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Ultra-processed foods and the development of obesity in adults

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Abstract

Ultra-processed foods (UPF) are ubiquitous in the modern-day food supply and widely consumed. High consumption of these foods has been suggested to contribute to the development of obesity in adults. The purpose of this review is to present and evaluate current literature on the relationship between UPF consumption and adult obesity. Cross-sectional studies ($n = 9$) among different populations worldwide show a positive association between UPF consumption and obesity. Longitudinal studies ($n = 7$) further demonstrate a positive association between UPF consumption and development of obesity, suggesting a potential causal influence of UPF consumption on obesity risk. However, only one randomized controlled trial has tested the causality of this association. The study included in this review found greater energy intake and weight gain with consumption of a high UPF diet compared to a high unprocessed food diet. The potential mechanisms by which UPF increase the risk of obesity include increased energy intake due to increased sugar consumption, decreased fiber consumption, and decreased protein density; however, more research is needed. Overall, the evidence identified in the current review consistently support a positive relation between high UPF consumption and obesity. While there is a need for more experimental research to establish causality and elucidate the mechanisms, the sum of the evidence supports a need for research on treatment modalities that include reductions in UPF consumption for the management of adult obesity.

INTRODUCTION

Purchase of ultra-processed foods (UPF) has increased from 2006 to 2019 in most countries around the world where data are available [1]. Higher sales of UPF and ultra-processed drinks have been linked to higher body mass index (BMI) [2]. In an analysis of 80 countries, researchers found a statistically significant increase in mean population BMI in men and

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women as sales of UPF and ultra-processed drinks increased per capita [2]. Similarly, in a study spanning 19 European countries, the national prevalence of obesity was positively related to national household availability of UPF [3].

The NOVA food classification system has been used to classify foods according to their level of processing [4]. This system was developed by researchers in Brazil where national dietary guidelines include recommendations based on the level of food processing. Guidelines from other countries, such as Uruguay, Ecuador, and Peru, as well as Canada, also include recommendations based on the level of food processing [5].

The NOVA food classification system groups foods according to four levels of processing: unprocessed or minimally processed foods (UMPF) such as milk and plain yogurt; processed culinary ingredients (PCI) such as butter; fresh processed foods (FPF) such as “freshly made” cheese; and UPF such as ice cream, milk drinks, and fruit yogurts [4]. UPF have 5 or more ingredients, including chemically synthesized ingredients that would not be found in UMPF and PCI, such as hydrogenated oils, modified starches, colorants, artificial sweeteners, and anti-caking agents [6]. UPF tend to be cheap (because they are made mostly of high yielding crops such as maize, soy, and wheat) [7], well-marketed, shelf-stable foods with multiple ingredients that should be reduced to prevent obesity according to the WHO, e.g. fat, sugar, and salt [8].

Several reviews have been published on the relationship between UPF and obesity/ non-communicable diseases [9-18]. All reported a positive association between UPF consumption and obesity. However, one review was focused on Latin America only [16], and another did not report a systematic search strategy [11]. Among the remaining eight reviews, four reviews did not include the newly published literature: one included literature up to August 2017 [18], another included literature up to July 2018 [15], and two included literature up through November 2019 [9, 10]. Among the remaining four reviews that included literature published in 2020 and 2021, three did not include clinical trials [12, 14, 17], and one included outcomes other than obesity [13]. In fact, only two of the ten reviews focused on obesity as an outcome [9, 18]. Also, many reviews included UPF defined by systems other than NOVA [9, 10, 12, 15, 18]. Here, we use a single definition of UPF and focus exclusively on obesity/excess adiposity to facilitate comparisons and discussion of the findings. In addition, we include a discussion of the status of the evidence using the Bradford-Hill criteria, which has not been done previously.

METHODS

A PubMed search was conducted in November 2021 using combinations of the following keywords: ultra-processed, ultra processed, ultraprocessed, obesity, weight gain, weight, body weight, cross-sectional, cross sectional, cohort. This search returned 126 results. Filters were used to identify randomized controlled trials (Clinical Trial, Randomized Controlled Trial) along with the following keywords: ultra-processed, ultra processed, ultraprocessed, obesity, weight gain, weight, and body weight. This search returned 27 results. Systematic reviews, meta-analyses, and reference lists were also checked for articles. Articles were restricted to studies performed in healthy adults with obesity or weight as a primary outcome and studies that used the four-level NOVA food classification system. In total, 16 articles were included in this review. Most of these studies were published in 2020 and 2021 (n = 11). We also repeated this search in September 2022 and added one article. We first provide information from observational studies, followed by clinical intervention studies (Tables 1, 2).

Findings from cross-sectional studies on UPF and obesity

Cross-sectional studies (n = 9) have been conducted on various populations around the world with the majority in high-income economies. The sample sizes ranged from 1459 [19] to 19,363 adults [20].

To determine the association of UPF consumption with BMI and waist circumference, Silva et al. (2018) performed a cross-sectional analysis using baseline data from the Brazilian Longitudinal Study of Adult Health (ELSA-Brasil) cohort [21]. The researchers found that those who consumed more than 29% of their total energy as UPF (the highest quartile) had a higher BMI by 0.8 kg/m^2 and a larger waist circumference by 1.7 cm compared to those who consumed less than 16% of their total energy as UPF (the lowest quartile). Additionally, those in the highest quartile had 31% greater odds of overweight, 41% greater odds of obesity, and 41% greater odds of large waist circumference (≥102 cm in men and ≥88 cm in women) when compared to those in the lowest quartile.

Similarly, Juul et al. (2018) conducted a cross-sectional study in American adults to determine the relationship between UPF consumption and BMI and waist circumference [22]. Using NHANES 2005–2014 data, the researchers found that American adults who consumed ≥74.2% of their calories as UPF (the highest quintile) had a higher BMI by 1.6 kg/m^2 and a larger waist circumference by 4.1 cm compared to those who consumed ≤36.5% of their calories as UPF (the lowest quintile). Americans in the highest quintile also had 48% greater odds of overweight/obesity, 53% greater odds of obesity, and 62% greater odds of abdominal obesity compared to adults in the lowest quintile of UPF consumption.

Data from the 2004–2005 Canadian Community Health Survey also showed a relation between UPF consumption and obesity [20]. In that representative sample of Canadian adults, those who consumed an average of 76% of their calories as UPF (the highest quintile) had 32% greater odds of obesity compared to those who consumed ≤20% of their calories as UPF (the lowest quintile). For every 10 percentage point increase in UPF consumption, there was a 5% increase in the odds of obesity. More recent data from the 2015 Canadian Community Health Survey-Nutrition found similar associations [23]. In that survey, those who consumed an average of 73% of their calories as UPF (the highest tertile) had 31% greater odds of obesity compared to those who consumed an average of 24% of their calories as UPF (the lowest tertile). Also, for every 10 percentage point increase in UPF consumption, there was a 6% increase in odds of obesity.

Two of the cross-sectional studies available were conducted in European countries [24, 25].

In the UK, Rauber et al. (2020) studied a representative sample of adults to determine the relationship between UPF consumption and BMI and waist circumference [25]. In the categorical analysis, the researchers used sex-specific quartiles. In the highest quartile, women consumed >73.1% of their total energy intake as UPF, whereas men consumed >76.2% of their total energy intake as UPF. In the lowest quartile, women consumed <35.2% of their total energy intake as UPF, whereas men consumed <36.3% of their total energy intake as UPF. In the combined analyses with both men and women, those in the highest quartile had a significantly greater BMI by 1.66 kg/m^2 and waist circumference by 3.56 cm compared to those in the lowest quartile. These high UPF consumers also had 90% greater odds of obesity compared to adults who were low consumers. In the continuous analysis, a 10 percentage point higher UPF consumption was associated with a higher BMI by 0.38 kg/m^2, a larger waist circumference by 0.87 cm, and 18% higher odds of obesity. Interestingly, there was no significantly higher odds of abdominal obesity in the categorical analysis nor the continuous analysis.

A 2021 study conducted among a representative sample of adult men and women from Switzerland noted sex differences in the associations between UPF consumption and three measures of excess body weight [24]. While there were no associations between UPF consumption and BMI, waist circumference, and composite measures of BMI-waist circumference among men, women who reported consuming 19.3–91.8% of their total food intake by weight as UPF (the highest quintile) had approximately 3 times greater odds of having obesity, abdominal obesity, and obesity + abdominal obesity compared to women who consumed ≤3.7% of their food weight as UPF (the lowest quintile). However, in women, there were no associations between UPF consumption and odds of overweight, abdominal overweight, and overweight + abdominal overweight. Notably, unlike the previous studies, the primary analysis did not measure UPF consumption as the percentage of total energy intake. Instead, the researchers measured percentage of food weight consumed as UPF. This allowed the study to capture consumption of non-caloric UPF, such as those made with artificial sugars. However, similar results were noted in a sensitivity analysis using UPF consumption as percentage of total energy intake.

Sex differences were also noted from the 2016–2018 Korea National Health and Nutrition Examination Survey (KNHANES) [26]. In that cohort, there was no relation between UPF consumption and BMI in men, but women who consumed >33.5% of their energy intake from UPF (the highest quartile) had a higher BMI by 0.6 kg/m^2 and a larger waist circumference by 1.3 cm compared to women for whom UPF provided <9.6% of their energy intake (the lowest quartile). They also had 51% greater odds of obesity (defined as ≥25 kg/m^2) and 64% greater odds of abdominal obesity (defined as ≥90 cm in men and ≤85 cm in women).

In the only study on a country in Oceania, Machado et al. (2020) analyzed a representative sample of Australian adults to examine the association between UPF consumption and obesity [27]. Adults who consumed a mean of 74.2% of their total energy as UPF (the highest quintile) had a higher BMI by 1.0 kg/m^2 and a larger waist circumference by 1.9 cm compared to adults who consumed a mean of 12.7% of their total energy intake as UPF (the lowest quintile). High UPF consumers also had 61% greater odds of obesity and 38% greater odds of abdominal obesity compared to those in the lowest quintile of UPF consumption.

Most recently, a study in Iran found no significant associations between UPF consumption and several indicators of obesity, including BMI, waist circumference, obesity, and abdominal obesity [19]. However, they noted sex differences such that while there was no association among women, men who consumed a mean of 39.2% of their total energy intake as UPF (the highest quartile) had 2.06 times greater odds of overweight compared to men who consumed a mean of 7.4% of their total energy intake as UPF (lowest quartile).

Overall, the findings from the cross-sectional studies on UPF consumption and obesity suggest that those who consume the most UPF are more likely to have obesity compared to those who consume the least UPF. Only one study found no associations [19]. Across the categorical analyses, higher UPF consumption was associated with a higher BMI by 0.6–1.7 kg/m^2 and a larger waist circumference by 1.3–4.1 cm. The greater odds of obesity with higher UPF consumption ranged from 31% to as high as three-fold. Notably, across the studies, there was wide variability in the cut-points of UPF consumption categories. For example, in Brazil, the highest quartile contained those who consumed >29% of their energy as UPF [21] whereas in the US, the highest quartile was at a level of intake over twice as high [22]. Six studies reported a dose-response relationship or significant trend with some measure of excess weight [21, 22, 24-27]. However, the association between UPF consumption and obesity was not consistent with respect to sex, with two studies reporting no association among men when stratified by sex [24, 26] and three studies reporting an association among both men and women [22, 25, 27]. However, one of these studies, by Juul et al. (2018), noted a stronger association of UPF consumption and obesity among women and a significant female sex by UPF consumption interaction for BMI, waist circumference, and odds of overweight, obesity, and abdominal obesity [22]. Conversely, Machado et al. (2020) noted a stronger association between UPF consumption and obesity among men [27]. However, contrary to inconsistencies in the findings by sex, there was more agreement in the findings on abdominal obesity: two studies found no association [19, 25], while four studies found a positive association [22, 24, 26, 27]. Nevertheless, a limitation of all cross-sectional studies is that the exposure and the outcome are measured together, precluding a determination of causality. Also, comparison of the findings is complicated due to large differences in the range of the percentage of the diet made up of UPF between studies. There seems to be cultural differences, and one cut-point in one country may not be appropriate for another country. There is a need for consensus on cut-points or a focus on continuous analyses to facilitate the comparison of findings between studies.

Findings from cohort studies on UPF and obesity

Cohort studies can be used to suggest directionality of an association because the exposure is measured before the outcome. We found seven cohort studies, mostly from countries with high-income economies, assessing the impact of UPF on later weight and obesity. The sample sizes ranged from 652 [28] to 348,748 adults [29]. The mean baseline age of the participants ranged from 37.6 [30] to 67 y [28] and follow-up ranged from 3.8 [31] to 10y [32].

In the ELSA-Brasil cohort, the association between UPF consumption and incident obesity was assessed over a mean follow-up of 3.8 y [31]. Adults who consumed >30.8% of their total energy as UPF (the highest quartile) had a 20% increased risk of incident overweight/obesity compared to adults who consumed <17.8% of their total energy as UPF (the lowest quartile). Those in the highest quartile also had a 27% higher risk of large weight gain (≥ 1.68 kg/y) and a 33% higher risk of large waist circumference gain (≥2.42 cm/y) compared to those in the lowest quartile of UPF consumption. In adults with overweight at baseline, there was no significant increased risk of obesity. In the continuous analysis, for every 15 percentage point increase in UPF consumption, there was a 12% increased risk of large weight gain and a 15% increased risk of large waist circumference gain.

Two cohort studies from Spain also evaluated the longitudinal influence of UPF consumption on weight status [28, 30]. Both studies found an increased risk of incident obesity with increasing UPF consumption. After a median of 8.9 y, middle-aged adults who consumed about 6 servings of UPF per day (the highest quartile) had a 26% increased risk of incident overweight/obesity compared to those who consumed about 1.5 servings of UPF per day (the lowest quartile) [30]. In older-aged adults, sex-specific tertiles were used to describe exposure to UPF [28]. In the highest tertile, women consumed 19.3–57.5% of their total energy as UPF, whereas men consumed 22.5–62.2% of their total energy as UPF. In the lowest tertile, women consumed ≤10.5% of their total energy as UPF, whereas men consumed ≤12.4% of their total energy as UPF. After a median follow-up of 6 y, those in the highest UPF tertile had a 62% increased risk of incident abdominal obesity compared to those in the lowest tertile.

In the UK Biobank cohort of adults aged 40–69 y, women in the highest quartile consumed >71.1% of their total energy intake as UPF, whereas men in the highest quartile consumed >72.2% of their total energy intake as UPF [33]. Women in the lowest quartile consumed <24.7% of their total energy intake as UPF compared to <26.3% for men. The results combining men and women showed that those in the highest quartile had a 79% increased risk of incident obesity and a 30% increased risk of incident abdominal obesity after a median of 5 y compared to those in the lowest quartile. Those in the highest UPF quartile also had a 31% increased risk of ≥5% BMI gain, a 35% increased risk of ≥5% waist circumference gain, and a 14% increased risk of ≥5% body fat percentage gain. For every 10 percentage point increase in UPF consumption, there was a 6% increased risk of incident abdominal obesity, a 6% increased risk of ≥5% waist circumference gain, and a 3% increased risk of ≥5% body fat percentage gain. However, there was no significant association between UPF consumption and incident obesity when data were analyzed on a continuous level.

The NutriNet-Sante cohort, conducted in France, also provided information on the risk of incident overweight and obesity, over median follow-ups of 4.1 and 5 y, respectively, with UPF consumption in adults [34]. Highest quartiles of UPF intake were >21.1 and 21.5% of food weight for women and men, respectively. The lowest quartiles contained women who consumed <9.6% of their food weight as UPF and men who consumed <9.9% of their food weight as UPF. Men and women in the highest quartile of UPF consumption had a 26% increased risk of incident overweight and a 15% increased risk of incident obesity compared to those in the lowest quartile. In the continuous analysis, for every 10% increase in UPF consumption, there was an 11% increased risk of incident overweight and a 9% increased risk of incident obesity.

Similarly, in the China Nutrition and Health Survey (CNHS), after a follow-up of 10 y, those who consumed ≥50 g of UPF per day had a 45% increased risk of incident overweight/obesity and a 50% increased risk of incident central obesity compared to those who consumed no UPF [32].

Analyses of the association between UPF consumption and incident obesity was conducted on a sample from nine European countries in the European Prospective Investigation into Cancer and Nutrition (EPIC) study [29]. After a median follow-up of 5 y, those who consumed an energy-adjusted average of 686 g/day of UPF (the highest quintile) had a 15% increased risk of incident overweight/obesity compared to those who consumed an energy-adjusted average of 176 g/day of UPF (the lowest quintile). Among those with overweight at baseline, there was a 16% increased risk of incident obesity in the highest vs. lowest quintile. The study also found that for every 1 standard deviation increase in UPF consumption, there was a 0.12 kg increase in weight over 5 y.

Like the cross-sectional studies in this review, the cohort studies consistently showed an increased risk of obesity with higher intakes of UPF. In categorical analyses, the increased risk of incident overweight/obesity with UPF consumption ranged from 15 to 79%, and the increased risk of abdominal obesity ranged from 30 to 62%. As with cross-sectional studies, there was variability in the cut-points defining higher and lower UPF consumption. For example, in China, the highest exposure group consisted of those who reported consuming ≥50 g of UPF per day [32] whereas in Europe, this group reported consuming an average of 686 g of UPF per day [29]. Six studies reported a dose-response relationship [28-30, 32-34]. Unlike the cross-sectional studies, there appears to be more consistency in the findings from the cohort studies. Only one study reported sex differences, showing no association between UPF consumption and risk of obesity among men [34]. However, they commented that this may have been due to low power. Conversely, four other cohorts found no sex differences [29-31, 33].

Findings from randomized controlled trials on UPF and weight gain

Randomized controlled trials are important because they can prove causation. We found only one randomized controlled trial testing the impact of UPF on body weight [35]. The trial compared the effects of a high UPF diet vs a high unprocessed food diet on weight change and energy intake among other outcomes. The high UPF diet provided 83.5% of the calories from UPF whereas the unprocessed food diet was completely devoid of UPF. The diets were otherwise matched for available total calories, macronutrients, energy density, and amount of fiber, sugar, and sodium. This randomized controlled trial provided foods for each diet to all 20 participants for 2 weeks each. Participants were inpatients and had ad libitum access to the foods included in their assigned diet. Food intake on the high UPF diet was 508 kcal/d higher compared to the unprocessed food diet. Over 2 weeks on the UPF diet, participants gained 0.9 kg compared to a loss of weight of similar magnitude after 2 weeks of consuming the unprocessed food diet. The researchers also found a statistically significant and strong correlation between weight change and difference in energy intake between the

UPF diet and unprocessed food diet. The authors suggested that a diet high in UPF results in excess energy intake, which can lead to weight gain and potentially, if sustained, obesity. However, some have argued that the effect of the UPF diet may not be sustained beyond 2 weeks because despite higher energy intake on the UPF diet, the gap between diets was decreasing at a rate of 25 kcal/d [36-38]. Another argument is that the carbohydrate-insulin model of obesity may provide a more plausible explanation of the relationship between UPF and weight than the energy balance model. They note that processing tends to increase the glycemic index levels of foods, which may lead to increased insulin secretion and fat storage [38]. These scientific debates highlight a need for trials of a longer duration to test the effect of the UPF diet on long-term energy balance and insulin.

Mechanisms

One potential mechanism by which high consumption of UPF can lead to obesity is through excess sugar consumption from the UPF themselves and displacement of fiber in the diet. Research shows that UPF consumption is positively associated with added sugar consumption and negatively associated with fiber intake [39, 40]. Furthermore, research also shows that, among American adults who consumed the most UPF, 82.1% exceeded their limit for added sugar [41]. The percentage of Americans exceeding the added sugar limit was three-fold greater among these individuals compared to those who consumed the least UPF. According to systematic reviews and meta-analyses of cohort studies and randomized controlled trials, increased sugar intake is associated with weight gain [42], while high dietary fiber intake leads to decreased body weight [43].

Another mechanism that may link increased consumption of UPF to obesity is decreased protein density of the diet. A study on a nationally representative sample of American adults found a significant negative association between percentage of total energy intake as UPF and percentage of total energy intake as protein [44]. This finding appears to support the protein leverage hypothesis of obesity, which proposes that a low protein density diet leads to increased energy intake in order to achieve a constant absolute protein intake [45]. A 2014 meta-analysis of intervention trials provides support for this hypothesis [46].

Notably, the one randomized controlled trial in this review matched the UPF and unprocessed diets for calories, fiber, sugar, and protein [35], which are implicated in the mechanisms discussed above. The researchers commented that this may have attenuated the effect of the UPF diet on energy intake. In addition to matching, the trial found no significant differences in the intakes of fiber, sugar, and protein. There was support for the protein leverage hypothesis because energy intake increased on the UPF diet while absolute protein intake remained the same. However, the authors commented that dietary protein density did not fully explain the observed increased energy intake, and other mechanisms linking UPF to increased energy intake and obesity may be implicated, such as eating rate, energy density and appetitive hormones. The UPF diet contained higher energy density and was consumed at a faster eating rate compared to the unprocessed food diet [35]. Participants had lower peptide YY (PYY) on the UPF diet vs. the unprocessed food diet. Meta-analyses of trials have concluded that higher eating rates and energy densities lead to higher energy intakes [47, 48]. There is also evidence linking PYY to obesity development

[49]. Furthermore, by design, the UPF and unprocessed food diets were not matched on content of added sugar/total sugar, insoluble fiber/total fiber, saturated fat/total fat, and omega-6 fatty acids/omega-3 fatty acids [35]. These ratios may link UPF to increased energy intake and obesity. To help elucidate specific mechanisms, future trials may consider matching diets for these nutrients, or future observational studies may consider controlling for these nutrients.

In addition to their nutrient composition, UPF may have contaminants from food packaging, and they are also characterized by the presence of chemically synthesized ingredients [4]. One of the potential contaminants is bisphenol-A (BPA), which has been dose-dependently linked with obesity in a recent systematic review and meta-analysis [50]. Phthalates is another contaminant that may be obesogenic [51]. Chemically synthesized ingredients that may be obesogenic include hydrogenated fats, high fructose corn syrup, sodium benzoate, and monosodium glutamate (MSG) [51, 52]. Although obesogens are “used in a large amount in highly processed food” [52], they are highly under-researched [51, 52].

DISCUSSION

This review presented the current state of knowledge on the relationship between UPF, as defined by the NOVA food classification system, and obesity. This relationship has been studied in different populations around the world, but mostly in countries with high-income economies. This may be considered appropriate as these countries tend to consume the most UPF. However, sales of UPF are increasing around the world [1]. Future studies may consider examining relations between trends in UPF consumption and prevalence of obesity in countries with lower income levels, especially countries that are in transition and thus, may have more abrupt increases in UPF consumption.

The Bradford-Hill criteria can be used to evaluate whether epidemiological evidence shows causation [53]. Of these criteria, the evidence in this review may be considered to show consistency, temporality, biological gradient, plausibility, coherence, and experiment. Most of the epidemiological evidence presented here consistently showed a positive relationship between UPF and obesity. However, findings on abdominal obesity were less consistent, with one cross-sectional study showing no association [25], and there may be potential differences by sex [19, 24, 26]. The cohort studies showed temporality, with exposure to UPF preceding obesity. Some studies assessed a dose-response relationship [21, 22, 24-30, 32-34], with evidence pointing to a larger effect with increasing intakes of UPF. A causal relationship is plausible since UPF are developed to be highly palatable, and there are mechanisms that link the nutrient composition of UPF to obesity. The one experimental study in this review may be considered to provide support for a causal pathway from UPF consumption to short-term weight gain through energy intake [35]. While there is a need for more experimental research to establish causality and elucidate the mechanisms, the sum of the evidence strongly suggests that research is needed to develop treatment modalities to effectively reduce UPF consumption in order to both prevent and treat adult obesity.

Like the previously published reviews on UPF consumption and obesity or non-communicable diseases [9-18], this review found an overall positive relationship between UPF consumption and obesity. However, there are several limitations in the evidence base.

There are limitations in the assessment of the association of UPF consumption with obesity. One of these limitations is the use of retrospective dietary assessment methods, which are potentially confounded by recall bias. Only one observational study did not use a retrospective dietary assessment method, using food diaries instead [25]. Another limitation is the need for more validation studies on the use of the NOVA food classification system with dietary assessment methods and food composition databases. A 2021 study reported only a moderate agreement between reviewers using the NOVA system with the USDA Food Composition Database [54]. A 2020 review reported disagreement in the classification of particular foods as UPF using the NOVA system [15]. Furthermore, there is a debate around the usefulness of the NOVA food classification system. Some have argued that using the NOVA system provides “little advantage” over using nutrients to classify foods [55]. However, others have argued that ultra-processing not only influences nutrients but also the physical structure and chemical composition of foods [13]. To address these limitations, there is a need for validation studies on the NOVA food classification system and control for nutrient confounders and mediation analysis to understand whether the effects of UPF are driven by their nutrient content only or by contaminants/chemically synthesized ingredients.

Relatedly, confounding is another limitation of the evidence base on UPF consumption and obesity because most of the evidence is from observational studies. Table 3 presents the covariates in the models for the main findings of the studies included in this review. It also presents the covariates in additional analyses. None of the studies reported a substantial change in the main findings after additional analyses. However, there was variability in the covariates used across the studies. Among the cross-sectional studies ($n = 8$), none adjusted for added sugar intake, fiber intake, and protein density, which are associated with both UPF consumption and obesity. Among the cohort studies ($n = 7$), the dietary covariates included a variety of dietary measures, including sugar and fiber intake [28, 34]. Consensus on covariates is needed to help compare the findings and elucidate potential mechanisms. There is also a need for mediation analyses to determine whether the associations between UPF and obesity are explained by nutrients only [56].

Strengths and limitations

This narrative review has several strengths. First, it provides an overview of the findings from the current literature on UPF consumption and adult obesity. Second, it describes the methods used to search for the literature included in the review. Third, to the best of our knowledge, this is the only review that uses the Bradford-Hill criteria to provide a critical evaluation of the literature, much of which is epidemiological. Fourth, to the best of our knowledge, compared to other reviews on UPF and obesity published before 2022 and in English, this is the first review that includes primary articles from 2020 and 2021 while also focusing only on the relationship between UPF, as defined by NOVA, and adult obesity. This focus facilitated comparison of the evidence and identification of limitations and gaps.

However, some limitations are worth noting. First, one database (PubMed) was used to search for articles. Second, the review did not involve grading the quality of the evidence. Third, the review did not weigh the strength of the evidence. Finally, there is a potential for author bias.

Implications

The sum of the evidence strongly suggests that research is needed on treatment modalities to effectively reduce UPF consumption as a means of preventing and treating adult obesity. There is also a need for intervention studies sufficiently powered to detect potential sex differences.

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Table 1.

Summary of Cross-Sectional Studies on UPF and Obesity.

Author	Sample	Exposure	Main Findings
Silva et al. [21]	Brazil, not nationally representative *n* = 8,977 Age: 35–64 y	Quartile 4: >29% Ein[a] vs. Quartile 1: <16% Ein[a]	BMI: +0.8 kg/m^2 WC[b]: +1.7 cm Odds of obesity: +41%
Juul et al. [22]	USA, nationally representative *n* = 15,977 Age: 20–64 y	Quintile 5: ≥74.2% Ein[a] vs. Quintile 1: ≤36.5% Ein[a]	BMI: +1.6 kg/m^2 WC[b]: + 4.1 cm Odds of obesity: +53% Odds of abdominal obesity: +62%
Nardocci et al. [20]	Canada, nationally representative *n* = 19,363 Age: 18- ≥65 y	Quintile 5: 76% Ein[a] vs. Quintile 1: 20% Ein[a]	Odds of obesity: +32%
Nardocci et al. [23]	Canada, nationally representative *n* = 13,608 adults Age: 19- ≥65 y	Tertile 3: 73% Ein[a] vs. Tertile 1: 24% Ein[a]	Odds of obesity: +31%
Rauber et al. [25]	UK, nationally representative *n* = 6,143 Age: 19–96 y	Quartile 4: 76.2% Ein[a] in men, 73.1% Ein[a] in women vs. Quartile 1: 36.3% Ein[a] in men, 35.2% Ein[a] women	BMI: +1.66 kg/m^2 WC[b]: +3.56 cm Odds of obesity: +90% Odds of abdominal obesity: NS[c]
Pestoni et al. [24]	Switzerland, nationally representative *n* = 2,057 Age: 18–75 y	Quintile 5: 19.3%-91.8% of food by wt[d] vs. Quintile 1: 0.0%-3.7% of food by wt[d]	*In men:* Odds of obesity: NS[c] Odds of abdominal obesity: NS[c] *In women:* Odds of obesity: 3.01x Odds of abdominal obesity: 2.69x
Sung et al. [26]	Korea, nationally representative *n* = 7,364 Age: 19–64 y	Quartile 4: >39.1% Ein[a] in men, >33.5% Ein[a] in women vs. Quartile 1: <12.5% Ein[a] in men, <9.6% Ein[a] in women	*In men:* BMI: NS[c] WC[b]: NS[c] Odds of obesity: NS[c] Odds of abdominal obesity: NS[c] *In women:* BMI: +0.61 kg/m^2 WC[b]: +1.34 cm Odds of obesity: +51% Odds of abdominal obesity: +64%
Machado et al. [27]	Australia, nationally representative *n* = 7411 Age: 20– ≥60 y	Quintile 5: 74.2% Ein[a] vs. Quintile 1: 12.7% Ein[a]	BMI: +0.97 kg/m^2 WC[b]: +1.92 cm Odds of obesity: +61% Odds of abdominal obesity: +38%
Haghighatdoost et al. [19]	Iran, not nationally representative *n* = 1459 Age: ≥19 y	Quartile 4: 39.2% Ein[a] in men, 33.2% in women vs. Quartile 1: 7.4% Ein[a] in men, 6.3% in women	*In men:* BMI: NS[c]

Author	Sample	Exposure	Main Findings
			WC[b]: NS[c] Odds of obesity: NS[c] Odds of abdominal obesity: NS[c] *In women:* BMI: NS[c] WC[b]: NS[c] Odds of obesity: NS[c] Odds of abdominal obesity: NS[c]

[a] *Ein* energy intake.

[b] *WC* waist circumference.

[c] *NS* non-significant.

[d] *Wt* weight.

Table 2.

Summary of cohort studies on UPF and obesity.

Author	Sample	Exposure	Main findings
Canhada et al. [31]	Brazil *n* = 11,872 Age: 51.3 y	F/u: 3.8 y Quartile 4: >30.8% Ein[a] vs. Quartile 1: <17.8% Ein[a]	Risk of large wt[b] gain: +27% Risk of large waist gain: +33% Risk of incident overweight/obesity: +20% Risk of incident obesity: NS[c]
Mendoça et al. [30]	Spain *n* = 8,451 Age: 37.6 y	F/u: 8.9 y Quartile 4: 6.1 servings/day vs. Quartile 1: 1.5 servings/day	Risk of incident overweight/obesity: +26%
Sandoval-Insausti et al. [28]	Spain *n* = 652 Age: 67 y	F/u: 6y Tertile 3: 22.5–62.2% Ein[a] in men, 19.31–57.5% Ein[a] in women vs. Tertile 1: 0.14–12.4% Ein[a] in men, 0–10.5% Ein[a] in women	Risk of abdominal obesity: +62%
Rauber et al. [33]	UK *n* = 22,659 Age: 55.9 y	F/u: 5 y Quartile 4: >72.2% Ein[a] in men, >71.1% Ein[a] in women vs. Quartile 1: <26.3% Ein[a] in men, <24.7% Ein[a] in women	Risk of incident obesity: +79% Risk of incident abdominal obesity: +30% Risk of ≥5% BMI gain: +31% Risk of ≥5% WC[d] gain: +35% Risk of ≥5% percentage body fat gain: +14%
Beslay et al. [34]	France *n* = 110,260 Age: 43.1 y	F/u: 4–5 y Quartile 4: >21.2% food by wt[b] in men, >21.1% food by wt[b] in women vs. Quartile 1: <9.8% food by wt[b] in men, <9.6% food by in women	Risk of incident obesity: +15%
Li et al. [32]	China *n* = 12,451 Age: 43.7 y	F/u: 10 y ≥50 g/day vs. 0 g/day	Risk of incident overweight/obesity: +45% Risk of central obesity: +50%
Cordova et al. [29]	European countries *n* = 348,748 Age: ~50 y	F/u: 5 y Quintile 5: 686 g/day vs. Quintile 1: 176 g/day	Risk of incident overweight/obesity: + 15% Risk of incident obesity: +16%

[a] *Ein* energy intake.

[b] *Wt* weight.

[c] *NS* non-significant.

[d] *WC* waist circumference.

Table 3.

Covariates in observational studies.

Author	Country	Covariates for main findings	Covariates in additional analyses	Substantial change in main findings?
Cross-sectional studies				
Silva et al. [21]	Brazil	Age, sex, race, income, smoking, physical activity, hypertension, diabetes.	Energy intake from UMPF and PCI, total energy intake.	No.
Juul et al. [22]	USA	Age, sex, race/ethnicity, income:poverty, education, marital status, smoking, physical activity.	Total energy intake.	No.
Nardocci et al. [20]	Canada	Age, sex, immigrant status, residential area, income, education, smoking, physical activity, under/plausible/over-reporter, measured/self-reported height/weight.	Total energy intake, fruit and vegetable consumption.	No.
Nardocci et al. [23]	Canada	Age, sex, immigrant status, residential area, Indigenous identity, income, education, smoking, physical activity, alcohol consumption, under/plausible/over-reporter, measured/self-reported height/weight.	N/A.	N/A.
Rauber et al. [25]	UK	Age, sex, ethnicity, region, social class occupation, smoking, physical activity, sleep, weight-loss diet, survey year.	Total energy intake, fruit and vegetable consumption.	No.
Pestoni et al. [24]	Switzerland	Age, nationality, language region, education, marital status, smoking, physical activity, weight-loss diet.	Total energy intake.	No.
Sung et al. [26]	Korea	Age, sex, residential area, income, education, marital status, one-person household, smoking, physical activity, alcohol consumption.	Total energy intake.	No.
Machado et al. [27]	Australia	Age, sex, country of birth, zones, income, education, smoking, physical activity.	N/A.	N/A.
Haghighatdoost et al. [19]	Iran	Age, sex, income, education, marital status, family member count, physical activity, total energy intake, fruit and vegetable consumption, legume consumption.	N/A.	N/A.
Cohort studies				
Canhada et al. [31]	Brazil	Age, sex, race, income, education, smoking, physical activity, baseline measures, center.	Total energy intake, fruit and vegetable consumption, ultra-processed drinks.	No.
Mendoça et al. [30]	Spain	Age, sex, education, marital status, smoking, physical activity, television watching, siesta sleep, snacking, special diet, baseline BMI, fruit and vegetable consumption.	Total energy intake, fruit and vegetable consumption (removed), family history of obesity, weight gain before cohort.	No.
Sandoval-Insausti et al. [28]	Spain	Age, sex, education, marital status, smoking, former drinker, physical activity, number of medications, number of chronic diseases.	Total energy intake, fiber intake, omega-3 fatty acid intake, Mediterranean diet adherence score.	No.
Rauber et al. [33]	UK	Sex, poverty, smoking, physical activity, sleep, baseline measures.	N/A.	N/A.
Beslay et al. [34]	France	Age, sex, education, marital status, smoking, physical activity, baseline BMI, alcohol intake, number of 24-hour recalls, total energy intake.	Sodium intake, sugar intake, saturated fatty acid intake, fiber intake, healthy diet, Western diet, fruit and vegetable consumption, sugar-sweetened beverages.	No.

Author	Country	Covariates for main findings	Covariates in additional analyses	Substantial change in main findings?
Li et al. [32]	China	Age, sex, urbanization, income, education, smoking, alcohol drinking, physical activity, fat intake, total energy intake, traditional diet vs. modern diet.	N/A.	N/A.
Cordova et al. [29]	European countries	Age, sex, country, education, smoking, physical activity, alcohol intake, plausible energy intake reporting, baseline BMI, f/u, Mediterranean diet adherence score.	Sugar-sweetened beverages.	No.