016. Ultra-processed foods and added sugars in the US diet: evidence from a nationally representative cross-sectional study. BMJ Open 6 (3), e009892. https://doi.org/10.1136/bmjopen-2015-009892. Mar 9.

Martínez Steele, E., Popkin, B.M., Swinburn, B., Monteiro, C.A., 2017 Feb 14. The share of ultra-processed foods and the overall nutritional quality of diets in the US: evidence from a nationally representative cross-sectional study. Popul. Health Metrics 15 (1), 6. https://doi.org/10.1186/s12963-017-0119-3.

Martínez-González, M.Á., Martín-Calvo, N., 2013. The major European dietary patterns and metabolic syndrome. Rev. Endocr. Metab. Disord. 14 (3), 265–271. https://doi.org/10.1007/s11154-013-9264-6. Sep.

Mendonça, R.D., Pimenta, A.M., Gea, A., de la Fuente-Arrillaga, C., Martinez-Gonzalez, M.A., Lopes, A.C., Bes-Rastrollo, M., 2016. Ultraprocessed food consumption and risk of overweight and obesity: the University of Navarra Follow-up (SUN) cohort study. Am. J. Clin. Nutr. 104 (5), 1433–1440 Nov. (Epub 2016 Oct 12).

Mendonça, R.D., Lopes, A.C., Pimenta, A.M., Gea, A., Martinez-Gonzalez, M.A., Bes-Rastrollo, M., 2017. Ultra-processed food consumption and the incidence of hypertension in a Mediterranean cohort: the Seguimiento Universidad de Navarra project. Mendonça RD, Lopes AC, Pimenta AM, Gea a, Martinez-Gonzalez MA, Bes-Rastrollo M. Am. J. Hypertens. 30 (4), 358–366. https://doi.org/10.1093/ajh/hpw137. Apr 1.

Monteiro, C.A., Cannon, G., 2012. The impact of transnational 'big food' companies on the south: a view from Brazil. PLoS Med. 9, e1001252.

Monteiro, C.A., Levy, R.B., Claro, R.M., et al., 2010. Increasing consumption of ultra-processed foods and likely impact on human health: evidence from Brazil. Public Health Nutr. 14 (1), 5–13. https://doi.org/10.1017/S1368980010003241.

Monteiro, C.A., Moubarac, J.C., Cannon, G., Popkin, B.M., 2013. Ultra-processed products are becoming dominant in the global food system. Obes. Rev. 14 (Suppl. 2), 21–28. https://doi.org/10.1111/obr.12107.

Monteiro, C.A., Cannon, G., Levy, R.B., Moubarac, J.C., Louzada, M.L., Rauber, F., Khandpur, N., Cediel, G., Neri, D., Martinez-Steele, E., Baraldi, L.G., Jaime, P.C., 2019 Feb. Ultra-processed foods: what they are and how to identify them. Public Health Nutr. 12, 1–6. https://doi.org/10.1017/S1368980018003762.

Moodie, R., Stuckler, D., Monteiro, C., et al., 2013. Profits and pandemics: prevention of harmful effects of tobacco, alcohol, and ultra-processed food and drink industries. Lancet 381 (9867), 670–679. https://doi.org/10.1016/S0140-6736(12)62089-3. Feb 23.

Moshfegh, A.J., Rhodes, D.G., Baer, D.J., Murayi, T., Clemens, J.C., Rumpler, W.V., Paul, D.R., Sebastian, R.S., Kuczynski, K.C., Ingwersen, L.A., Staples, R.C., Cleveland, L.C., 2008. The USDA automated multiple-pass method reduces bias in the collection of energy intakes. Am. J. Clin. Nutr. 88, 324–332.

Moubarac, J.-C., Martins, A.P.B., Claro, R.M., Levy, R.B., Cannon, G., Monteiro, C.A., 2012. Consumption of ultra-processed foods and likely impact on human health. Evidence from Canada. Public Health Nutr. https://doi.org/10.1017/S1368980012005009.

Moubarac, J.C., Batal, M., Louzada, M.L., Martinez Steele, E., Monteiro, C.A., 2017. Consumption of ultra-processed foods predicts diet quality in Canada. Appetite 108, 512–520. https://doi.org/10.1016/j.appet.2016.11.006. Jan 1. (Epub 2016 Nov 4).

National Cholesterol Education Program (U.S.), 2002. Expert Panel on Detection Evaluation and Treatment of High Blood Cholesterol in Adults. Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III): Final Report. The Program, Washington, D.C.

National Health and Nutrition Examination Survey NHANES Response Rates and Population Totals. Response Rates (2009–2014). https://wwwn.cdc.gov/nchs/nhanes/ResponseRates.aspx> (accessed April 2018).

NHANES, 2009a. MEC in-Person Dietary Interviewers Procedures Manual. January. Available at: http://www.cdc.gov/nchs/data/nhanes/nhanes_09_10/DietaryInterviewers_Inperson.pdf.

NHANES, 2009b. Phone follow-up dietary interviewer procedures manual. September. Available at: http://www.cdc.gov/nchs/data/nhanes/nhanes_09_10/Dietary_PFU_09.pdf.

Pérez-Martínez, P., Mikhailidis, D.P., Athyros, V.G., Bullo, M., Couture, P., Covas, M.I., de Koning, L., 2017. Lifestyle recommendations for the prevention and management of metabolic syndrome: an international panel recommendation. Nutr. Rev. 75 (5), 307–326. https://doi.org/10.1093/nutrit/nux014. May 1.

Prentice, R.L., Mossavar-Rahmani, Y., Huang, Y., Van Horn, L., Beresford, S.A.A., Caan, B., et al., 2011. Evaluation and comparison of food records, recalls, and frequencies for energy and protein assessment by using recovery biomarkers. Am. J. Epidemiol. 174 (5), 591–603 Sep 1.

Pryer, J.A., Vrijheid, M., Nichols, R., et al., 1997. Who are the “low energy reporters” in the dietary and nutritional survey of British adults? Int. J. Epidemiol. 26, 146–154.

Rauber, F., Campagnolo, P.D., Hoffman, D.J., Vitolo, M.R., 2015. Consumption of ultra-processed food products and its effects on children's lipid profiles: a longitudinal study. Nutr. Metab. Cardiovasc. Dis. 25 (1), 116–122. https://doi.org/10.1016/j.numecd.2014.08.001. Jan. (Epub 2014 Aug 20).

Rauber, F., da Costa Louzada, M.L., Steele, E.M., Millett, C., Monteiro, C.A., Levy, R.B., 2018. Ultra-processed food consumption and chronic non-communicable diseases-related dietary nutrient profile in the UK (2008¯2014). Nutrients 10 (5). https://doi.org/10.3390/nu10050587. pii: E587. May 9.

Rodríguez-Monforte, M., Sánchez, E., Barrio, F., Costa, B., Flores-Mateo, G., 2017. Metabolic syndrome and dietary patterns: a systematic review and meta-analysis of observational studies. Eur. J. Nutr. 56, 925–947.

Rumpler, W.V., Kramer, M., Rhodes, D.G., Moshfegh, A.J., Paul, D.R., Kramer, M., 2008. Identifying sources of reporting error using measured food intake. Eur. J. Clin. Nutr. 62, 544–552.

Schuit, A.J., van Loon, A.J., Tijhuis, M., et al., 2002. Clustering of lifestyle risk factors in a general adult population. Prev. Med. 35 (3), 219–224.

Shab-Bidar, S., Golzarand, M., Hajimohammadi, M., Mansouri, S., 2018. A posteriori dietary patterns and metabolic syndrome in adults: a systematic review and meta-analysis of observational studies. Public Health Nutr. 21, 1681–1692.

Slining, M.M., Yoon, E.F., Davis, J., Hollingsworth, B., Miles, D., Ng, S.W., 2015. An approach to monitor food and nutrition from “factory to fork”. J. Acad. Nutr. Diet. 115 (1), 40–49.

Stuckler, D., McKee, M., Ebrahim, S., Basu, S., 2012. Manufacturing epidemics: the role of global producers in increased consumption of unhealthy commodities including processed foods, alcohol, and tobacco. PLoS Med. 9, e1001235.

Subar, A.F., Freedman, L.S., Tooze, J.A., et al., 2015. Addressing current criticism regarding the value of self-report dietary data. J. Nutr. https://doi.org/10.3945/jn.115.219634. First published online October 14.

Tavares, L.F., Fonseca, S.C., Garcia Rosa, M.L., Yokoo, E.M., 2012. Relationship between ultra-processed foods and metabolic syndrome in adolescents from a Brazilian family doctor program. Public Health Nutr. 15 (1), 82–87. https://doi.org/10.1017/S1368980011001571. Jan. (Epub 2011 Jul 14).

U.S. Department of Agriculture, Agricultural Research Service USDA food and nutrient database for dietary studies 5.0, 2011-2012 and 2013-2014. Food surveys research group home page. http://www.ars.usda.gov/ba/bhnrc/fsrg.

U.S. Department of Health and Human Services, 2008. 2008 physical activity guidelines for Americans. U.S. Department of Health and Human Services, Washington (DC) ODPHP Publication No. U0036. Available at: http://www.health.gov/paguidelines, Accessed date: April 2018.

Ultra-Processed Food and Drink Products in Latin America: Trends, Impact on Obesity, Policy Implications. Panamerican Health Organization, Washington D.C.

US Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory, May 2016US Department of Agriculture, Agricultural Research Service. USDA National Nutrient Database for Standard Reference, Release 24; Release 26; Release 28. Version Current. Internet. http://www.ars.usda.gov/ba/bhnrc/ndl.

Zinöcker, M.K., Lindseth, I.A., 2018. The Western diet–microbiome-host interaction and its role in metabolic disease. Nutrients 10, 365. https://doi.org/10.3390/nu10030365.