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Association of ultra-processed foods and dental health—results from Bandare-Kong cohort: structural equation modeling

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Ultra-processed foods (UPFs) have become a major component of modern diets and have been linked to adverse health outcomes. However, evidence regarding their association with dental health in adults remains limited. This cross-sectional study analyzed baseline data from 3947 adults (35–75 years old, 57.8% females), enrolled in the Bandare-Kong Non-Communicable Disease (BKNCD) cohort. Dietary intake was assessed using a validated food frequency questionnaire, and UPFs consumption was classified according to the NOVA system. Dental health was evaluated through clinical examinations measuring the number of teeth, missing teeth, decayed teeth, and filled teeth. Structural equation modeling (SEM) was employed to assess the relationships, incorporating age and gender as a potential mediating variables. UPFs intake across tertiles was 14.2, 28.9, and 49.2% of total intake. Age and gender partially mediated the associations between UPFs consumption and dental health. Higher UPFs intake (NOVA T3 vs. T1) was linked to more decayed teeth in females 35–50 years ($\beta = 0.521$) and to fewer total teeth ($\beta = -0.976$), more missing teeth ($\beta = 0.987$), and more decayed teeth ($\beta = 0.536$) in females 50–75 years. Among males, higher UPFs intake was associated with more missing teeth in those 35–50 years ($\beta = 0.387$) and with fewer teeth ($\beta = -0.937$), more missing teeth ($\beta = 0.911$), and more decayed teeth ($\beta = 0.754$) in older males. This study highlights significant associations between greater UPFs consumption and poorer dental health among Iranian adults. A longitudinal study is required.

Keywords Ultra-processed foods, Foods, Western diets, Processed, Oral health, Dental health surveys

Abbreviations

UPFs	Ultra-processed foods
BKNCD	Bandare-Kong non-communicable disease
SEM	Structural equation modeling
WSI	Wealth score index
MCA	Multiple correspondence analysis
FFQ	Food frequency questionnaire
CI	Confidence intervals
SDs	Standard deviations
VIF	Inflation factors
TEI	Total energy intake
BMI	Body mass index
GFI	Goodness-of-fit index
AGFI	Adjusted GFI
NFI	Normed fit index
RMSEA	Root mean square error of approximation
TLI	Tucker-Lewis index

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CFI	Comparative fit index
MIs	Modification indices
Il-6	Interleukine-6
CRP	C-reactive protein

Dental caries is one of the most common chronic infectious diseases, particularly in childhood, and represents a major global public health challenge. It affects approximately 2.3 billion adults and over 530 million children worldwide, making it a significant contributor to the global disease burden[1–3]. Although the incidence of dental caries increases with age, its consequences—such as tooth loss, pain, infection, and impaired quality of life—can be lifelong and irreversible. These impacts extend beyond individual health contributing to increased socioeconomic costs. In fact, dental caries accounts for an estimated 5–10% of total healthcare expenditures in industrialized countries[4–7].

Dental caries is a multifactorial disease characterized by the demineralization of tooth structure, primarily resulting from acid production by oral bacteria during the fermentation of dietary carbohydrates[8–12]. Among various risk factors, diets high in simple sugars are well documented as major contributors to caries development, with strong evidence showing a direct correlation between sugar intake and caries risk[9,13–16]. Consequently, reducing sugar consumption not only lowers the incidence of caries but also provides broader health benefits by preventing several chronic diseases[17]. In recent years, global dietary patterns have shifted. Consumption of natural and minimally processed foods such as rice, beans, fruits, and vegetables has declined, while the intake of ultra-processed foods (UPFs)—rich in oils, sugar, salt, and additives—has sharply increased[18–20]. According to the NOVA classification, UPFs are energy-dense products largely composed of unhealthy fats, added sugars, sodium, and artificial ingredients, and are low in essential nutrients and fiber[21–24]. Numerous studies indicate a strong association between UPFs consumption and increased free sugar intake; moreover, reducing daily energy intake from UPFs has been linked to lower sugar consumption and decreased intake of cariogenic foods[25–27]. Despite the well-established link between high sugar intake and dental caries[9,15,28], the specific role of UPFs in caries development remains insufficiently understood. UPFs, which are industrial formulations typically high in added sugars, fats, salts, and additives, have become a dominant component of modern diets. While some studies have identified a significant association between UPFs intake and increased risk of dental caries, others have yielded inconsistent or inconclusive findings[29–31]. These discrepancies underscore the necessity for deeper exploration of the intricate relationship between UPFs consumption and oral health, particularly given their high prevalence in Iran. Such inconsistencies may be attributed to differences in study design, population characteristics, or insufficient adjustment for mediating factors, including oral hygiene behaviors, socioeconomic status, and overall dietary patterns. To advance understanding, future research should employ robust analytical frameworks capable of capturing the multifactorial and interrelated determinants of caries risk, with particular attention to Middle Eastern populations. To address this gap, the present study aims to examine the association between UPFs consumption and dental caries index using structural equation modeling (SEM) in Iranian adults. SEM provides a comprehensive statistical framework to simultaneously evaluate direct and indirect pathways among observed and latent variables. This approach allows for a more nuanced understanding of how UPFs consumption, potentially interacting with behavioral and demographic variables, may influence oral health outcomes. Additionally, given potential age and gender-based differences in dietary behaviors and oral health, we explored whether the associations differ between males and females by incorporating sex as a moderating variable and age in two groups 35-50 and age ≤ 50 year old in the structural model and conducting subgroup analyses.

Materials and methods

Participants

This cross-sectional, population-based study utilized baseline data from the Bandare-Kong Non-Communicable Disease (BKNCD) cohort, which is a subset of the broader, Prospective Epidemiological Research Studies in Iran (PERSIAN) cohort study. The PERSIAN Cohort Study is a large-scale, nationwide, prospective study launched in 2014 to investigate the risk factors and burden of Non-Communicable Diseases (NCDs) across Iran's diverse ethnic and geographic groups. Participant recruitment was conducted in Bandare-Kong, Iran, between October 2016 and November 2018. Comprehensive details of the cohort have been described previously[32]. Ethical approval for this study was obtained from the Ethics Committee of Hormozgan University of Medical Sciences (Ethics code: IR.HUMS.REC.1403.246). All participants provided written informed consent after meeting the inclusion criteria and voluntarily agreeing to participate. The inclusion criteria were as follows: (i) willingness to participate, (ii) age between 35 and 75 years, (iii) residence in Bandare-Kong for at least one full year and a minimum of nine months per year, (iv) ability to provide written informed consent, and (v) Iranian nationality. Individuals were excluded if they were unwilling to participate, temporarily residing in the region, had any mental or physical disabilities, were pregnant or lactating, or reported inaccurate total energy intake. Participants' dental health status was meticulously evaluated using specific criteria for the outcome variables, including the total number of natural teeth (excluding implants), number of decayed teeth (where both decayed and filled teeth were classified as decayed), and number of filled teeth. Crucially, the outcome measure for number of missing teeth was restricted: only those lost due to dental caries were included in the final count, while congenitally missing teeth, those lost due to trauma, orthodontic reasons, or other non-caries-related causes were excluded from the analysis to establish a tighter link with diet-related pathology. The Presence of oral lesions and periodontitis was also recorded.

Of the 4,103 individuals initially enrolled in this cross-sectional analysis, 3,947 participants aged 35–75 years were included in the final sample. Recruitment was conducted using local health center registries and stratified by urban and rural populations. A detailed flowchart of participant inclusion is presented in Fig. 1.

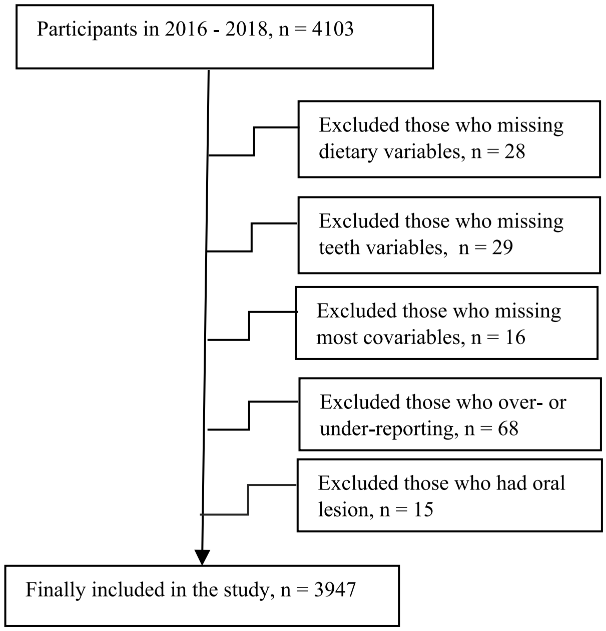

Fig. 1. Flow chart of the study population, Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018.

Data collection

Data were collected through face-to-face interviews conducted by well-trained and experienced interviewers. A standardized questionnaire was used to gather comprehensive information on sociodemographic characteristics, lifestyle factors, dietary habits, physical activity levels, and medical history. To assess socioeconomic status, a Wealth Score Index (WSI) was constructed using Multiple Correspondence Analysis (MCA). The index was based on ownership and access to household items and services, including: freezer, washing machine, dishwasher, personal computer, internet, motorcycle, car (categorized as no car, a car valued under 50 million tomans, or a car valued over 50 million tomans), vacuum cleaner, and type of color television (no TV, standard color TV, or plasma TV). Additional indicators included mobile phone ownership, possession of a personal computer or laptop, and experience of international travel (categorized as none, only for pilgrimage, or for both pilgrimage and non-pilgrimage purposes).

Oral health status

Participants' oral health status was evaluated based on several indicators: frequency of tooth brushing, total number of natural teeth, number of decayed teeth, number of missing teeth, number of filled teeth, presence of oral lesions, and whether participants used dental floss, wore dentures, or used mouthwash. Smoking status was assessed separately for cigarettes and waterpipes, distinguishing between current use and previous exposure.

Anthropometry measurements

Following the questionnaire, at first, height was measured in centimeters, standardized to the nearest 0.5 cm, by means of a Height Rod Wall, FAZZINI S208, Italy, 2015. Weight was measured to the nearest 10 g, in kilograms via transportable Weighing scale, RGZ 160, China.

Assessment of dietary intake and NOVA calculation

Dietary intake was assessed using a validated semi-quantitative Food Frequency Questionnaire (FFQ) specifically adapted for the Iranian population. The 132-item FFQ was administered by trained nutritionists to evaluate participants' usual dietary intake over the previous year. For each food item, participants were asked two questions: (1) the frequency of consumption (per day, week, or month) during the past year, and (2) the portion size typically consumed at each occasion, based on standard serving size and household measures[33]. All dietary data were converted into grams per day using household portion size conversion factors. The dietary data were then categorized into 32 food groups based on prior literature and similarities in nutrient content, as detailed in Supplementary Table 1 (S1). Nutrient and energy intakes were calculated using NUTRITIONIST IV software (version 7.0; N-Squared Computing, Salem, OR, USA). For the purpose of this study, foods were also classified according to the NOVA food classification system. UPFs were identified and grouped into seven major categories based on their representation in the FFQ. Daily intake (in grams) was calculated for each of the following UPFs categories[34]:

1. Non-dairy beverages: including coffee, cola, nectar, and commercially sweetened beverages.
2. Dairy beverages: such as ice cream, pasteurized and unpasteurized milk, chocolate milk, and cocoa milk.

3. Cakes and cookies: including biscuits, cookies, pastries (with and without cream), cakes, pancakes, industrial bread, toasted bread, noodles, and pasta.
4. Fast food and processed meats: including hamburgers, sausages, pizza, and bologna.
5. Salty snacks: such as chips, crisps, crackers, and cheese puffs.
6. Oils and sauces: including mayonnaise, margarine, and ketchup.
7. Sweets and confectioneries: including traditional Iranian sweets such as Gaz, Sohan, Noghl, sesame halva, chocolate, candies, rock candy, jams, and assorted sweets.

Ethical approval and consent to participate

Ethical approval for this study was obtained from the Ethics Committee of Hormozgan University of Medical Sciences (Ethics code: IR.HUMS.REC.1403.246). All participants provided written informed consent before taking part in the study. The study was conducted in accordance with the Declaration of Helsinki on human experimentation.

Statistical analysis

All statistical analyses were performed using SPSS version 26 (IBM Corp., Armonk, NY, USA), while SEM, including both mediation and multi-group analyses, was conducted using AMOS version 24.

The Kolmogorov–Smirnov test was applied to evaluate the normality of continuous variables. Descriptive statistics are reported as means with 95% confidence intervals (CI) or as means ± standard deviations (SDs) for continuous variables, and as frequencies and percentages for categorical variables, both for the total population and stratified by gender. Additionally, independent sample *t*-tests were used to compare the intake of different food groups between females and males. Mean differences across NOVA score tertiles (T) for demographic variables, outcomes, and dietary intake were assessed using ANCOVA in the total population and in age- and gender-specific stratified samples, adjusting for potential confounders. Bonferroni post-hoc tests were used to evaluate pairwise differences between tertiles in the total population.

Based on predefined dietary energy cut-offs, 68 participants were excluded: men reporting less than 800 kcal/day or more than 4000 kcal/day, and women reporting less than 500 kcal/day or more than 3500 kcal/day[35]. Before SEM analysis, multicollinearity among predictors was assessed in SPSS using variance inflation factors (VIF) and tolerance values to ensure that independent variables were not highly correlated. A VIF value above 10 or a tolerance value below 0.1 indicated multicollinearity, which was addressed before entering variables into the SEM model[36].

Structural equation modeling (SEM)

The study hypotheses tested with SEM are illustrated in Fig. S1. In the first step, SEM was used to examine the association between the NOVA score and dental health, as well as the mediating role of gender and age. To examine the association between levels of food processing and dental health, the NOVA score was divided into tertiles. Two dummy variables were generated: Dummy 1 represented the comparison between the second and first tertiles (T2 vs. T1), and Dummy 2 represented the comparison between the third and first tertiles (T3 vs. T1). The model was adjusted for body mass index (BMI), WSI, cigarette use, drug use, alcohol consumption, tooth brushing habits, and total energy intake (TEI).

Model evaluation and fit criteria

Model fit was assessed using the normed χ^2 statistic (χ^2/df), goodness-of-fit index (GFI), adjusted GFI (AGFI), normed fit index (NFI), root mean square error of approximation (RMSEA), tucker-lewis index (TLI), and comparative fit index (CFI). Standardized regression coefficients and correlation effects were reported. Modification indices (MIs) were used to identify and incorporate modifications that improved model fit. The model development process followed an iterative approach involving initial model fitting, modification using MIs, and refitting. These steps were repeated until acceptable model fit criteria were met[37]. $P < 0.05$ was considered to indicate statistical significance according to two-sided tests. Acceptable model fit was defined according to the following criteria: $\chi2/df < 3$, $GFI > 0.90$, $AGFI > 0.80$, $NFI > 0.90$, $CFI > 0.90$, $TLI > 0.90$, $RMSEA \leq 0.05$, and 90% $CI < 0.08$[38,39].

Mediation analysis

To evaluate mediation, the framework illustrated in Fig. S2 was used. In this approach, path *ab* represents the indirect effect, *c* the total effect, and *c′* the direct effect. If all paths (a, b, c, and c′) were significant, the mediator (M) was considered to have a partial mediating effect. If path *c*’ was non-significant in the absence of the mediator but the indirect effect (*ab*) was significant, the mediating variable (*M*) was considered a full mediator. If only the indirect path (*ab*) was significant, the association was interpreted as purely indirect[40].

Sensitivity analysis

In the sensitivity analysis, age- and gender-specific models were employed to assess the relationship between the NOVA score and dental health.

Data exclusion

Participants with implausible energy intakes were excluded from the analysis based on predefined cut-offs. Specifically, men reporting average daily intakes below 800 kcal or above 4000 kcal, and women reporting below 500 kcal or above 3500 kcal were excluded[35]. In total, 68 participants (42 females) were identified as over- or under-reporters and removed from the final dataset.

Results

Participants characteristics

This study used baseline data from the Bandare-Kong Non-Communicable Disease (BKNCD) cohort, part of the prospective PERSIAN study. In this cross-sectional study 3947 adults (57.8% female) with an average age of 48.33 years (95% CI 38.03–48.62) were included. Females had a higher mean BMI of 27.47 kg/m^2 (95% CI 27.27–27.82) compared to males at 25.63 kg/m^2 (95% CI 25.42–25.95), obesity prevalence was 30.2% in females vs. 15.7% in males. Most participants were married (89.5%). Lifestyle factors such as smoking (17.1%) and alcohol consumption (4.7%) were more common among males. Average daily energy intake was significantly higher in men, at 3166.42 kcal/day (95% CI 3125.36–3207.04), compared to women, at 2521.41 kcal/day (95% CI 2491.63–2551.18), with carbohydrates comprising about 64% of TEI in both gender, Table 1.

Table S2 presents anthropometric and oral health measures across tertiles of the NOVA score. Age significantly decreased across increasing NOVA tertiles (T1: 50.18 ± 9.44 years; T3: 47.66 ± 9.21 years; p trend < 0.001). Bonferroni post-hoc analysis showed significant pairwise differences of age between T1 vs. T2 and T1 vs. T3 of NOVA (p < 0.001). No significant differences were observed in mean BMI, weight, or height across tertiles. Regarding oral health, both the number of teeth and missing teeth differed significantly (p-trend < 0.001), with the third NOVA group (T3) exhibiting the fewest number of teeth and the highest missing teeth after controlling for confounders. Additionally, Bonferroni post-hoc analysis indicated significant differences between T1 vs. T3 and T2 vs. T3 (p < 0.001). Furthermore, the number of filled teeth was significantly lower in the highest NOVA

	Total population	**Females**	**Males**
Variables	**Mean (95% CI) or n (%)**	**Mean (95% CI) or n (%)**	**Mean (95% CI) or n (%)**
Subjects	3947	2281	1666
Females *n (%)*	2281 (57.80%)	2281 (100)	0 (0)
Age (year)	48.33 (38.03 – 48.62)	48.22 (47.84 – 48.61)	48.46 (48.00—48.92)
Wealth score index (WSI) *n (%)*			
Low	1317 (33.40)	654 (28.70)	663 (39.8)
Medium	1332 (33.70)	763 (33.50)	569 (34.20)
High	1289 (32.90)	864 (37.90)	434 (26.10)
Body mass index (BMI) (kg/m2)	26.68 (26.54—26.68)	27.47 (27.27 – 27.82)	25.63 (25.42 – 25.95)
Overweight (25 ≤ BMI > 30) *n (%)*	1548 (39.20)	896 (39.30)	652 (39.10)
Obese (BMI ≥ 30) *n (%)*	950 (24.10)	689 (30.20)	261 (15.70)
Marriage status			
Married (yes) *n (%)*	3532 (89.50)	1903 (83.40)	1629 (97.80)
Lifestyle factors			
Alcohol consumption (yes) *n (%)*	187 (4.70)	4 (0.20)	183 (11.00)
Smoking (yes) *n (%)*	674 (17.10)	300 (13.20)	374 (22.40)
Drug (yes) *n (%)*	168 (4.20)	10 (0.40)	153 (9.20)
Brush teeth (no) *n (%)*	189 (5.20)	106 (6.79)	83 (4.01)
Breastfeeding duration	–	75.33 (72.99 – 77.67)	–
Number of pregnancies	–	4.92 (4.80 – 5.08)	–
Oral health status			
Teeth number	25.14 (24.85 –25.43)	25.02 (24.64 – 25.40)	25.31 (24.86 – 25.76)
Decayed teeth number	2.94 (2.84 – 3.04)	2.92 (2.79 – 3.05)	2.96 (2.80 – 3.12)
Not decayed teeth *n (%)*	872 (22.09)	494 (21.70)	378 (22.70)
Missing teeth number	6.58 (6.19 – 6.77)	6.63 (6.25 – 7.01)	6.28 (5.82 – 6.73)
Not missing teeth *n (%)*	781 (19.78)	400 (17.5)	381 (22.80)
Filled teeth number	1.69 (1.62 – 1.77)	1.82 (1.71 – 1.93)	1.52 (1.41 – 1.64)
Not filled teeth *n (%)*	2043 (51.76)	1150 (50.40)	893 (53.60)
Dietary intake			
Total energy intake (TEI) (kcal/day)	2793.57 (2767.27 – 2767.27)	2521.41 (2491.63 – 2551.18)	3166.42 (3125.36 – 3207.04)
Carbohydrate (% of TEI)	64.38 (64.21 – 64.55)	64.29 (64.07 – 64.51)	64.48 (64.21 – 64.74)
Protein intake (% TEI)	12.84 (12.79 – 12.90)	12.66 (12.59 – 12.73)	13.10 (13.02 – 13.17)
Fat intake (% of TEI)	24.43 (24.27 – 24.59)	24.75 (24.54 – 24.95)	23.95 (23.71 – 24.02)
Added sugar (gr/day)	146.26 (144.13 – 148.53)	133.70 (131.34 – 136.05)	164.10 (160.76 – 167.44)
Fiber (gr/1000 kcal)	10.29 (10.20 – 10.37)	10.43 (10.31 – 10.55)	10.08 (9.96 10.21)

Table 1. Demographic, lifestyle characteristics of participants, n = 3947, Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018. Values are presented as mean (95% confidence interval) for continuous variables or as number (percentage) for categorical variables. *n* Number, *CI* Confidence interval, *TEI* Total energy intake.

tertile (p-trend = 0.001). Bonferroni post-hoc analysis indicated significant differences between T1 vs. T3 and T2 vs. T3 (p = 0.01).

Dietary characteristics

In Table 2, most dietary intake variables showed a significant positive trend across tertiles of the NOVA score (p-trend < 0.05), including TEI, non-dairy beverages, cookies and cakes, potato chips, processed meat and fast food, oil and sauce, sweets, grains, legumes, vegetables, fruits, eggs, dairy, protein intake (% TEI), fat intake (% TEI), fiber (g/1000 kcal), added sugar, PUFA with all associations showing p-trend values < 0.001. Similar trend for SAF (p-trend = 0.03), selenium (p-trend = 0.01), magnesium, phosphorus, potassium, zinc, iron, fluoride, vitamins A, C, K, and D (all p-trend < 0.001). A few variables, including dairy beverages, nuts, vegetable oils, fish and seafood, red meat, poultry, and carbohydrate intake (% TEI) did not show significant associations p-trend > 0.05. Calcium intake showed a borderline significant trend (p-trend = 0.05). The mean intakes of 32 food groups in the total population, along with gender differences assessed using independent t-tests, are reported in Table S1. Only seven food groups—dairy products, liquid vegetable oils, solid oil, olive oil, butter, pickles, and sauce/salt—showed no significant differences between genders (p > 0.05), while intake of all other food groups was significantly higher in males.

Gender- and age-specific characteristics

Table 3 presents the demographic characteristics, dietary intake, and oral health outcomes stratified by gender and age group (35–50 years vs. 50–75 years). Among females, the mean NOVA score was higher in the younger females (35–50 years: 154.85 ± 117.51) compared to the older females (50–75 years: 136.68 ± 117.46), while among males, younger participants also had a higher mean NOVA score (35–50 years: 234.87 ± 170.38 vs. 50–75 years: 172.26 ± 144.79). When examining dietary intake across NOVA tertiles, higher NOVA scores (T3) were associated with higher TEI, increased consumption of non-dairy beverages, cookies and cakes, potato chips, processed meat/fast food, oil/sauce, and sweets in all gender–age groups (P-trend < 0.05).

Macronutrients intake varied across NOVA tertiles. In younger males, protein and fat intake increased significantly across tertiles, while carbohydrate intake decreased (P-trend < 0.001). In older males, both fat and carbohydrate intake increased across tertiles, whereas protein intake decreased with higher NOVA scores. In females, higher NOVA scores were generally associated with lower protein intake in both age groups.

Regarding oral health, participants with higher NOVA scores tended to have fewer teeth and more decayed or missing teeth, particularly in the older age groups and among males.

Overall, higher consumption of UPFs was associated with greater mean energy intake, shifts in macronutrients composition, and poorer oral health outcomes, with variations observed across age and sex stratified.

SEM analysis the mediatory role of gender and age

In the assessment of multicollinearity for all SEM models, the variance inflation factor (VIF) values were within acceptable ranges. Specifically, VIF ranged from 1.001 to 4.86 in the mediatory SEM, 1.002 to 3.27 in females aged 35–50 years, 1.006 to 3.41 and 1.013 to 3.93 in males aged 35–50 years, and 1.023 to 4.28 in participants aged 50–75 years. These findings suggest that multicollinearity was not a significant concern, allowing for robust interpretations of the relationships among the variables included in the analysis.

The mediation analysis showed that higher NOVA scores, reflecting increased intake of UPFs, were significantly associated with poorer dental health in the total population. Model fit indices are presented in Table S3. Compared to the lowest NOVA tertile (T1), participants in T2 and T3 had significantly fewer teeth (β = –0.953, p < 0.001; β = –0.677, p = 0.03, respectively), and those in T3 also had more missing teeth (β = 0.947, p < 0.001), indicating a direct association. Gender, coded as females = 2 and males = 1, significantly mediated several of these associations. NOVA scores were negatively associated with gender and age as shown in Table 4 and Fig. 2. These findings highlight both direct, indirect, partially gender-, and age-mediated pathways linking UPFs consumption with adverse dental outcomes. All endogenous variables included unique error terms. Based on modification indices, three residual covariances were added to improve model fit and reflect conceptual relationships between variables. These included covariances between the error terms of teeth number and missing teeth number (r = –0.47), between NOVA categories (T2 vs. T1) and (T3 vs. T1) (r = –0.17), and between age and TEI (r = –0.17). All modifications were theoretically justifiable and contributed to a better-fitting model.

According to Table 5, gender partially mediated the effect of NOVA T2 vs. T1 on number of teeth and of NOVA T3 vs. T1 on missing teeth. Indirect-only mediation by gender was observed in the associations between NOVA T2 vs. T1 and missing, and between NOVA T3 vs. T1 and decayed. Some relationships, such as NOVA T3 vs. T1 with number of teeth, were direct only. These results suggest that gender plays a partial or indirect mediating role in the relationship between UPFs intake and dental health outcomes, particularly those related to tooth loss and dental restorations.

Similarly, age partially mediated the effect of NOVA T2 versus T1 and NOVA T3 versus T1 on the total number of teeth. In addition, the association between NOVA T3 versus T1 and the number of missing teeth was also partially mediated by age.

Gender- and age- specific SEM analysis

Age-stratified SEM results for participants aged 35–50 years and 50–75 years are presented in Fig. 3 and Table 6 for females and Fig. 4 and Table 7 for males, with model fit indices provided in Table S4.

In age-stratified SEM analyses, among females aged 35–50 years (n = 1328), higher NOVA intake (T3 vs. T1) was directly associated with an increased number of decayed teeth (β = 0.521, 95% CI: 0.298, 0.794, p = 0.02), while TEI and cigarette use positively influenced NOVA consumption. Age had a small negative direct effect on NOVA (T2 vs. T1). Several covariates showed significant direct effects on dental outcomes:

Variables	NOVA (mean ± SD) T1 NOVA > 94.58 (55.82 ± 23.96)	T2 94.58 ≤ NOVA ≥ 191.05 (138.08 ± 27.56)	T3 NOVA < 191.05 (332.82 ± 140)	P-trend *
Subjects	1334	1338	1275	
Total energy intake (TEI) (kcal/d)	2240.50 ± 623.46	2738.56 ± 661.97	3429.95 ± 777.14	**< 0.001**
NOVA score components				
Non-dairy beverages (g/d)	22.94 ± 17.85	75.58 ± 34.58	250.10 ± 173.95	**< 0.001**
Cookies-cakes (g/d)	24.80 ± 15.49	45.66 ± 24.54	68.95 ± 41.96	**< 0.001**
Dairy beverages (g/d)	0.77 ± 1.53	0.007 ± 0.26	0.09 ± 2.27	0.23
Potato chips—salty	1.66 ± 3.07	4.42 ± 7.58	9.87 ± 14.97	**< 0.001**
Processed meat—fast food (g/d)	3.38 ± 5.39	6.98 ± 9.16	13.86 ± 20.40	**< 0.001**
Oil—sauce (g/d)	0.53 ± 1.15	1.08 ± 2.27	1.98 ± 3.17	**< 0.001**
Sweet (g/d)	2.51 ± 3.12	4.36 ± 4.53	7.51 ± 8.92	**< 0.001**
Food groups				
Grains (g/d)	296.15 ± 155.16	354.82 ± 164.67	389.77 ± 162.13	**< 0.001**
Nuts (g/d)	5.95 ± 4.33	6.90 ± 5.70	9.71 ± 8.12	0.11
Legumes (g/d)	51.51 ± 39.67	65.32 ± 50.55	71.20 ± 52.00	**< 0.001**
Vegetables(g/d)	213.56 ± 139.96	219.34 ± 129.13	234.44 ± 130.35	**< 0.001**
Fruits (g/d)	329.66 ± 248.32	355.86 ± 229.77	422.36 ± 243.19	**< 0.001**
Eggs (g/d)	27.39 ± 23.52	33.60 ± 25.17	40.56 ± 30.67	**< 0.001**
Dairy (ml/d)	236.19 ± 176.11	251.11 ± 169.41	276.74 ± 185.88	**< 0.001**
Vegetable oils	6.47 ± 5.96	6.13 ± 6.03	6.13 ± 6.04	0.61
Fish and seafood (g/d)	8.65 ± 6.83	11.87 ± 9.32	11.57 ± 11.26	0.31
Red meat (g/d)	11.43 ± 10.23	14.22 ± 13.78	19.40 ± 19.03	0.28
Poultry (g/d)	25.63 ± 18.91	31.12 ± 22.79	38.14 ± 28.61	0.69
Macronutrients				
Carbohydrate (% of TEI)	64.61 ± 5.64	64.39 ± 5.29	64.09 ± 5.20	0.43
Protein intake (% TEI)	13.09 ± 1.79	12.89 ± 1.59	12.43 ± 1.53	**< 0.001**
Fat intake (% of TEI)	23.68 ± 5.28	24.37 ± 5.01	25.22 ± 4.69	**< 0.001**
Fiber (gr/1000 kcal)	11.02 ± 3.20	10.26 ± 2.54	9.54 ± 2.29	**< 0.001**
Added sugar (g/d)	111.68 ± 51.37	140.09 ± 53.16	189.75 ± 63.12	**< 0.001**
PUFA (g/d)	9.51 ± 3.61	11.94 ± 4.17	15.62 ± 5.52	**< 0.001**
SAF (g/d)	21.54 ± 10.12	27.16 ± 10.82	35.06 ± 12,91	**0.03**
Micronutrient				
Calcium (mg/d)	602.01 ± 280.03	716.54 ± 271.85	921.21 ± 336.46	0.05
Magnesium (mg/d)	286.95 ± 100.84	378.37 ± 114.86	528.69 ± 210.42	**< 0.001**
Phosphorus (mg/d)	945.06 ± 338.39	1170 ± 347.36	1507.91 ± 431.57	**< 0.001**
Potassium (mg/d)	3137.41 ± 1210.33	4051.65 ± 1352.34	5735.31 ± 2409.83	**< 0.001**
Zinc (mg/d)	6.89 ± 2.44	8.42 ± 2.61	10.34 ± 2.89	**< 0.001**
Iron (mg/d)	13.90 ± 4.35	16.70 ± 4.85	20.35 ± 5.34	**< 0.001**
Fluoride (mg/d)	1331.22 ± 1285.56	1520 ± 1387.90	1876.01 ± 1527.26	**< 0.001**
Selenium (mg/d)	59.10 ± 25.31	75.28 ± 28.24	95.49 ± 31.83	**0.01**
Vitamin A (IU/d)	1110.88 + 898.76	1206.88 ± 881.14	1361.94 967.08	**< 0.001**
Vitamin C (mg/d)	119.58 ± 74.74	134.71 ± 75.12	166.86 ± 82.61	**< 0.001**
Vitamin K (mg/d)	169.83 ± 117.18	183.03 ± 116.37	203.84 ± 123.65	**< 0.001**
Vitamin D (mg/d)	182.78 ± 122.35	213.33 ± 119.71	244.46 ± 140.72	**< 0.001**

Table 2. Daily dietary intake according to tertile categories of NOVA score, n = 3947, Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018. Values are mean ± standard deviation (SD), p < 0.05 was considered significant. Significant values are in bold. * Analyses were adjusted for gender, age, BMI, wealth status index (WSI), total energy intake (TEI), and smoking status using analysis of covariance (ANCOVA), except when TEI was outcome. *T* Tertile, *kcal/d* Kilocalories per day, *g/d* grams per day, *TEI* Total energy intake.

age and breastfeeding duration negatively influenced total teeth, while cigarette use and number of pregnancy were positively associated with decayed teeth. BMI and WSI were positively associated with filled teeth, and age and breastfeeding duration with missing teeth. Model fit indices were acceptable (χ^2/df = 2.39, NFI = 0.915, CFI = 0.908, GFI = 0.913, AGFI = 0.899, TLI = 0.955, RMSEA = 0.062). In females aged 50–75 years (n = 953),

Age & sex group (number) (Mean ± SD of NOVA score)	Females (n = 2281) Age 35 – 50 (n = 1328) (154.85 ± 117.51)				Age 50 – 75 (n = 953) (136.68 ± 117.46)				Males (n = 1666) Age 35 – 50 (n = 969) (234.87 ± 170.38)				Age 50 – 75 (n = 697) (172.26 ± 144.79)			
Tertile of NOVA (Mean ± SD)	**T1 NOVA (58.14 ± 22.92)**	**T2 NOVA (138.13 ± 27.50)**	**T3 NOVA (306.01 ± 115.83)**	**P-trend**	**T1 NOVA (51.58 ± 24.30)**	**T2 NOVA (137.86 ± 27.52)**	**T3 NOVA (317.98 ± 115.26)**	**P-trend**	**T1 NOVA (62.87 ± 22.16)**	**T2 NOVA (137.67 ± 28.55)**	**T3 NOVA (361.79 ± 158.80)**	**P-trend**	**T1 NOVA (53.97 ± 24.97)**	**T2 NOVA (138.89 ± 26.43)**	**T3 NOVA (328.09 ± 147.19)**	**P-trend**
Subjects	480	487	361		341	307	305		290	322	357		243	222	232	
Variables																
Age (year)	41.76 ± 4.27	41.17 ± 4.28	41.57 ± 4.36	0.08	57.66 ± 5.43	57.33 ± 5.36	57.91 ± 5.47	0.44	42.49 ± 4.31	41.57 ± 4.16	40.96 ± 4.01	**0.001**	58.72 ± 5.49	57.92 ± 5.44	58.04 ± 5.38	0.39
BMI (kg/m^2)	27.49 ± 5.22	27.87 ± 5.41	28.49 ± 5.43	0.92	27.70 ± 4.96	27.31 ± 4.77	27.70 ± 5.28	0.17	25.52 ± 4.58	25.83 ± 4.39	26.33 ± 4.67	0.83	25.09 ± 4.30	25.47 ± 4.08	25.46 ± 4.18	0.55
Dietary intake																
Total energy intake (TEI) (kcal/day)	2169.31 ± 330.71	2587.01 ± 397.73	2918.38 ± 401.23	**< 0.001**	2029.99 ± 346.53	2441.06 ± 377.90	2875.29 ± 486.34	**< 0.001**	2613.11 ± 604.28	3056.72 ± 657.92	3370.53 ± 70.9.72	**< 0.001**	2502.52 ± 560.93	3020.96 ± 578.64	3220.60 ± 635.89	**< 0.001**
Carbohydrate (% of TEI)	63.65 ± 5.33	63.39 ± 5.26	63.35 ± 4.83	0.69	64.98 ± 5.82	64.53 ± 4.94	65.22 ± 4.51	0.81	64.76 ± 5.72	64.03 ± 5.24	62.35 ± 5.53	**< 0.001**	65.71 ± 5.23	64.12 ± 5.18	66.81 ± 4.59	**0.01**
Protein intake (% TEI)	13.11 ± 1.55	12.54 ± 1.42	12.41 ± 1.55	**0.01**	12.90 ± 1.57	12.54 ± 1.49	12.34 ± 162	**0.001**	12.50 ± 1.55	13.19 ± 1.74	13.32 ± 1.75	**< 0.001**	13.32 ± 1.61	13.13 ± 1.41	12.78 ± 1.46	**0.001**
Fat intake (% of TEI)	24.91 ± 5.15	25.57 ± 4.99	25.68 ± 4.41	0.09	23.79 ± 5.48	24.32 ± 4.78	24.12 ± 3.96	0.21	23.41 ± 5.31	23.96 ± 4.91	25.74 ± 4.86	**< 0.001**	22.43 ± 4.95	22.55 ± 4.86	24.14 ± 4.28	**< 0.001**
NOVA score components																
Non-dairy beverages (g/d)	21.72 ± 16.85	69.89 ± 33.88	207.33 ± 103.64	**< 0.001**	22.86 ± 18.81	88.05 ± 35.27	223.05 ± 113.98	**< 0.001**	27.06 ± 17.02	71.24 ± 33.45	252.28 ± 146.07	**< 0.001**	22.89 ± 18.22	77.32 ± 32.25	236.67 ± 124.31	**< 0.001**
Cookies-cakes (g/d)	26.76 ± 15.55	48.95 ± 23.70	65.60 ± 39.57	**< 0.001**	22.04 ± 14.36	36.32 ± 20.44	53.63 ± 31.59	**< 0.001**	26.81 ± 15.30	48.44 ± 25.89	74.88 ± 41.77	**< 0.001**	24.44 ± 16.74	47.33 ± 26.42	66.07 ± 39.29	**< 0.001**
Dairy beverages (g/d)	0.16 ± 2.50	0.02 ± 0.44	0.005 ± 0.10	0.35	0.011 ± 0.003	0.007 ± 0.0001	0.003 ± 0.0001	0.74	0.75 ± 0.05	0.007 ± 0.0001	0.24 ± 3.71	0.21	0.008 ± 0.001	0.005 ± 0.00	0.001 ± 0.0001	0.65
Potato chips—salty	2.30 ± 3.68	5.97 ± 9.02	11.52 ± 16.07	**< 0.001**	1.35 ± 2.84	3.98 ± 7.40	5.97 ± 9.14	**< 0.001**	1.70 ± 2.77	3.84 ± 6.74	10.33 ± 14.51	**< 0.001**	0.94 ± 1.98	2.49 ± 4.21	6.51 ± 10.29	**< 0.001**
Processed meat—fast food (g/d)	4.10 ± 5.33	7.69 ± 9.56	12.07 ± 17.64	**< 0.001**	2.45 ± 4.48	4.22 ± 5.99	6.04 ± 7.64	**0.01**	4.25 ± 5.31	9.22 ± 10.61	18.67 ± 23.46	**< 0.001**	2.77 ± 5.36	5.69 ± 7.92	10.49 ± 15.44	**< 0.001**
Oil—sauce (g/d)	0.60 ± 1.10	1.16 ± 1.88	2.09 ± 3.25	**< 0.001**	0.39 ± 0.99	0.95 ± 2.48	1.25 ± 2.46	**0.01**	0.67 ± 1.13	1.02 ± 1.64	2.51 ± 3.64	**< 0.001**	0.44 ± 1.06	1.44 ± 3.34	1.16 ± 1.95	**< 0.001**
Sweet (g/d)	2.65 ± 3.14	4.45 ± 4.44	7.38 ± 6.78	**< 0.001**	2.45 ± 2.83	4.31 ± 4.30	7.34 ± 8.98	**< 0.001**	2.36 ± 3.88	3.89 ± 4.16	6.81 ± 9.67	**0.002**	2.46 ± 3.02	4.89 ± 5.44	8.03 ± 9.19	**< 0.001**
Oral health status																
Teeth number	28.95 ± 4.50	28.72 ± 4.75	27.77 ± 5.95	0.21	21.14 ± 10.57	20.18 ± 11.50	17.79 ± 11.64	**0.003**	28.94 ± 5.89	28.72 ± 5.38	27.07 ± 6.17	0.09	22.46 ± 10.31	21.07 ± 11.39	19.31 ± 11.90	**0.04**
Decayed teeth number	2.05 ± 2.11	2.55 ± 2.52	2.99 ± 2.87	**0.04**	2.61 ± 3.04	3.54 ± 3.88	3.78 ± 4.41	**0.03**	2.73 ± 3.55	2.43 ± 2.85	2.25 ± 2.79	0.17	3.23 ± 3.56	3.51 ± 3.63	3.93 ± 3.31	0.05
Missing teeth number	2.79 ± 4.50	2.82 ± 4.67	3.80 ± 5.90	0.19	10.59 ± 10.63	11.48 ± 11.58	13.82 ± 11.82	**0.004**	2.74 ± 5.31	3.12 ± 5.82	3.59 ± 6.15	**0.04**	9.65 ± 11.53	10.50 ± 10.42	12.37 ± 12.06	**0.03**
Filled teeth number	2.38 ± 2.78	2.35 ± 2.97	1.92 ± 2.54	0.41	1.37 ± 2.52	1.22 ± 2.26	0.94 ± 1.92	0.49	1.75 ± 2.43	1.83 ± 2.49	1.81 ± 2.39	0.49	0.91 ± 1.75	1.31 ± 2.23	1.32 ± 2.51	0.09

Table 3. Participant characteristics by tertiles of ultra-processed food intake (sex- and age-stratified), Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018. Values are mean ± standard deviation (SD). Significant values are in bold. * Analyses were adjusted for age, BMI, wealth status index (WSI), and total energy intake (TEI) using analysis of covariance (ANCOVA), except when age or BMI were the outcomes. *T* Tertile, *g/d* Grams per day, *BMI* Body mass index.

Variables	Estimate	SE	95%CI	P value	Direction
Direct effect of dependent variables					
NOVA (T2 vs. T1) → Teeth number	−0.953	0.296	−1.530,−0.370	< 0.001	−
NOVA (T3 vs. T1) → Teeth number	−0.677	0.267	−1.200, −0.154	0.03	−
NOVA (T3 vs. T1) → Missing teeth number	0.947	0.324	0.187, 1.705	< 0.001	+
Indirect effect of independent variables					
NOVA (T2 vs. T1) → Gender	−0.099	0.019	−0.136, −0.062	< 0.001	−
NOVA (T3 vs. T1) → Gender	−0.250	0.019	−0.287, −0.213	< 0.001	−
Gender → Teeth number	−0.800	0.260	−1.310, −0.290	0.002	−
Gender → Missing teeth number	0.842	0.261	0.330, 1.358	0.001	+
NOVA (T2 vs. T1) → Age	−0.035	0.017	−0.068, −0.002	0.03	−
NOVA (T3 vs. T1) → Age	−0.54	0.013	−0.565, −0.514	< 0.001	−
Age → Teeth number	−0.917	0.210	−1.329, −0.505	< 0.001	−
Age → Decayed teeth number	0.906	0.101	0.708, 1.104	< 0.001	+
Age → Missing teeth number	0.915	0.209	0.505, 1.325	< 0.001	+
Age → Filled teeth number	−0.538	0.075	−0.685, −0.391	< 0.001	−
Direct effect of independent variables					
TEI → NOVA (T2 vs. T1)	0.121	0.086	0.056, 0.296	0.008	+
TEI → NOVA (T3 vs. T1)	0.282	0.100	0.084, 0.476	< 0.001	+
Cigarette use (yes) → NOVA (T3 vs. T1)	0.040	0.017	0.007, 0.073	0.02	+
Brusch teeth → NOVA (T3 vs. T1)	−0.170	0.014	−0.198, −0.143	001	−
Alcoho consumption (yes) → NOVA (T3 vs. T1)	0.065	0.030	0.006, 0.124	0.03	+
Direct effect of counfounders					
Age → Teeth number	−0.494	0.013	−0.520,−0.469	0.01	−
BMI → Teeth number	0.067	0.027	0.015, 0.121	0.01	+
Drug use (yes) → Teeth number	−0.946	0.404	−1.738,−0.154	< 0.001	−
Brush teeth (no) → Teeth number	0.918	0.301	0.328, 1.508	< 0.001	+
Age → Decayed teeth number	0.045	0.005	0.035, 0.055	0.01	+
Drug use (yes) → Decayed teeth number	0.942	0.252	0.455, 1.443	< 0.001	+
Cigarette use (yes) → Decayed teeth number	0.323	0.134	0.060, 0.586	0.001	+
Brush teeth (no) → Decayed teeth number	0.971	0.201	0.577, 1.365	< 0.001	+
BMI → Missing teeth number	−0.064	0.027	−0.117, -0.011	0.01	−
Drug use (yes) → Missing teeth number	0.931	0.387	0.163, 1.679	< 0.001	+
Alcohol consumption (yes) → Missing teeth number	0.926	0.401	0.140, 1.712	< 0.001	+
Brush teeth (no) → Missing teeth number	0.915	0.305	0.325, 1.512	< 0.001	−
WSI → Filled teeth number	0.321	0.107	0.112, 0.530	0.002	+
χ2/df	2.88				
NFI	0.912				
CFI	0.905				
GFI	0.922				
AGFI	0.901				
TLI	0.959				
RMSEA	0.061				

Table 4. Standardized regression weight of mediatory role of gender in association between NOVA score and dental health, only significant associations reported, n = 3947, Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018. *χ2.df* Chi-square test, *RMSEA* Root mean square error of approximation, *NFI* Normed fit index, *CFI* Comparative fit index, *GFI* Goodness-of-fit index, *AGFI* Adjusted GFI, *TLI* Tucker-Lewis index, *TEI* Total energy intake, *BMI* Body mass index, *WSI* Wealth status index.

NOVA (T3 vs. T1) was negatively associated with total teeth (β = -0.976, 95% CI – 1.963, – 0.015, p < 0.001) and positively with missing teeth (β = 0.987, 95% CI 0.056, 1.918, p = 0.001), while NOVA (T2 vs. T1) was positively associated with decayed teeth (β = 0.536, 95% CI 0.089, 1.034, p = 0.009). TEI was positively associated with NOVA intake. Fit indices indicated acceptable model performance (χ^2/df = 2.75, NFI = 0.919, CFI = 0.908, GFI = 0.905, AGFI = 0.897, TLI = 0.945, RMSEA = 0.062).

These included covariances between the error terms of teeth number and missing teeth number (r = –0.37), between NOVA categories (T2 vs. T1) and (T3 vs. T1) (r = –0.15), and between age and TEI (r = -0.14) in females 35–50 yr, error terms of teeth number and missing teeth number (r = –0.39), between NOVA categories (T2 vs. T1) and (T3 vs. T1) (r = –0.18), and between age and TEI (r = -0.17) in females 50—75 yr.

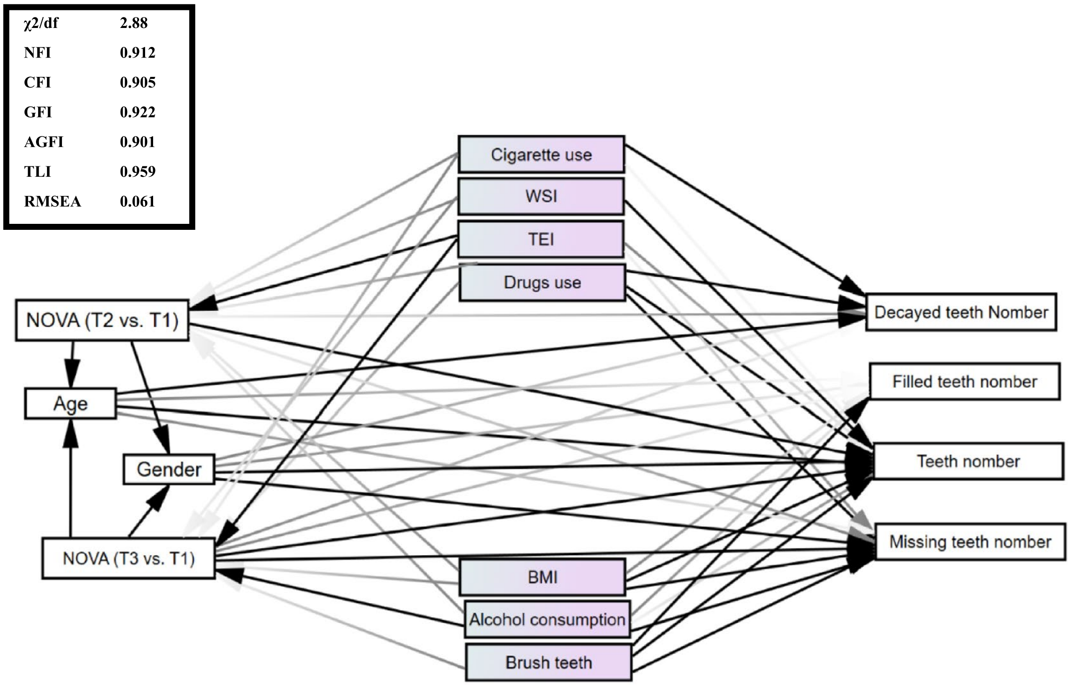

Fig. 2. Modified structured equation model of the mediatory role of gender and age in associations between NOVA score and dental health (n = 3947 adults). Data are from the 2016–2018 Bandare-Kong Non-Communicable Disease (BKNCD) cohort. The mediatory role of gender and age in association between NOVA score and the dental health outcomes, model was adjusted for BMI, WSI, cigarette use, drug use, alcohol consumption, tooth brushing habits, and TEI. For visual clarity, significant paths are depicted in black, while non-significant paths are shown in gray. *T* Tertile, *χ2.df* Chi-square test, *RMSEA* Root mean square error of approximation, *NFI* Normed fit index, *CFI* Comparative fit index, *GFI* Goodness-of-fit index, *AGFI* Adjusted GFI, *TLI* Tucker-Lewis index, *TEI* Total energy intake, *BMI* Body mass index, *WSI* Wealth status index.

	c	c'	a	b	Mediator
Gender mediator					
NOVA (T2 vs. T1) → Gender → Teeth number	✓	✓	✓	✓	Partial mediator
NOVA (T2 vs. T1) → Gender → Decayed teeth number	✗	✗	✓	✗	No mediation
NOVA (T2 vs. T1) → Gender → Missing teeth number	✗	✗	✓	✓	Indirect only
NOVA (T2 vs. T1) → Gender → Filled teeth number	✗	✗	✓	✓	Indirect only
NOVA (T3 vs. T1) → Gender → Teeth number	✓	✓	✓	✗	Direct only
NOVA (T3 vs. T1) → Gender → Decayed teeth number	✗	✗	✓	✓	Indirect only
NOVA (T3 vs. T1) → Gender → Missing teeth number	✓	✓	✓	✓	Partial mediator
NOVA (T3 vs. T1) → Gender → Filled teeth number	✗	✗	✓	✗	No association
Age mediator					
NOVA (T2 vs. T1) → Age → Teeth number	✓	✓	✓	✓	Partial mediator
NOVA (T2 vs. T1) → Age → Decayed teeth number	✗	✗	✓	✓	Indirect only
NOVA (T2 vs. T1) → Age → Missing teeth number	✗	✗	✓	✓	Indirect only
NOVA (T2 vs. T1) → Age → Filled teeth number	✗	✗	✓	✓	Indirect only
NOVA (T3 vs. T1) → Age → Teeth number	✓	✓	✓	✓	Partial mediator
NOVA (T3 vs. T1) → Age → Decayed teeth number	✗	✗	✓	✓	Indirect only
NOVA (T3 vs. T1) → Age → Missing teeth number	✓	✓	✓	✓	Partial mediator
NOVA (T3 vs. T1) → Age → Filled teeth number	✗	✗	✓	✓	Indirect only

Table 5. Mediation analysis of gender in the association between nova score and dental health outcomes, Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018. ✓ = Path is significant. ✗ = Path is not significant. c = Total effect. c′ = Direct effect (controlling for mediator). a = NOVA → Gender. b = Gender → Outcome. a = NOVA → Age. b = Age → Outcome.

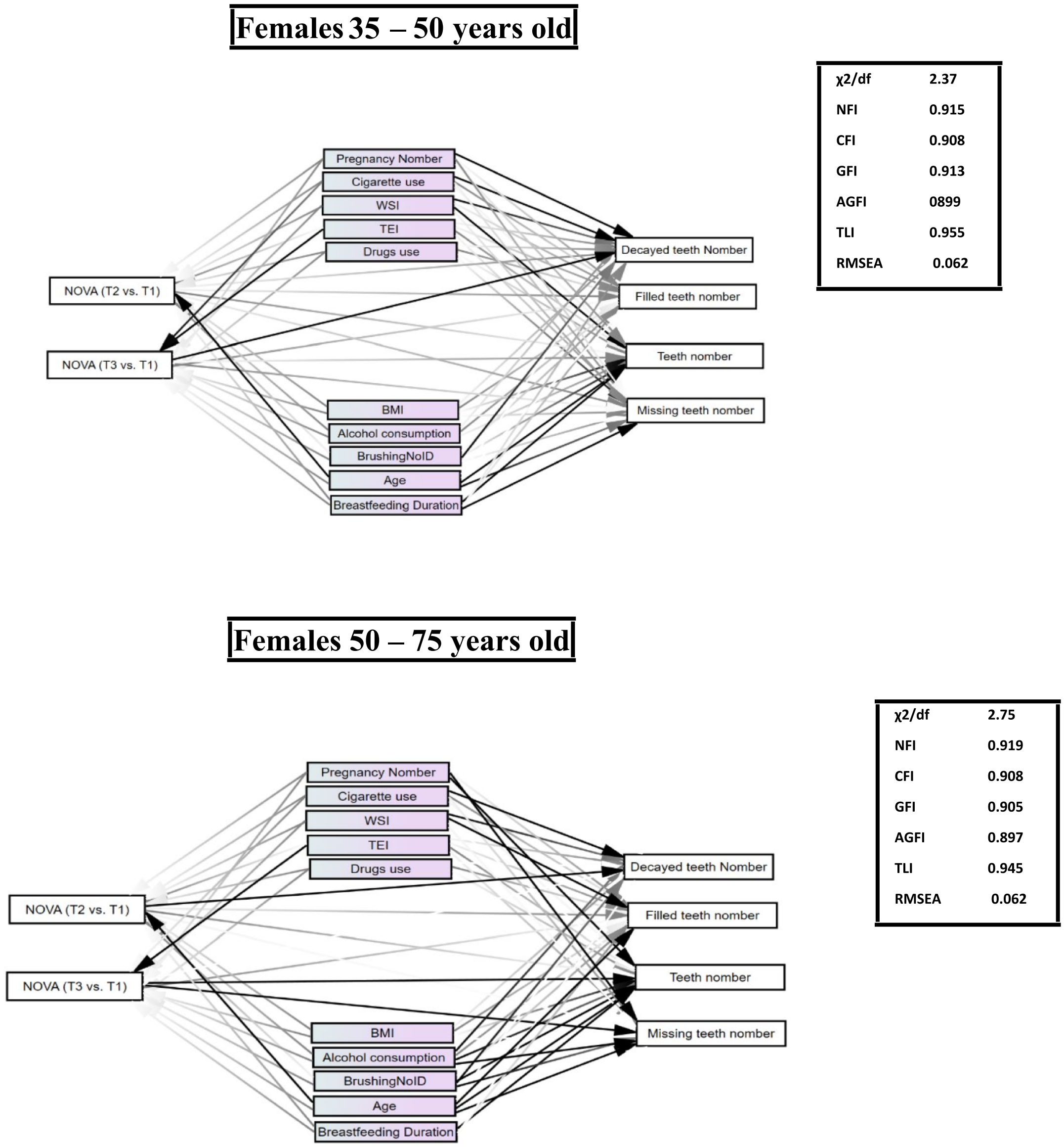

Fig. 3. Modified structured equation model of NOVA score in association with dental health in females n = 2281 (age 35–50 and 50–75 years old) Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016–2018. The model was adjusted for age, BMI, WSI, cigarette use, drug use, alcohol consumption, tooth brushing habits, breastfeeding duration, number of pregnancy, and TEI. The model were included with paths to both the independent variable (NOVA score) and the dental health outcomes. For visual clarity, significant paths are depicted in black, while non-significant paths are shown in gray. *T* Tertile, *NOVA (T2 vs. T1) as Dammy_1* compares the NOVA score at Tertile 1 (T1) with the NOVA score at Tertile 2 (T2), *NOVA (T3 vs. T1) as Dammy_2* compares the NOVA score at Tertile 1 (T1) with the NOVA score at Tertile 3 (T3), *χ2.df* Chi-square test, *RMSEA* Root mean square error of approximation, *NFI* Normed fit index, *CFI* Comparative fit index, *GFI* Goodness-of-fit index, *AGFI* Adjusted GFI, *TLI* Tucker-Lewis index, *TEI* Total energy intake, *BMI* Body mass index, *WSI* Wealth status index.

In males aged 35–50 years (n = 969), higher NOVA intake (T3 vs. T1) was directly associated with an increased number of missing teeth (β = 0.387, 95% CI 0.250, 0.524, p = 0.001). TEI, WSI, and cigarette use positively influenced NOVA intake, whereas age had a small negative effect on NOVA (T3 vs. T1). Covariates including age and alcohol consumption negatively affected total teeth, while age positively affected missing teeth. Model fit indices indicated acceptable performance (χ^2/df = 2.23, NFI = 0.927, CFI = 0.914, GFI = 0.911, AGFI = 0.903, TLI = 0.946, RMSEA = 0.061). For males aged 50–75 years (n = 697), NOVA (T3 vs. T1) was negatively associated with total teeth (β = −0.937, 95% CI – 1.862, – 0.020, p < 0.001) and positively associated with missing teeth (β = 0.911, 95% CI 0.086, 1.736, p < 0.001), while NOVA (T2 vs. T1) was positively associated with decayed teeth (β = 0.754, 95% CI 0.174, 1.334, p = 0.009). Fit indices indicated acceptable model performance (χ^2/df = 2.83,

Variables	Estimate	SE	95%CI	P value	Direction
Females 35–50 years, n = 1328					
Direct effect of dependent variables					
NOVA (T3 vs. T1) → Decayed teeth number	0.521	0.115	0.298, 0.794	0.02	+
Direct effect of independent variables					
TEI → NOVA (T3 vs. T1)	0.817	0.105	0.614, 1.024	< 0.001	+
Cigarette use → NOVA (T3 vs. T1)	0.097	0.033	0.031, 0.164	0.003	+
Age → NOVA (T2 vs. T1)	−0.068	0.003	−0.074, −0.062	0.034	-
Direct effect of counfounders					
Age → Teeth number	−0.271	0.031	−0.341, −0.210	0.03	-
Breastfeeding duration → Teeth number	−0.012	0.003	−0.018, −0.006	0.01	-
Cigarette use → Decayed teeth number	0.661	0.268	0.142, 1.97	0.001	+
WSI → Decayed teeth number	−0.193	0.071	−0.331, −0.08	0.03	-
Brush teeth (no) → Decayed teeth number	−0.299	0.067	−0.430, −0.168	0.001	-
Pregnancy number → Decayed teeth number	0.221	0.031	0.156, 0.286	0.001	+
Breastfeeding duration → Missing teeth number	0.011	0.003	0.004, 0.016	0.03	+
Age → Missing teeth number	0.118	0.026	0.067, 0.173	0.009	+
BMI → Filled teeth number	0.081	0.033	0.016, 0.146	0.04	+
WSI → Filled teeth number	0.918	0.172	0.581, 1.255	< 0.001	+
χ2/df	2.37				
NFI	0.915				
CFI	0.908				
GFI	0.913				
AGFI	0.899				
TLI	0.955				
RMSEA	0.062				
Females 50–75 years, n = 953					
Direct effect of dependent variables					
NOVA (T3 vs. T1) → Teeth number	−0.976	0.520	−1.963, −0.015	< 0.001	-
NOVA (T3 vs. T1) → Missing teeth number	0.987	0.475	0.056, 1.918	0.001	+
NOVA (T2 vs. T1) → Decayed teeth number	0.536	0.253	0.089, 1.034	0.009	+
Direct effect of independent variables					
Age → NOVA (T2 vs. T1)	0.006	0.002	0.003, 0.005	0.01	+
TEI → NOVA (T3 vs. T1)	0.179	0.117	0.021, 0.415	0.009	+
Direct effect of confounders					
Age → Teeth number	−0.331	0.045	0.245, 0.421	0.001	+
Alcohol consumption (yes) → Teeth number	−0.904	0.301	−1.494, −0.314	0.009	-
Brush teeth (no) → Teeth number	−0.895	0.283	-1.450, -0.340	< 0.001	-
Pregnancy number → Teeth number	−0.175	0.081	−0.328, −0.022	0.02	-
Alcohol consumption (yes) → Decayed teeth number	0.334	0.046	0.244, 0.424	< 0.001	+
WSI → Decayed teeth number	0.626	0.129	0.373, 0.879	< 0.001	+
Age → Missing teeth number	0.331	0.044	0.247, 0.419	0.001	+
Alcohol consumption (yes) → Missing teeth number	0.971	0.206	0.567, 1.375	< 0.001	+
Brush teeth (no) → Missing teeth number	0.904	0.347	−1.584, −0.224	0.001	+
Pregnancy number → Missing teeth number	0.179	0.077	−0.332, −0.026	0.02	+
Brush teeth (no) → Filled teeth number	0.248	0.039	−0.324, −0.172	< 0.001	+
Age → Filled teeth number	−0.054	0.008	−0.070, −0.038	< 0.001	-
Continued					
WSI → Filled teeth number	−0.247	0.073	−0.320, −0.174	0.001	+
χ2/df	2.75				
NFI	0.919				

Variables	Estimate	SE	95%CI	P value	Direction
CFI	0.908				
GFI	0.905				
AGFI	0.897				
TLI	0.945				
RMSEA	0.062				

Table 6. Standardized regression weight of NOVA score in association with dental health in females 35–50 years and 50 -75 years old, only significant associations reported, Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018. *χ2.df* Chi-square test, *RMSEA* Root mean square error of approximation, *NFI* Normed fit index, *CFI* Comparative fit index, *GFI* Goodness-of-fit index, *AGFI* Adjusted GFI, *TLI* Tucker-Lewis index, *TEI* Total energy intake, *BMI* Body mass index, *WSI* Wealth status index.

NFI = 0.926, CFI = 0.918, GFI = 0.915, AGFI = 0.904, TLI = 0.957, RMSEA = 0.061). These results indicate that both younger and older males exhibit complex direct effects of UPFs intake and covariates on dental health indicators, particularly on missing and decayed teeth. These included covariances between the error terms of teeth number and missing teeth number (r = –0.47) in males 50–75 yr, between NOVA categories (T2 vs. T1) and (T3 vs. T1) (r = –0.21), and between age and TEI (r = –0.23) in males 50–75 yr.

Discussion

To the best of our knowledge, this study is the first to investigate the association between UPFs consumption, defined per NOVA scores, and dental health in a large-sample of Iranian adults. The current study demonstrated more intake of UPFs, measured as higher NOVA score versus lower one, was associated with poorer dental health. In the total population, both the second and third tertiles of the NOVA score were associated with a lower number of teeth, while only the third tertile—compared to the first—was significantly associated with a higher number of missing teeth, gender and age were partial mediator in these associations. When stratified by gender and age. SEM revealed both direct and indirect pathways: in younger and older adults, NOVA score tertiles were associated with poorer dental outcomes directly, while factors such as TEI, alcohol consumption, smoking, and brushing habits partially mediated these relationships. Notably, older adults and males showed stronger associations between higher UPFs consumption and tooth loss, suggesting that cumulative dietary exposure may exacerbate dental deterioration. These gender- and age-related differences may reflect behavioral, hormonal, and biological factors influencing the effects of UPF consumption on oral health.

In line with our findings, a cross-sectional study of 5720 US adults aged 20–59 years reported that a higher proportional intake of UPFs, based on the NOVA classification, was associated with a higher DMFT index, whereas processed food consumption was linked to lower DMFT[41]. The DMFT index summarizes a person's dental caries experience by counting the number of Decayed, Missing (due to caries), and Filled permanent Teeth, with higher scores indicating poorer oral health. Similar associations have been reported in adolescents. For example, Costa et al. found that ultra-processed food-rich diets were linked to higher rates of decayed teeth in Brazilian adolescents, and the meta-analysis confirmed a positive relationship between greater UPFs consumption and increased caries risk in childhood and adolescence[42]. Likewise, another Brazilian study (n = 309) demonstrated that high UPFs intake was directly associated with early childhood caries[43]. Data from 996 adolescents aged 12–13 years who participated in an oral health sub-study of the 2004 Pelotas Birth Cohort in southern Brazil showed that higher exposure to ultra-processed foods (UPFs) during adolescence was strongly associated with caries development[44].

Not all studies support these associations. An exploratory analysis of 893 participants aged 55–80 years from the Longitudinal Aging Study Amsterdam examined 19 oral health characteristics in 2007 and their association with incident malnutrition over 9 years, defined by low BMI and/or involuntary weight loss. Sixteen characteristics were not associated with malnutrition. Overall, toothache while chewing emerged as the only oral health factor significantly predicting incident malnutrition[45,46]. In another cross-sectional study of 50,146 Brazilian adults aged 18–49, functional dentition (≥ 20 teeth) was not associated with UPF consumption[47]. In our study, we identified only an indirect association between NOVA score and the number of decayed teeth, with age and gender acting as modifying factors. Higher UPFs intake was associated with poorer dental health in older adults of both sexes, while younger males exhibited the highest UPFs consumption, which was linked to a greater number of missing teeth. In a cross-sectional study of 11,608 Chinese adults aged ≥ 65 from the 2017–2019 CLHLS, protein and anti-inflammatory diets were positively associated with the number of existing natural teeth, while sugar-salt diets were negatively associated. Joint low-protein, high sugar-salt, and low anti-inflammatory diets further reduced tooth count. Body mass index partially mediated these associations, suggesting that promoting healthy dietary patterns may help preserve teeth in older adults[48].

Overall, research on UPFs consumption and oral health has produced mixed findings. Most existing studies have focused on children and adolescents[41,42,49], with limited attention to adults. Given the high global prevalence of dental caries[50], and their profound impact on quality of life[51], and economic burden[52], understanding the multifactorial determinants of caries risk is essential for developing effective prevention strategies. Nutrition plays a key role in the etiology of dental caries, and healthy dietary habits are critical for maintaining oral health[53]. However, global shifts in dietary patterns indicate that vulnerable populations may be more likely to consume UPFs due to their low cost and convenience[54]. This underscores the importance of monitoring UPF-

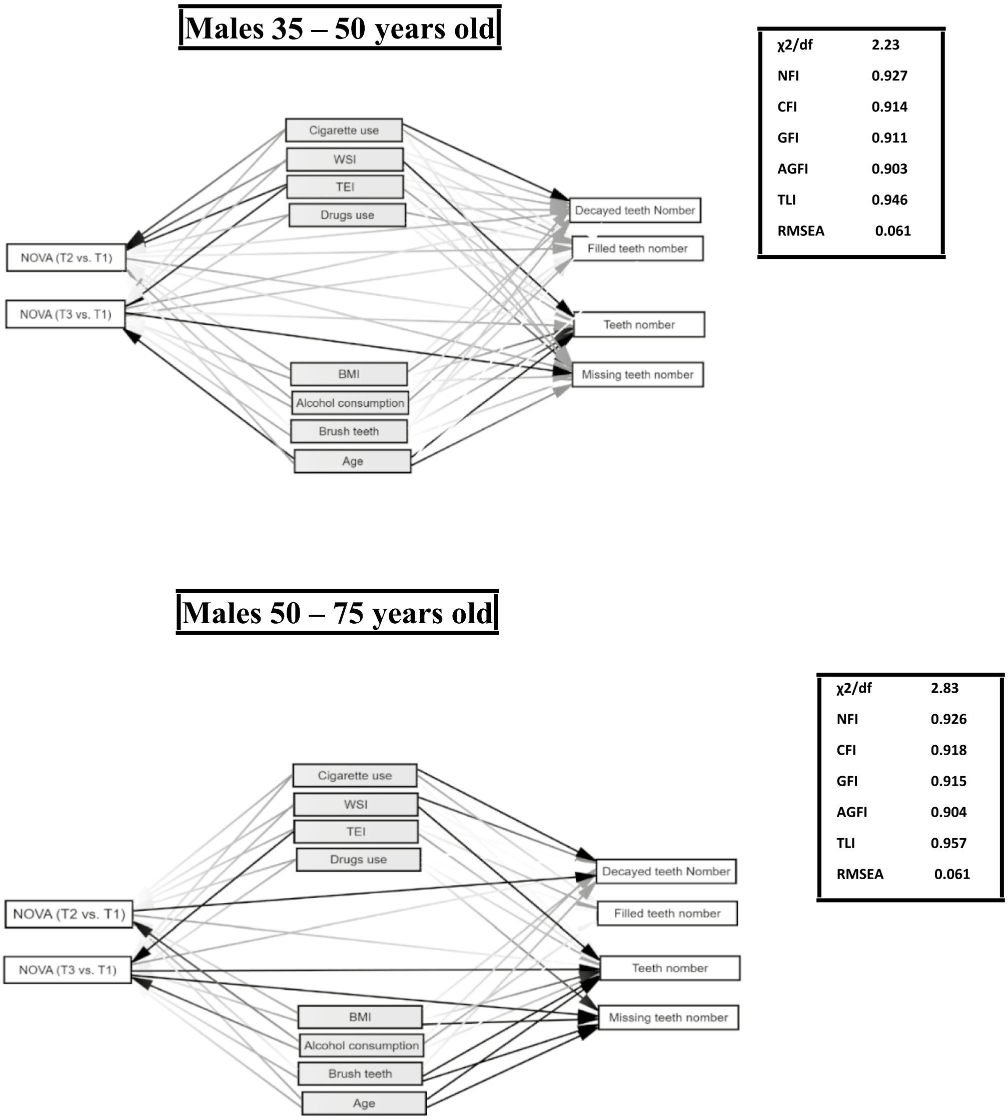

Fig. 4. Modified structured equation model of NOVA score in association and with dental health in males n = 1666 (age 35–50 and 50–75 years old) Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016–2018. The model was adjusted for age, BMI, WSI, cigarette use, drug use, alcohol consumption, tooth brushing habits, and TEI. These covariates were included with paths to both the independent variable (NOVA score) and the dental health outcomes. For visual clarity, significant paths are depicted in black, while non-significant paths are shown in gray. *T* Tertile, *NOVA (T2 vs. T1) as Dammy_1* compares the NOVA score at Tertile 1 (T1) with the NOVA score at Tertile 2 (T2), *NOVA (T3 vs. T1) as Dammy_2* compares the NOVA score at Tertile 1 (T1) with the NOVA score at Tertile 3 (T3), *χ2.df* Chi-square test, *RMSEA* Root mean square error of approximation, *NFI* Normed fit index, *CFI* Comparative fit index, *GFI* Goodness-of-fit index, *AGFI* Adjusted GFI, *TLI* Tucker-Lewis index, *TEI* Total energy intake, *BMI* Body mass index, *WSI* Wealth status index.

rich diets and evaluating their potential impact on oral health across different age groups, particularly in relation to caries risk.

UPFs have poor nutritional quality with low protein, vitamins and micronutrients, and fiber[55]. They also contain sugars and salt in their composition and diets high in salt and sugar have been shown to have deleterious effects on dental caries[56–59]. As a matter of fact, anti-inflammatory diets, characterized by high consumption of fruits, vegetable, and poly-unsaturated fatty acids, can decrease systemic inflammatory markers levels such as interleukine-6 (Il-6), C-reactive protein (CRP)[60] and mitigate inflammation to prevent periodontal destruction[61], which is considered as a main contributor to tooth loss. Furthermore, fermentable carbohydrates such as sugars and starches are essential components of ultra-processed food-rich diet and can be converted to lactic acid which alter oral microbiota balance, reduce the pH of saliva, leading to demineralization and tooth

Variables	Estimate	SE	95%CI	P value	Direction
Males 35–50 years, n = 969					
Direct effect of dependent variables					
NOVA (T3 vs. T1) → Missing teeth number	0.387	0.07	0.250, 0.524	0.001	+
Direct effect of independent variables					
TEI → NOVA (T2 vs. T1)	0.187	0.018	0.152, 0.224	0.009	+
TEI → NOVA (T3 vs. T1)	0.239	0.017	0.206, 0.272	0.007	+
WSI → NOVA (T2 vs. T1)	0.038	0.016	0.007, 0.069	0.01	+
Cigarette use → NOVA (T3 vs. T1)	0.076	0.025	0.027, 0.125	0.03	+
Age → NOVA (T3 vs. T1)	−0.019	0.003	−0.025, −0.013	0.009	-
Direct effect of counfounders					
Age → Teeth number	−0.264	0.037	−0.337, −0.191	0.001	-
Alcohol consumption (yes) → Teeth number	−0.897	0.122	−1.134, -0.691	0.001	-
Cigarette use → Decayed teeth number	0.901	0.114	−1.124, -0.678	< 0.001	-
Age → Missing teeth number	0.269	0.036	0.198, 0.340	0.001	-
χ2/df	2.23				
NFI	0.927				
CFI	0.914				
GFI	0.911				
AGFI	0.903				
TLI	0.946				
RMSEA	0.061				
Males 50–75 years, n = 697					
Direct effect of dependent variables					
NOVA (T3 vs. T1) → Teeth number	−0.937	0.473	-1.862, -0.020	< 0.001	
NOVA (T3 vs. T1) → Missing teeth number	0.911	0.421	0.086, 1.736	< 0.001	
NOVA (T2 vs. T1) → Decayed teeth number	0.754	0.296	0.174, 1.334	0.009	
Direct effect of independent variables					
Alcohol consumption (yes) → NOVA (T2 vs. T1)	0.112	0.039	0.036, 0.188	0.01	
Alcohol consumption (yes) → NOVA (T3 vs. T1)	0.154	0.059	0.038, 0.270	0.002	
TEI → NOVA (T3 vs. T1)	0.118	0.047	0.026, 0.210	0.009	
Direct effect of counfounders					
Age → Teeth number	−0.431	0.055	−0.546, −0.322	0.003	
BMI → Teeth number	0.154	0.053	0.012, 0.302	0.03	
Brush teeth (no) → Teeth number	0.276	0.081	0.117, 0.435	0.01	
WSI → Decayed teeth number	0.578	0.077	0.445, 0.751	< 0.001	
Age → Missing teeth number	0.439	0.057	0.327, 0.551	0.001	
Cigarette use → Missing teeth number	0.815	0.121	0.578, 1.052	< 0.001	
Brush teeth (no) → Missing teeth number	0.283	0.101	0.085, 0.481	0.01	
WSI → Filled teeth number	0.636	0.133	0.375, 0.897	0.002	
χ2/df	2.83				
NFI	0.926				
CFI	0.918				
GFI	0.915				
AGFI	0.904				
TLI	0.957				
RMSEA	0.061				

Table 7. Standardized regression weight of NOVA score in association with dental health in males 35–50 years and 50 -75 years old, only significant associations reported, Bandare-Kong Non-Communicable Disease (BKNCD) cohort, 2016—2018. *χ2.df* Chi-square test, *RMSEA* Root mean square error of approximation, *NFI* Normed fit index, *CFI* Comparative fit index, *GFI* Goodness-of-fit index, *AGFI* Adjusted GFI, *TLI* Tucker-Lewis index, *TEI* Total energy intake, *BMI* Body mass index, *WSI* Wealth status index.

structure impairments and decays[62,63]. Also, sticky UPFs such as breakfast cereals, industrialized pies and pizzas, and cookies can stay longer in the mouth due to retentive features and intra-oral bioavailability and predispose populations to dental caries[64].

The observed association between higher UPFs intake and lower number of filled teeth may also be explained by differences in food choices. While evaluating individual foods in each groups, some components of UPFs such as cheese[65] and cow's milk[66,67] can be regarded as protective factors and are more likely to decline caries levels. The main reason behind the protection role of cheese is stimulating salivary secretion and increasing the calcium concentration of dental plaque[68]. The cow's milk, in turn, contains calcium, lactose, phosphorus, and casein which are believed to prevent caries[69,70]. Moreover, individuals with fewer filled teeth may be more likely to experience tooth loss rather than receiving restorative treatment due to the financial burden of dental care.

Our SEM analysis provided deeper insights into the pathways linking UPFs consumption and dental health. The results indicated a significant direct effect of UPFs intake on dental outcomes such as missing and filled teeth. Specifically, sex and age partially mediated the associations between UPFs consumption and both the number of remaining and missing teeth. Indirect associations were also observed between NOVA score and the number of filled and decayed teeth. These findings may reflect underlying gender- and age-related differences in dietary patterns, health behaviors, or access to dental care. The associations were particularly pronounced in younger males, who consumed more UPFs, and in older adults of both sexes.

This cross-sectional study is valuable as it broadens the limited literature by focusing on the association between high UPFs consumption and the outcome of dental health in adults. Although the exact timing and causes of tooth loss were not captured, the findings provide important insights and generate hypotheses regarding the potential associations of UPFs as a lifelong risk factor for poor dental health. Some other limitations of this study include the use of FFQ for diet evaluation, which is subjected to memory bias and potential food misclassification, which could affect the precision of UPF categorization according to the NOVA system. However, the FFQ used in our study has been previously validated for the Iranian population, which helps to minimize such bias. Additionally, the study focused on adults aged 35–75 in south of Iran, consequently the results might not be generalizable to entire populations with different age groups. To the best of our knowledge, no similar study has been conducted in Iran. Our findings help to address this important research gap. The use of NOVA classification system to determine food-processing level and focusing on SEM analysis to evaluate structural relationship are key strengths of the study. Moreover, our study with large-scale data collection design provided comprehensive adjustment of several major confounders. Importantly, dental examination was performed by a trained examiner to diagnose dental caries. Further research with more diverse populations and longitudinal designs is needed to strengthen and expand upon our findings.

Conclusion

In conclusion, this study highlights a significant association between more UPFs consumption and adverse dental health outcomes among Iranian adults. Indicating positive relationships between higher consumption of UPFs with fewer teeth, more missing teeth, that partially are mediated by gender and age. Longitudinal studies are needed to better understand these associations and to establish potential causal relationships between UPFs consumption and dental health outcomes. Given the findings, implementation of healthy dietary patterns could be an effective strategy to improve oral health outcomes and quality of life.

Data availability

The datasets used and analyzed in this study can be obtained from the corresponding author upon reasonable request.

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Author contributions
FGh and SSh contributed to the concept and design and wrote the manuscript. AL contributed to data analysis, statistical analysis and manuscript preparation. MS and FD contributed to the manuscript preparation, manuscript editing, and manuscript review. FGh and AL assumed equal responsibility for the integrity and accuracy of the work. All authors reviewed and approved the final version of manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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