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Ultraprocessed beverages and processed meats increase the incidence of hypertension in Mexican women

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Abstract

Higher intake of ultraprocessed foods (UPF), which have undergone multiple processes and have poor nutrient quality, is associated with higher incidence of non-communicable diseases. Yet, its association with hypertension has scarcely been studied, especially in low- and middle-income countries (LMIC). We aimed to estimate the associations between consumption of UPF (total, liquid and solid) and UPF subgroups and incident hypertension in a prospective cohort study. We used data from the Mexican Teachers' Cohort including 64 934 disease-free women aged ≥25 years at baseline. We assessed baseline usual dietary intake using a validated FFQ, and each item was categorised according to NOVA, a degree of food processing classification system. UPF and UPF subgroups were categorised according to the distribution of their contribution to total energy intake. Hypertension was self-reported. We estimated incidence rate ratios (IRR) and their 95 % CI. During a median follow-up of 2·2 years, we identified 3752 incident cases of hypertension. Mean contribution of UPF to total energy intake was 29·8 (SD 9·4) % energy (23·4 (SD 8·9) % solid, 6·4 (SD 4·8) % liquid). Comparing extreme categories showed that higher total and solid UPF consumptions were not associated with incident hypertension (IRR 0·96, 95 % CI 0·79, 1·16; IRR 0·91, 95 % CI 0·82, 1·01, respectively). However, liquid UPF and processed meats were associated with increased hypertension (IRR 1·32, 95 % CI 1·10, 1·65; IRR 1·17, 95 % CI 1·01, 1·36, respectively). Addressing intake of liquid UPF and processed meats may help in managing hypertension in LMIC.

Key words: Ultraprocessed foods: Hypertension: Diet: Mexican women

High blood pressure is a major public health problem and remains as one of the leading causes of death and disability worldwide[1]. High blood pressure is also a risk factor for CVD and non-CVD such as cancer[2]. However, there are disparities in low- and middle-income countries (LMIC), where prevalence is higher and control of high blood pressure is worse compared with high-income countries (HIC). From 2000 to 2010, the prevalence of hypertension decreased by 2·6 % in HIC but increased by 7·7 % in LMIC. During the same period, the proportions of hypertension awareness, treatment, and control increased substantially in HIC. In contrast, hypertension awareness and treatment increased less in LMIC, and hypertension control even slightly decreased[3,4]. Therefore, it is urgent to identify intervention strategies that could help prevent and control the disease in LMIC. According to the 2019 Global Burden of Diseases, 255 million disability-adjusted life years are attributable to unhealthy diets, characterised by high intakes of Na, sugar, saturated fat and meats, and low intake of fruits and vegetables, whole grains, nuts and seeds[5]. High Na intake has been associated with elevated blood pressure, while a diet rich in fruits, vegetables, low-fat dairy products, low in Na and saturated fat has been associated with lower blood pressure[6].

Over the past decades, the consumption of ultraprocessed foods (UPF) has substantially increased in LMIC; in Brazil, UPF purchases increased from 18·7 to 26·1 in one decade[7,8]. This increase can be explained by, but is not limited to, urbanisation and the nutrition transition[9]. As income grows, and as the participation of women in the labour market increases, ready-to-eat foods have become convenient and attractive choices. Moreover, national food systems have been shaped by dominant

Abbreviations: HIC, high-income countries; IRR, incidence rate ratio; LMIC, low- and middle-income countries; MTC, Mexican Teachers' Cohort; SSB, sugar-sweetened beverage; UPF, ultraprocessed foods.

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international economic policies, which have been designed to promote the flow of capital and the rapid expansion of trade, without considering the long-term impact on health[8]. UPF are foods which have undergone multiple physical, biological and/or chemical processes and generally contain food additives. Moreover, UPF are characterised by their poor nutrient quality: energy-dense foods, high in Na, saturated and *trans*-fats, added sugars and low in fibre and K[10,11]. The increased consumption of UPF has triggered the recent interest in researchers to investigate the links between UPF and health outcomes. While evidence on the association between UPF and BMI, CVD, diabetes, cancer and mortality[12–22] exists, evidence on the association between UPF consumption on chronic diseases in LMIC is scarce. In order to make informed public health decisions, it is imperative to evaluate the association between UPF consumption and hypertension in LMIC. Thus, our aim was to estimate the association between UPF consumption, in liquid and solid forms, as well as UPF subgroups, and the incidence of hypertension in a large cohort of Mexican women.

Subjects and methods

Study population

The Mexican Teachers' Cohort (MTC) is an ongoing prospective study established between 2006 and 2008 and includes 115 313 female public school teachers from twelve economically diverse states in Mexico. Detailed information about the cohort has been described previously[23]. Briefly, recruitment was initiated in 2006 when 27 979 female public school teachers, aged ≥35 years from two Mexican states, Jalisco and Veracruz, responded to a baseline questionnaire on socio-demographic characteristics, reproductive history, diet, lifestyle and medical conditions. The second phase took place in 2008–2010, to include 87 334 additional women aged ≥25 years from ten additional states. We followed-up women via self-reported questionnaires every 3–4 years to ascertain disease diagnoses and to update their risk factor profiles, with 83 % follow-up through 2012–2013. This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects/patients were approved by the Institutional Review Board at the National Institute of Public Health of Mexico (project number 1130). Written informed consent was obtained from all subjects. For this study, we excluded women with implausible energy intake (<500 or >3500 kcal/d (<2092 or >14 644 kJ/d))[24] and an incomplete FFQ (response to ≤70 items and/or empty staple section) (*n* 27 244). We also excluded women with self-reported hypertension at baseline (*n* 10 273) and women with self-reported cancer or heart disease at baseline (*n* 1816) because these diagnoses may result in changes in diet. We also excluded women who only responded to the baseline questionnaire (*n* 11 047) in 2006–2008. The final analytical sample included 64 934 women.

Dietary assessment

At baseline, we collected detailed dietary information using a 140-item semi-quantitative FFQ. For each food item, participants reported the average frequency of consumption over the previous year in a commonly used unit or portion size. Ten multiple-choice frequencies of consumption were possible: never, once a month or less, two to three times a month, once a week, two to four times a week, five to six times a week, once a day, two to three times a day, four to five times a day and six or more times a day. Such frequencies were converted to a daily intake value. Energy and nutrient intake were calculated by multiplying the energy and nutrient content of the specified pre-defined portion sizes by the frequency of consumption using the US Department of Agriculture food composition database[25] supplemented with a database used in the National Health and Nutrition Survey in Mexico (personal communication). Our FFQ was previously validated, using four 4-d 24-h recalls and two FFQ (at the beginning and end of the study) in 134 Mexico City female residents in a 12-month study. Pearson correlation coefficients for total energy, carbohydrate, protein and total fat intakes between the FFQ and four 4-d 24-h recalls were 0·52, 0·57, 0·32 and 0·63, respectively[26].

Ultraprocessed food classification

Each FFQ item was classified according to the NOVA food classification system[27]. This system considers the extent and purpose of food processing, rather than nutrient contents, and categorises all foods and beverages into four groups: (1) Unprocessed or minimally processed foods are parts of plants or animals with or without minimal processing that has not added any substance, such as sugar, oils or fats. Examples include fruits, vegetables, legumes, grains and meats. (2) Processed culinary ingredients, which are ingredients derived from unprocessed foods and are used to prepare, season and cook like salt, oils and sugar. (3) Processed foods are made from adding culinary ingredients to minimally processed foods. Examples are canned fruits, vegetables and legumes; salted, cured or smoked meats; and cheese. (4) UPF are industrial formulations with multiple ingredients that are usually not used for cooking (like food additives), such as sugar-sweetened beverages (SSB), packed snacks and candies. The second group is usually used when working with purchase data[28]. For food consumption data, it is not usually analysed alone because it is included in culinary preparations based on unprocessed or minimally processed foods[27].

Five trained dietitians (A. M., D. S. C., D. S., E. D., M. M.) who are also specialists in nutritional epidemiology categorised the liquid and solid food items of the MTC FFQ into one of the four NOVA groups. When an item could have been classified in more than one group, we divided the energy contribution from that item between competing NOVA groups. The FFQ was not specific enough for the level of processing of only five items (beans, flavoured water, tortas, orange juice and oats). We determined the proportion of each item allocated to each NOVA group based on the consumption distribution of each item using either published data[29] or personal communication. Since only one item was classified under NOVA group 2, we collapsed groups 1 and 2. A comprehensive classification of the MTC's FFQ items by processing level can be found in online Supplementary Table S1. To estimate the average daily percentage energy contribution from each NOVA group, relative to total energy intake, we summed the energy intake from each FFQ item by NOVA group and divided it by the total energy intake. For this analysis, we focused on UPF consumption. We also estimated the percentage contribution of solid UPF to total energy intake, as well as the percentage contribution of liquid UPF to total energy intake. All beverages were classified as liquids (Yakult (a sweetened probiotic fermented milk drink), soya milk, orange juice, cola, soda, diet soda (when using volume), artificial flavoured waters, distilled liquors (brandy, whiskey, tequila, mescal, rum, aguardiente)), and the rest of the items were classified as solids. We also classified UPF into food subgroups: dairy products (yogurt, ice cream, petite suisse, Yakult), added fats (cream, margarine, cream cheese), sugary products (jello, flan, sweet breads, cakes, cookies, candies, chocolate, honey, jelly and fruit paste candy), SSB (soya milk, orange juice, soda, flavoured water), alcoholic beverages, processed meats (bacon, sausage, ham, chorizo, longaniza (a spicy pork sausage) and other deli meats), cereals (processed oats, low- and high-fibre breakfast cereals, cereal bars, white and whole-grain loaf of bread), salty snacks (chips and saltines) and fast food (burgers, hotdogs, pizza, tortas).

Hypertension assessment

The primary outcome of this study was incident hypertension. At the baseline and follow-up questionnaire, participants responded whether they had ever been medically diagnosed with elevated blood pressure in the previous 2 years, if treatment was received, and the year of diagnosis. We defined an incident case of hypertension when women reported having a medical diagnosis and being under treatment. We evaluated the validity of self-reported hypertension in a random subsample of 101 participants who reported having an elevated blood pressure diagnosis. With a structured phone interview, we confirmed the diagnosis, year of diagnosis and treatment. We confirmed the diagnosis of hypertension in 79 % of participants who had previously reported having a treated diagnosis of elevated blood pressure (positive predictive value 79 %, 95 % CI 65·90 %)[30].

Covariates assessment

We defined covariates using self-reported information from the baseline questionnaires (2006–2008). Ethnicity was defined as whether or not women or her parents spoke an indigenous language/dialect. We also assessed Internet access at home and the type of insurance women used for serious conditions (public, private or other) as indicators for socio-economic position[31]. Smoking status was defined as current, ever, never or unknown status. Physical activity was categorised into tertiles of total metabolic equivalent of task per week of multiple-choice frequencies of activity. The correlation between the MTC questionnaire and the International Physical Activity Questionnaire[32] was 0·64 for moderate and vigorous physical activity (Pearson correlation coefficient 0·64 (95 % CI 0·54, 0·97); intraclass correlation coefficient 0·77 (95 % CI 0·64, 0·86)) (personal communication). We defined menopause using an algorithm that considered last menstruation, hot flushes, hysterectomy, oophorectomy and hormonal treatments; if these data were unknown, then an algorithm using current age was used to determine status. BMI was calculated by dividing self-reported weight in kg by squared height in metres and categorised into normal weight (<25 kg/m^2), overweight (25 to <30 kg/m^2), obese (≥30 kg/m^2) and missing. Energy and nutrient intake were derived from the FFQ as total energy and nutrients per d. We defined multivitamin use during the last year as yes/no. Family history of hypertension was based on self-reported disease in parents, siblings or children; and type 2 diabetes was defined as self-reported diagnosis with treatment.

Statistical analyses

We summarised continuous variables as means and standard deviations or median and interquartile range and categorical variables as percentages. Our main exposure was the proportion (%) of energy from total UPF relative to total energy intake in a day. Secondary exposures included the % of energy from solid UPF, liquid UPF and % energy for UPF food subgroups. Categories were created using the consumption distribution of each exposure, and cut-off values were chosen to allow for meaningful % energy differences for each exposure[33]. For total UPF, the second category is not equidistant because we had to allow for enough sample size in the reference category. For each exposure, women were categorised as follows: % of energy from total UPF (≤20, 21–25, 26–35, 36–45, >45 %), solid UPF (≤15, 16–20, 21–25, 26–30, >30 %) and liquid UPF (≤5, 6–10, 11–15, 16–20, >20 %), using the lowest category as the reference. For food subgroups, we classified women as follows: added fats (≤0·5, 0·6–1·5, 1·6–2·5, >2·5 %), dairy and processed meats (≤0·5, 0·6–1·5, 1·6–2·5, 2·6–3·5, >3·5 %), sugary products, SSB and cereals (≤5, 6–10, 11–15, 16–20, >20 %), fast food (0, >0–5, >5 %), using the lowest category as the reference. For snacks and alcoholic beverages, women were categorised as consumers/non-consumers because of the low consumption (% of energy: 0·90 and 0·17 %, respectively). We calculated each woman's person-time from the date of response of the baseline questionnaire to the date of diagnosis of hypertension, or the date of response to their last questionnaire. We imputed the date of diagnosis to the midpoint between the date of response to the last questionnaire where they self-reported being free of hypertension and the date of response to the questionnaire where they self-reported having hypertension. We used Poisson regression models to estimate age-adjusted and multivariable-adjusted incidence rate ratios (IRR) and 95 % CI adding an offset equal to the natural logarithm of person-time because it is not a closed cohort[34]. Using the goodness-of-fit χ^2 test, we evaluated whether the Poisson model form fit our data with an outcome with a binomial distribution (P value >0·99; if this test is significant, then the model is not a good fit for the data).

We used previous knowledge on biological mechanisms, as well as risk factors for UPF consumption and hypertension to decide which variables to include in the multivariable models to adjust for confounding[35]. We adjusted for age (continuous); proxies for socio-economic status, such as: ethnicity (yes/no), Internet access (yes/no) and insurance for serious conditions (public, private, other); smoking status (current, ever, never, unknown); physical activity (tertiles); menopausal status (pre, post and unknown); total energy intake (continuous); multivitamin supplementation (yes/no) and family history of

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hypertension (yes/no). BMI was not included in the main analysis because the role of BMI in the association between UPF and hypertension is unclear. On the one hand, BMI may be a mediator of the relation between UPF consumption and incidence of hypertension. In other words, BMI can be in the causal pathway between UPF consumption and incident hypertension. However, BMI may also be a confounder by altering UPF consumption. Nevertheless, to compare with other analyses, we additionally adjusted for BMI (normal, overweight, obese, unknown) at baseline. The same rationale was used for baseline type 2 diabetes diagnosis (yes/no). We also calculated the *P* value for trend using a Wald test of a continuous variable based on the median % of UPF consumption for each category. We used missing indicator variables to handle partially missing confounder data for BMI (8·8 %) and smoking status (2·9 %)[36].

We conducted several sensitivity analyses to evaluate the robustness of our findings. First, we used a different definition of hypertension, where hypertension cases were defined as having responded to any one of the three questions on high blood pressure described above. We conducted this analysis under the assumption that some people might have been previously diagnosed but are not treated[37], others might know that they are taking medications but might not know/accept they have a disease or participants might have forgotten to answer the other questions regarding high blood pressure. Second, considering that not all UPF contribute to total energy (e.g. diet soda), we also defined the exposure as the sum of the weights in g from each FFQ item of UPF and divided it by the total weight consumed. We estimated the average daily percentage gram contribution from UPF to total grams consumed. Third, we also ran the models amongst women free of diabetes, to exclude potential confounding. Yet, it is important to acknowledge that this approach may also induce selection bias, since type 2 diabetes may be an intermediate in the causal pathway between UPF consumption and incident hypertension[38]. We conducted all analyses using SAS software version 9.4 (SAS Institute Inc.).

To calculate the power of the Poisson regression in this study, comparing extreme categories, we assumed an α of 0·05, a base rate exp(B0) of 0·030, a mean exposure of 2·2 years and an expected squared multiple correlation (R^2) between the exposure and the other covariates of 0·04. For total UPF, power to detect an exp(B1) of 1·21 (as the University of Navarra Follow-Up cohort study) was 82 % (GPower version 3.1.9.7).

Results

During a median follow-up of 2·2 years (interquartile range 1·8, 4·4) and a total of 142 603 person-years, we identified 3752 incident cases of hypertension. The incidence rate was 26·3 cases of hypertension per 1000 person-years. The mean age at baseline was 41·7 (SD 7·2) years. The mean contribution of UPF to the overall diet was 29·8 (SD 9·4) % energy and 17·3 (SD 9·4) % g, of liquid UPF was 6·4 (SD 4·8) % energy and of solid UPF was 23·4 (SD 8·9) % energy. The median energy contribution of food subgroups to total energy intake was: sugary products (7·8 %), SSB (4·8 %), cereals and breakfast cereals (4·8 %), fast foods (2·2 %), processed meats (1·6 %), dairy products (1·5 %), added fats (0·7 %), salty snacks (0·5 %) and alcoholic beverages (0 %) (Fig. 1). Women who consumed more than 45 % of their total energy from UPF were more likely to be obese, smoke, exercise less, lived in the Northern regions and had higher consumption of Na and fat, compared with women consuming <20 % of their total energy from UPF. In contrast, women who consumed <20 % of their total energy from UPF had the highest contribution of their total energy from unprocessed or minimally processed foods and dietary fibre and the lowest prevalence of type 2 diabetes (Table 1).

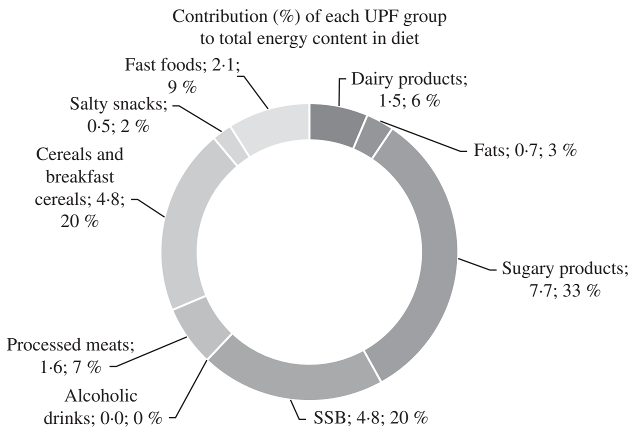

Fig. 1. Median percentage contribution of each ultraprocessed food (UPF) subgroup to total energy among 64 934 women from the Mexican Teachers' Cohort. The first percentage reported is the proportion of energy from total energy intake; the second percentage is the proportion of energy from total UPF consumption. For example, sugar-sweetened beverages (SSB) contribute a median 4·8 % to total energy intake and contribute 20 % to the total energy of UPF.

Incidence rates for extreme categories of UPF consumption were 29·6 (≤20 % energy UPF) and 25·6 (>45 % energy UPF) cases of hypertension per 1000 person-years. When comparing extreme categories, UPF consumption was not associated with incident hypertension in the age-adjusted model (IRR 1·02, 95 % CI 0·87, 1·19, P_{trend} 0·95). Similar results were observed after adjusting for confounders (IRR 0·98, 95 % CI 0·84, 1·14, P_{trend} 0·57). In multivariable models, women who consumed more than 20 % of their total energy from liquid UPF had a 34 % (95 % CI 1·10, 1·65, P_{trend} < 0·001) higher rate of hypertension than women who consumed <5 % from liquid UPF. Solid UPF were not associated with incidence of hypertension when comparing women who consumed more than 30 % of total energy from solid UPF with those who consumed <15 % (IRR 0·91, 95 % CI 0·82, 1·01, P_{trend} 0·03) (Table 2). While we consider BMI and type 2 diabetes as mediators in the association between UPF consumption and incidence of hypertension, we also present these results. After adjusting for BMI, the results were slightly attenuated. While conclusions remained similar for total and liquid UPF, solid UPF were inversely associated with hypertension. After adjustment for type 2 diabetes, results remained similar to the main results (online Supplementary Table S2).

When we estimated the association by UPF subgroups, we found that processed meats and SSB were associated with a higher rate of hypertension. Compared with those in the lowest category (≤0·5 %), women who consumed more than 3·5 % of energy from processed meats had a higher rate of hypertension

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Table 1. Age-standardised characteristics of 64 934 Mexican women from the Mexican Teachers' Cohort at baseline by categories of ultra-processed food (UPF) intake*
(Mean values and standard deviations; percentages)

	UPF intake (% energy), categories									
	≤20 % energy (*n* 9258)		21–25 % energy (*n* 11 296)		26–35 % energy (*n* 26 932)		36–45 % energy (*n* 13 475)		>45 % energy (*n* 3973)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
NOVA categories (% energy/d)										
UPF										
Total	16·1	3·2	22·7	1·4	29·8	2·8	39·0	2·7	50·6	5·2
Liquid	3·8	2·5	5·2	3·1	6·4	3·9	8·0	5·5	10·5	9·2
Solid	12·3	3·4	17·4	3·3	23·4	4·6	31·0	5·9	40·1	9·7
Unprocessed or minimally processed foods	75·1	6·1	68·2	4·8	60·9	5·1	52·0	4·7	41·3	5·9
Processed foods	8·8	5·2	9·1	4·5	9·3	4·2	9·0	3·9	8·0	3·7
Age (years)†	43·6	7·0	42·6	7·1	41·5	7·1	40·4	7·3	40·0	7·3
BMI (kg/m^2)	26·7	4·3	26·8	4·3	27·0	4·4	27·1	4·6	27·4	4·9
BMI, categories										
Normal weight										
%	35·5		34·7		33·4		33·2		31·8	
Overweight										
%	37·5		38·2		38·8		37·9		35·3	
Obese										
%	17·7		18·0		19·2		20·4		24·1	
Unknown										
%	9·5		9·2		8·6		8·5		8·8	
Insurance – serious condition										
Social security										
%	71·5		70·8		70·0		67·9		65·7	
Private										
%	17·9		17·7		18·2		18·7		18·5	
Other										
%	10·6		11·5		11·8		13·3		15·8	
Internet use										
%	40·9		46·7		51·0		55·4		55·0	
Indigenous										
%	15·4		9·2		6·8		5·1		5·1	
Mexican regions†										
North										
%	14·0		15·8		19·7		24·9		30·4	
Central										
%	16·1		17·2		17·4		15·7		14·4	
Mexico City and State of Mexico										
%	22·6		24·5		25·9		25·8		23·6	
South										
%	47·3		42·5		37·1		33·6		31·6	
Family history of hypertension										
%	51·7		54·9		57·9		59·1		59·2	
Type 2 diabetes mellitus										
%	5·5		3·1		2·4		1·5		1·7	
Hypercholesterolaemia										
%	10·2		9·9		9·4		9·1		8·7	
Menopausal status										
Premenopausal										
%	77·1		78·2		78·8		78·9		79·3	

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Table 1. (*Continued*)

	UPF intake (% energy), categories									
	≤20 % energy (*n* 9258)		21–25 % energy (*n* 11 296)		26–35 % energy (*n* 26 932)		36–45 % energy (*n* 13 475)		>45 % energy (*n* 3973)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Postmenopausal										
%	13·6		13·1		12·7		12·8		12·8	
Unknown										
%	9·3		8·7		8·5		8·3		8·0	
Multivitamin use										
%	34·7		35·5		34·0		31·2		27·1	
Smoking, categories										
Current smoker										
%	5·4		7·1		9·1		12·2		13·2	
Past smoker										
%	8·6		9·7		11·4		12·4		12·3	
Never smoker										
%	82·9		80·2		76·7		72·7		71·0	
Unknown										
%	3·1		3·1		2·8		2·8		3·5	
Physical activity (MET/week)										
Tertile 1										
%	30·9		29·4		30·8		34·3		42·4	
Tertile 2										
%	34·9		34·1		34·3		34·2		31·5	
Tertile 3										
%	34·2		36·4		34·9		31·5		26·1	
Total energy										
kcal/d	1771	781	1783	683	1813	676	1855	663	1946	699
kJ/d	7410	3268	7460	2858	7586	2828	7761	2774	8142	2925
Macronutrients (g/d)										
Dietary fibre (g/1000 kcal (4184 kJ))	20·4	5·4	18·1	4·4	16·2	3·9	14·1	3·6	11·9	3·3
Na (mg/1000 kcal (4184 kJ))	830	219	896	211	965	202	1028	209	1053	226
MUFA	17·7	9·9	18·9	8·3	20·2	8·3	21·9	8·9	23·8	10·3
PUFA	8·7	5·8	8·9	4·5	9·3	4·5	9·8	4·5	10·2	4·8
Trans-fatty acids	0·6	0·6	0·8	0·7	1·1	1·0	1·6	1·4	2·6	2·5
SFA	16·3	8·9	17·9	8·6	19·1	8·4	20·4	9·0	21·6	9·9
Protein	71·8	35·4	72·9	27·9	73·6	26·9	73·0	26·4	70·3	26·9
Fat	51·1	26·4	54·3	23·0	57·8	23·0	61·5	24·5	65·4	27·5
Carbohydrate	269·5	130·5	262·4	114·8	259·8	111·1	261·3	104·2	277·6	107·8
UPF subgroups (% energy/d)										
Dairy products	1·4	1·3	1·9	1·7	2·3	2·0	2·5	2·5	2·5	3·5
Added fats	0·7	0·8	0·9	1·0	1·1	1·2	1·2	1·2	1·1	1·4
Sugary products	4·5	2·5	6·4	3·2	9·0	4·5	13·1	6·8	20·0	11·1
SSB	3·6	2·4	4·8	3·1	6·0	3·9	7·5	5·5	10·1	9·2
Alcohol	0·1	0·3	0·1	0·3	0·2	0·4	0·2	0·5	0·2	0·7
Processed meats	1·3	1·0	1·6	1·2	2·0	1·5	2·3	1·7	2·2	1·9
Cereals	3·0	2·2	4·4	2·9	6·0	3·8	7·9	5·3	9·1	7·3
Salty snacks	0·4	0·5	0·6	0·7	0·8	1·0	1·3	1·5	1·9	2·5
Fast foods	1·4	1·2	2·0	1·4	2·6	1·7	3·1	2·2	3·6	3·3

MET, metabolic equivalent of task; SSB, sugar-sweetened beverages.
* Values are means and standard deviations for continuous variables and percentages for categorical variables. Values are age standardised to the age distribution of the study population. Values of categorical variables may not add up to 100 % due to rounding.
† Variable is not age adjusted.

Table 2. Multivariable-adjusted incidence rate ratios of total, liquid and solid ultraprocessed food (UPF) consumption, measured as percentage of total energy intake among 64 934 women from the Mexican Teachers' Cohort
(Incidence rate ratios and 95 % confidence intervals)

		Incidence rate ratio		95 % CI	Incidence rate ratio		95 % CI	Incidence rate ratio		95 % CI	Incidence rate ratio		95 % CI	P_{trend}
Total UPF	≤20 %		21–25 %			26–35 %			36–45 %			>45 %		
Cases	585		675			1517			748			227		
Person years	19 777		24 515			59 355			30 102			8855		
Age adjusted*	Reference	0·97		0·87, 1·08	0·95		0·86, 1·04	0·97		0·87, 1·08	1·02		0·87, 1·19	0·95
Multivariable 1†	Reference	0·96		0·86, 1·07	0·93		0·84, 1·02	0·95		0·85, 1·06	0·99		0·85, 1·15	0·65
Multivariable 2‡	Reference	0·96		0·86, 1·07	0·92		0·84, 1·02	0·95		0·85, 1·06	0·98		0·84, 1·14	0·57
Liquid UPF	≤5 %		6–10 %			11–15 %			16–20 %			>20 %		
Cases	1703		1368			449			133			99		
Person years	67 382		51 410			16 163			4700			2943		
Age adjusted*	Reference	1·07		1·00, 1·15	1·12		1·01, 1·24	1·14		0·96, 1·36	1·35		1·10, 1·65	<0·001
Multivariable 1†	Reference	1·06		0·99, 1·14	1·11		1·00, 1·23	1·13		0·95, 1·35	1·33		1·09, 1·63	<0·001
Multivariable 2‡	Reference	1·06		0·99, 1·14	1·10		0·99, 1·22	1·14		0·96, 1·36	1·34		1·10, 1·65	<0·001
Solid UPF	≤15 %		16–20 %			21–25 %			26–30 %			>30 %		
Cases	703		827			838			648			736		
Person years	23 403		29 391			32 859			26 444			30 506		
Age adjusted*	Reference	0·98		0·89, 1·08	0·91		0·83, 1·01	0·91		0·82, 1·02	0·93		0·83, 1·03	0·07
Multivariable 1†	Reference	0·97		0·87, 1·07	0·90		0·81, 0·99	0·90		0·81, 1·00	0·91		0·82, 1·01	0·04
Multivariable 2‡	Reference	0·97		0·87, 1·07	0·90		0·81, 0·99	0·90		0·81, 1·00	0·91		0·82, 1·01	0·03

* Age adjusted: adjusted for age (years).
† Multivariable 1: adjusted as in previous model plus indigenous (yes/no), Internet access (yes/no), insurance (private, social, other), family history of hypertension (yes/no), menopausal status (premenopausal, postmenopausal, unknown), smoking (never, past, current and missing) and physical activity (tertiles).
‡ Multivariable 2: adjusted as in previous model plus energy intake (continuous) and multivitamin intake (yes/no).

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(IRR 1·17, 95 % CI 1·01, 1·36, P_{trend} 0·15). Women who consumed more than 20 % of energy from SSB had 38 % higher rate of hypertension (95 % CI 1·12, 1·70, $P_{trend} < 0·001$) compared with participants who consumed ≤5 %. Added fats were inversely associated with hypertension (IRR 0·82, 95 % CI 0·73, 0·94, $P_{trend} < 0·001$). However, dairy products, sugary products, cereals, fast food, snacks and alcoholic beverages were not associated with hypertension (Table 3).

Changing the outcome definition to women who responded to any of the three questions on high blood pressure slightly attenuated our results (online Supplementary Table S3). Conducting the analysis among women without diabetes did not change the conclusions and slightly strengthened the association between liquid UPF and the rate of hypertension (data not shown). Changing the exposure to % g/d (online Supplementary Table S4) did not change the conclusions. Mutually adjusting for solid or liquid UPF in the final model slightly attenuated the associations, but the conclusions were the same (results not shown).

Discussion

In this prospective study of Mexican women, the consumption of total and solid UPF was not associated with hypertension. Yet, UPF beverages were associated with an increased incidence of hypertension. The NOVA classification includes a very broad group of foods that may affect diseases differently, potentially masking the associations[39,40]. Thus, we conducted the analysis by UPF food subgroups to help elucidate which food groups were associated with hypertension and found that processed meats and SSB were associated with an increased incidence of hypertension.

To the best of our knowledge, only one previous study has assessed the relationship between UPF consumption and hypertension[16] and found that the highest tertile (5·0 servings/d) of UPF had 20% higher risk of hypertension compared with the lowest tertile (2·1 servings/d). While they did not stratify their analyses by liquid/solid UPF, they had a longer follow-up (9 years) in a younger population. In a similar study, a higher % of UPF in diet was associated with higher incidence of CVD, CHD and cerebrovascular disease[17]. In this study, participants were followed-up for about 5 years, the mean contribution of UPF (in weight) in diet was the same as in our study (17·3%); however, its mean contribution of UPF (as % energy) in diet was higher (35·9 *v.* 29·8%)[41].

Contrary to what we expected, we did not find an association between total UPF consumption and incidence of hypertension. Several reasons may explain our null findings. First, in HIC, the % energy contribution of UPF is higher than in LMIC (from 49 % in Norway to 62 % in the USA, compared with 10 % in small towns in Kenya to 29 % in Chile)[40,42]; a higher % energy contribution could increase the variability in the exposure, as well as the segment of the population which may be at higher risk of disease if the association is not linear. Second, previous studies had longer follow-up than our study; thus, it is likely that the detrimental effects of UPF are observed in the long term. Third, there are differences in the ascertainment of the exposure, either by the use of different dietary assessment methods or by the way UPF were analysed and categorised. Yet, in our analysis, results were similar when analysing % energy contribution *v.* % weight contribution. Finally, the distribution of food subgroups within the UPF category is different across studies. For example, SSB and sugary products contributed more to total UPF in MTC compared with NutriNet-Santé and University of Navarra Follow-Up cohorts, processed meats and fats contributed more in NutriNet-Santé, and finally processed meats, dairy products, cereals and breakfast cereals contributed more in University of Navarra Follow-Up[17,22].

A high consumption of added sugars may explain the association between liquid UPF (SSB, *Yakult* and distilled liquors) and hypertension[43]. The highest energy contributors were artificially flavoured water (31 %), cola (25 %), orange juice (19 %) and non-cola sodas (17 %). These beverages contain added sugars, like sucrose and high-fructose corn syrup, both of which are important sources of fructose. Fructose has been associated with increases in blood pressure[44] through several potential pathways[45]. Sugary products, cereals and breakfast cereals may also contain high-fructose corn syrup and represent about 50 % of total UPF consumption in our study. However, they were not associated with hypertension. Therefore, it is likely that there are other mechanisms by which liquid UPF are associated with hypertension, including lack of compensation for liquid energy and adverse glycaemic effects[46]. A previous meta-analysis also observed that SSB intake is associated with hypertension and CHD[47].

We did not observe an association between solid UPF and hypertension. The suggested inverse association between solid UPF and hypertension might be explained by reverse causation due to baseline diet capturing diet changes caused by recommendations on increased hypertension disease risk due to early markers of disease such as weight change. When we stratified the analysis by UPF subgroups, we observed an association between processed meats and hypertension. Multiple studies have also found that processed meats are associated with hypertension[48,49]. The reasons by which processed meats might be associated with a higher risk of hypertension include: (1) overall unhealthy nutrient profile (e.g. energy dense, high in salt and saturated fat, and low in fibre)[11]; (2) its high salt content causes to overeat[50]; (3) food additives[51] and (4) toxic compounds in packaging (e.g. Bisphenol A)[52]. Contrary to what we expected, higher added fat consumption from UPF products was associated with a lower incidence of hypertension. We must note that the mean contribution of cream, cream cheese and margarine to total energy intake was small (0·8, 0·6 and 0·6 %, respectively). Cream and cream cheese are rich in saturated fat, which has been associated with CVD[53], and margarine (in 2008–2011 when the FFQ was conducted) is rich in *trans*-fat which has also been associated with CVD[54]. However, studies have found that dairy fat is not associated with an increased risk of CVD[55]. Moreover, the amount and distribution of margarine intake might not have given us enough variability in consumption to detect an association.

The strengths of the study include its prospective design and large sample size. This is also the first prospective analysis to estimate the association between UPF consumption and

Table 3. Multivariable-adjusted incidence rate ratios of ultraprocessed food (UPF) consumption by food groups (% of total energy intake) in 64 934 women from the Mexican Teachers' Cohort (Incidence rate ratios and 95 % confidence intervals)

	Incidence rate ratio		95 % CI	Incidence rate ratio		95 % CI	Incidence rate ratio		95 % CI	Incidence rate ratio		95 % CI	Incidence rate ratio		95 % CI	*P*-trend
Added fats		≤0·5 %			0·5–1·5 %			1·5–2·5 %			>2·5 %					
Median	0·28		0·16, 0·39	0·83		0·65, 1·10	1·88		1·68, 2·14	3·23		2·81, 4·06				<0·001
Cases		1472			1429			483			288					
Person time		50 190			56 977			19 830			12 099					
Model*		Reference		0·88		0·82, 0·95	0·84		0·76, 0·93	0·82		0·73, 0·94				
Dairy products		≤0·5 %			0·5–1·5 %			1·5–2·5 %			2·5–3·5 %			>3·5 %		
Median	0·31		0·16, 0·41	0·93		0·71, 1·18	1·94		1·71, 2·21	2·95		2·72, 3·21	4·82		4·04, 6·18	0·83
Cases		558			1402			596			435			695		
Person time		19 048			51 828			25 324			17 067			26 754		
Model*		Reference		0·99		0·90, 1·10	0·88		0·78, 0·98	0·97		0·86, 1·10	0·99		0·88, 1·11	
Processed meat		≤0·5 %			0·5–1·5 %			1·5–2·5 %			2·5–3·5 %			>3·5 %		
Median	0·33		0·18, 0·42	1·03		0·80, 1·26	1·90		1·69, 2·16	2·88		2·68, 3·16	4·5		3·92, 5·60	0·15
Cases		303			1529			1078			413			413		
Person time		10 984			56 522			41 095			17 408			15 932		
Model*		Reference		1·09		0·96, 1·23	1·14		1·00, 1·29	1·04		0·90, 1·21	1·17		1·01, 1·36	
Sugary products		≤5 %			5–10 %			10–15 %			15–20 %			>20 %		
Median	3·46		2·52, 4·23	7·21		6·04, 8·50	12·06		10·97, 13·37	16·98		15·92, 18·33	24·43		21·82, 28·74	0·03
Cases		1084			1364			711			335			252		
Person time		38 288			52 672			28 839			12 534			10 004		
Model*		Reference		0·95		0·87, 1·02	0·88		0·80, 0·97	0·94		0·84, 1·07	0·88		0·76, 1·01	
SSB		≤5 %			5–10 %			10–15 %			15–20 %			>20 %		
Median	2·90		1·81, 3·90	6·89		5·85, 8·16	11·75		10·76, 13·03	16·83		15·81, 18·12	23·88		21·59, 27·76	<0·001
Cases		1910			1234			397			119			92		
Person time		75 377			46 130			14 189			4195			2683		
Model*		Reference		1·07		0·99, 1·15	1·11		0·99, 1·23	1·14		0·95, 1·37	1·38		1·12, 1·70	
Cereals		≤5 %			5–10 %			10–15 %			15–20 %			>20 %		
Median	2·61		1·60, 3·74	6·94		5·90, 8·23	11·77		10·81, 13·04	16·81		15·80, 18·10	23·06		21·30, 26·14	0·75
Cases		1967			1223			394			121			45		
Person time		72 194			48 069			15 868			4459			1862		
Model*		Reference		0·97		0·90, 1·04	0·97		0·87, 1·08	1·07		0·89, 1·29	0·94		0·70, 1·26	
Fast food		0 %			0–5 %			>5 %								
Median		0		2·10		1·30, 2·98	6·16		5·49, 7·41							0·30
Cases		192			3232			283								
Person time		6669			121 581			12 793								
Model*		Reference		1·02		0·88, 1·18	0·95		0·79, 1·14							
Snacks		Non-consumers			Consumers											
Median		0		0·56		0·33, 1·05										
Cases		156			3547											
Person time		5421			135 214											
Model*		Reference		1·00		0·85, 1·18										
Alcohol		Non-consumers			Consumers											
Median		0		0·21		0·13, 0·51										
Cases		2096			1473											
Person time		79 092			56 934											
Model*		Reference		0·95		0·89, 1·02										

SSB, sugar-sweetened beverages.

* Model: adjusted for age (years), indigenous (yes/no), Internet access (yes/no), insurance (private, social, other), family history of hypertension (yes/no), menopausal status (premenopausal, postmenopausal, unknown), smoking (never, past, current and missing), physical activity (tertiles), energy intake (kJ/d) and multivitamin intake (yes/no).

hypertension in an LMIC. Additionally, we collected information on multiple risk factors for hypertension to adjust for confounding. However, our study is not without limitations. Our FFQ was not designed to assess UPF items, thus leading to potential misclassification of UPF (non-differential to hypertension status) and may have decreased the variability of the exposure[40]. However, there may be some UPF that were well captured by our FFQ, as well as UPF that are better recalled than others. For example, processed meat consumption may not change in shorter periods of time or it may be better recalled. Another limitation is that hypertension diagnosis was self-reported, but it has been used in other cohort studies and has been shown to be a valid indicator in Hispanics[56,57]. Self-reported hypertension had a moderately high positive predictive value (79 %), so while measurement error is possible, this error is likely non-differential since the exposure was assessed before the outcome. The short follow-up time might also have diminished our ability to detect an association. It is also possible that UPF intake has a long-term effect which was not captured in 2·2 years of follow-up. Loss to follow-up was about 15 %, which may result in selection bias. Yet, when comparing baseline characteristics of the women included in our analysis *v.* lost to follow-up, we did not observe important differences (online Supplementary Table S5). We also included a table comparing the characteristics of women who had a valid FFQ *v.* an invalid FFQ (about 27 000). Participants with a valid FFQ were more likely to have family history of hypertension and also had higher multivitamin intake; otherwise, they did not appear healthier (online Supplementary Table S6). Due to the observational nature of our data, residual confounding cannot be ruled out. All participants were teachers, while it may increase internal validity, it may decrease generalisability to other populations if potential effect modifiers of this association differ by population or age distribution. Yet, we do not believe there are biological differences among female teachers and other women that would make us believe that the effect of UPF consumption on hypertension is different.

The NOVA classification helps communicate to the general population the potential harmful effects of foods with common characteristics (e.g. nutritional profile, additives and packaging that allows for carefree eating). However, for hypertension, highlighting some UPF subgroups could be important. In conclusion, in a cohort of Mexican women, liquid UPF and processed meats were associated with incident hypertension. Our study provides growing evidence on the impact of UPF on cardiovascular health on an unstudied population, especially ultraprocessed beverages and processed meats. Thus, future programmes and policies should consider limiting access to UPF through policies that affect demand, food services, retailers, marketing and clear front-of-pack labelling[7].

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Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114520004432

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