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Dental caries and body mass index in adult and elderly lithuanians: a cross-sectional study exploring sex-specific patterns

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Abstract

Background WHO calls to end the global oral health crisis, as oral diseases impact more people than all other noncommunicable diseases (NCDs) combined. Obesity, a global epidemic, is the fifth leading cause of death worldwide. Both caries and obesity substantially contribute to the global NCDs burden and share common risk factors including commercial determinants of health. However, the relationship between caries and obesity has been inconsistently reported and it has been suggested that sex may play a role. Therefore, the aim of this study was to investigate the sex-specific association between body mass index (BMI) and dental caries in a national sample of Lithuanian adults and early elderly, adjusting for common risk factors.

Methods The study was based on data from the Lithuanian National Oral Health Survey (2017–2019), comprising a stratified random sample of 1405 adults aged 34–78 from major cities and suburban/rural areas. Information on sociodemographic factors, health-related behaviors, height, and weight was collected using the WHO Oral Health Questionnaire, BMI index was calculated and categorized per WHO criteria. Caries experience was assessed at a surface level and recorded as intact, decayed, missing, or filled surfaces. The count of decayed-, missing-, and filled surfaces (D_3MFS), and counts of individual components, namely, the total numbers of decayed surfaces (D_3S), filled surfaces (FS) and missing teeth (MT) were also recorded. Negative binomial regression analyses were conducted. Ratios of means (RMs) with 95% confidence intervals (CI) for the associations were estimated, accounting for the natural logarithm of age and common risk factors.

Results The study included 886 (67%) females, mean age 55.2 (SD 11.7) years and 441 (33%) males, mean age 54.0 (SD 12.1) years. Males with obesity had an average of 37% more missing teeth (adjusted RM 1.37; 95% CI 1.01, 1.85), and males with overweight had an average of 41% fewer D_3S than normal-weight males (adjusted RM 0.59; 95% CI 0.39, 0.86). Overweight females had an average of 33% and obese 74% more missing teeth than normal-weight females (adjusted RM 1.33; 95% CI 1.10, 1.61 and adjusted RM 1.74; 95% CI 1.43, 2.15, respectively). Moreover, obese females had an average D_3MFS that was 14% higher than normal-weight females (adjusted RM 1.14; 95% CI 1.05, 1.24). The crude inverse associations between obesity and FS in females disappeared after the adjustment for common risk factors.

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Conclusion Sex-specific associations between caries and overweight/obesity were observed. The associations were stronger and more pronounced in females, with a notable BMI-related gradient in tooth loss. Some sex-specific associations diminished after adjusting for the common risk factors, partly supporting the common risk factor approach. Our findings may inform gender- and sex-responsive public health strategies simultaneously targeting overweight/obesity and caries. Future studies should confirm our findings, including a more comprehensive set of common risk factors and performing sufficiently powered age-stratified sex-specific analyses.

Keywords Dental caries experience, Obesity, Overweight, Tooth loss, Association, Common risk factors, Noncommunicable diseases

Background

The World Health Organization (WHO) calls to end the global crisis of oral health: 3.5 billion people suffer from oral diseases, and these impact more people than all other noncommunicable diseases (NCDs) combined [1]. Caries is the most prevalent oral disease, which is also considered the most prevalent NCD globally [2, 3]. Obesity is considered a global epidemic with steadily increasing prevalence worldwide and globally is the fifth leading risk factor for deaths. Obesity is associated with various health conditions such as diabetes and cardiovascular diseases [4]. Despite being largely preventable, dental caries and obesity are linked to social inequalities and pose a major public health challenge, substantially contributing to the global burden of NCDs. Importantly, the direct and indirect costs of dental caries and obesity impose a substantial economic burden on both individuals and societies [5–7]. Oral diseases, like other NCDs, arise from common risk factors such as lifestyle and diet. These risk factors, along with the commercial influences driving unhealthy behaviors, e.g., marketing of sugary products, are ultimately shaped by broader social determinants. Social factors—like income, education, and access to care—create the environment in which commercial and individual lifestyle factors operate, underscoring the interconnected nature of these determinants in driving oral and other NCDs outcomes [8]. Therefore, the integration of oral diseases into general NCDs prevention and health promotion frameworks might contribute to their reduction.

Although dental caries and obesity share common risk factors, evidence regarding their association across the life course is inconsistent [9]. In adults, the literature regarding the association between obesity and caries is scarce and inconclusive. One systematic review included only studies from the Kingdom of Saudi Arabia and found two studies reporting positive and two studies finding only a non-significant association between caries and obesity; these studies were evaluated as having from low to moderate risk of bias [10]. Several single studies also reported inconsistent relationships between overweight/obesity and caries. A positive association was found in Moroccan, Saudi, and South Korean adult studies when adjusting for several sociodemographic and behavioral determinants. However, in Australian adults, after adjusting for social and dietary factors, an association between caries and obesity was not confirmed. Another South Korean study demonstrated an inverse association, however, this association was not adjusted for diet, one of the main common risk factors for both caries and obesity [11–15]. It has been suggested that this inconsistency may be due to varying socio-cultural contexts across different populations, biological variation including genetics, lifestyle and diet behaviors, and, to some extent, differences in methodological approaches [16]. Additionally, only a few European studies are available with a focus on young adults or females. A Swedish study showed that caries experience was higher in overweight/obese 20-year-olds compared to normal-weight peers [17] and a Finnish study found that normal-weight conscripts had lower rates of untreated caries and caries experience [18]. Another Swedish female study demonstrated an adjusted association between the lower number of teeth (< 20) and higher body mass index (BMI) [19].

Sex has been suggested as a modifier of health and disease through two primary pathways: (i) biological mechanism such as genetics, epigenetics and hormones affecting physiology, diseases susceptibility and manifestation, and (ii) socio-behavioral mechanism in which constructs of gender influence behaviors of individuals and communities [20]. Even though sex-stratified data in literature is scarce, globally, sex-differences in health-related behaviors and disease prevalence have been demonstrated. For example, males had higher prevalence of smoking, lower rates of health care utilization, and higher prevalence of hypertension and diabetes while females had higher prevalence of obesity [21]. In Norway, links between caries and obesity exhibited sex-specific patterns, predominantly social factors manifesting among adolescent males [22]. Sex-disaggregated data may help to identify sex-specific patterns of health outcomes and health inequalities informing gender- and sex-responsive public health interventions [23]. To the best of our knowledge, evidence of sex-specific associations between dental caries and overweight/obesity in adults is limited.

Dental caries is highly prevalent in Lithuania and Lithuania has been ranked as the 3rd European country having the highest prevalence of overweight with notable social inequalities and sex-differences observed in distribution of these conditions [24–26]. Although integrating oral diseases into national NCD prevention and health promotion frameworks in Lithuania may help reduce their prevalence, there is a lack of evidence supporting an association between the two conditions.

Therefore, the aim of this study was to investigate the sex-specific association between BMI and dental caries in a national sample of Lithuanian adults and early elderly, adjusting for common risk factors.

Methods

Study design and participants

This study is based on the cross-sectional Lithuanian National Oral Health Survey (LNOHS) conducted from 2017 to 2019. LNOHS included a random sample of 1405 34-78-year-old adults from 5 biggest Lithuanian cities and 10 randomly selected suburban/rural areas, one from each of 10 Lithuanian counties (response rate 53%) [27, 28]. This data formed the basis for the study's secondary analysis.

Questionnaire

The self-administered World Health Organization (WHO) Oral Health Questionnaire for Adults, supplemented with additional questions (addQ), was used to collect information on sociodemographic characteristics (age in years and sex), common social risk factors (years of education, and urban or suburban/rural residence), and health-related behaviors, including diet (sugar-containing diet, refined carbohydrates and starch-containing diet [addQ]), oral hygiene practices (tooth brushing frequency), and self-reported height and weight (addQ) [29]. The questionnaire was translated into Lithuanian language and back to English by two independent persons, and minor inconsistencies were subsequently corrected. The questionnaire was pilot-tested in 10 adults who were not part of the main study, subsequently, the questionnaire was slightly revised, where needed. For the diet assessments, the participants were asked to indicate the frequency of consuming 10 different groups of foods and drinks (jam/honey, sugar-sweetened chewing gum, candies, sugar-sweetened beverages, tea with sugar and coffee with sugar, cookies, cakes, pasta/rice and potatoes). The response options to choose from were as follows: 1 indicated 'rarely/never', 2 'several times a month', 3 'once a week', 4 'several times a week', 5 'every day', and 6 'several times a day'. Sugar-containing diet consumption frequency score was composed of summed first six items. Refined carbohydrates and starch-containing diet consumption frequency score included four items (cookies, cakes, pasta/rice and potatoes) and was calculated in the same way. The higher score indicated a higher consumption frequency of those foods and drinks. Oral hygiene was assessed by tooth brushing frequency 'twice a day or more' and 'once a day or less'.

Body mass index (BMI) was calculated using the formula BMI = body weight (kg)/height (m^2). BMI was categorized into four groups based on the WHO criteria: underweight (< 18.5 kg/m2), normal weight (18.5–24.9 kg/m2), overweight (25.0–29.9 kg/m2) and obesity (≥ 30.0 kg/m2) [30].

Dental caries

Dental clinical examination was performed according to the recommendations of WHO Oral Health Survey Basic Methods, using a Community Periodontal Index (CPI) periodontal probe, and an oral mirror [29]. Clinically visible dental caries was registered at a dentine level following the WHO criteria [29]. The status of tooth surfaces was recorded either as intact, decayed, missing or filled and third molars were excluded from this registration. The count of decayed-, missing-, and filled surfaces (D_3MFS), and counts of individual components, namely, the total numbers of decayed surfaces (D_3S), filled surfaces (FS) and missing teeth (MT) were also recorded. One trained and calibrated examiner (IS) performed all dental examinations. The intra-examiner agreement was based on duplicate recordings in a sample of 10 randomly selected individuals and the corresponding values were 100% for D_3S, 99% for MT and 100% for FS.

Statistics

The SPSS version 25 (IBM, Armonk, NY, USA) was used for statistical analyses. The level of significance was set at $p < 0.05$. Mean and standard deviation (SD) were calculated for continuous variables and frequencies for categorical variables. Likelihood ratio test for categorical and one-way ANOVA with LSD post-hoc test for continuous variables were used to compare participants from different BMI categories in Table 1. One-way ANOVA with LSD post-hoc test compared mean differences of D_3MFS, D_3S, FS and MT values between four BMI categories (refer to Figs. 1 and 2.). To examine sex-specific association between the independent variable BMI and dependent variable caries (D_3MFS, D_3S, FS and MT), due to overdispersion, negative binomial regression analyses stratified by sex were used. The natural logarithm (LN) of age was used as an offset variable to account for different observation periods, ensuring age-adjusted comparisons. Due to the low number, participants in the underweight group were excluded from the univariable and multivariable analyses. In addition, participants with missing data were excluded from the multivariable analyses. Crude ratio of means (crude RM) and adjusted RM (adRM) with their 95% confidence intervals (CI) were calculated [31]. To obtain adRM, the association between the D_3MFS

Table 1 Distribution of common risk factors for dental caries and overweight/obesity stratified by the body mass index categories among the study participants ($n = 1327$)

Characteristics	Males				Females			
BMI	Under weight $n = 2$	Normal weight $n = 133$	Over weight $n = 189$	Obese $n = 117$	Under-weight $n = 12$	Normal weight$n = 341$	Over-weight$n = 288$	Obese $n = 245$
n (%)	*2 (100)*	*133 (100)*	*189 (100)*	*117 (100)*	*12 (100)*	*341 (100)*	*288 (100)*	*245 (100)*
Age, years *(mean (SD))*	66.5 (2.12)	52.8 (12.3)^{a}	53.3 (11.8)^{b}	56.3 (12.0)^{ab}	43.8 (11.5)^{abcd}	50.8 (11.7)^{abcd}	57.0 (10.6)^{abcd}	59.6 (10.3)^{abcd}
n (%)	*2 (100)*	*133 (100)*	*189 (100)*	*117 (100)*	*12 (100)*	*341 (100)*	*288 (100)*	*245 (100)*
Education, years *(mean (SD))*	15.5 (0.7)	14.6 (3.3)	15.0 (3.3)	14.0 (3.3)	18.3 (2.2)^{abcd}	15.7 (3.1)^{abcd}	14.6 (3.2)^{abc}	14.2 (3.0)^{abd}
Residence *n (%)*	*2 (100)*	*133 (100)*	*189 (100)*	*117 (100)*	*12 (100)*	*341 (100)*	*288 (100)*	*244 (99)*
Urban	2 (100)	108 (81)	151 (80)3	87 (74)	12 (100)*	249 (73)*	192 (67)*	154 (63)*
Suburban/rural	0 (0)	25 (19)	38 (20)	30 (26)	0 (0)	92 (27)	96 (33)	90 (37)
n (%)	*1 (50)*	*101(76)*	*146 (77)*	*80 (68)*	*11(92)*	*272 (80)*	*205 (71)*	*169 (69)*
Sugar-containing diet score *(mean (SD))*	10 (10)	16.5 (5.8)^{ab}	15.0 (5.0)^{a}	15.0 (5.2)^{b}	15.4 (6.6)	14.2 (4.9)^{ab}	13.1 (4.9)^{a}	13.0 (4.4)^{b}
n (%)	*0 (0)*	*107(80)*	*153 (81)*	*96 (82)*	*12 (100)*	*277 (81)*	*220*	*187*
RCS-containing diet score *(mean (SD))*	-	13.7 (3.2)^{a}	13.0 (3.3)	12.6 (3.1)^{a}	14.7 (2.7)^{ab}	12.9 (3.3)^{c}	12.4 (3.5)^{a}	12.1 (3.2)^{bc}
n (%)	*2 (100)*	*133 (100)*	*187(99)*	*117(100)*	*12 (100)*	*339 (99)*	*287(99)*	*244 (99)*
Brushing frequency *n (%)*								
≥Twice a day	1 (50)	49 (37)	68 (36)	27 (23)	8 (67)*	224 (66)*	161 (56)*	120 (49)*
≤Once a day	1 (50)	84 (63)	119 (64)	90 (77)	4 (33)	115 (34)	126 (44)	124 (51)

BMI body mass index, *RCS* refined carbohydrates and starch-containing diet, *SD* standard deviation.

n (%) indicates the number of participants who had recorded value for this variable. Mean (SD) are presented for continuous and frequencies for categorical variables.

P-values < 0.05 from likelihood ratio tests comparing categorical variables across BMI categories within each sex are marked with an asterisk (*).

P-values < 0.05 from one-way ANOVA with LSD post-hoc tests for continuous variables are indicated by letters; BMI categories within each sex sharing the same letter differ significantly

index, its components and BMI categories was adjusted for covariates, i.e., pre-selected common risk factors, namely, education, residence, sugar-containing diet score, refined carbohydrates and starch-containing diet score, and tooth brushing frequency. McFadden's R^2, which is a pseudo R^2, was calculated for multivariable models. The analytical strategy and the assumed relationship between variables used in the analyses are presented by a directed acyclic graph (DAG) (Supplementary Fig. 1). DAG was included to guide the selection of covariates for adjustment in the analysis: BMI (independent variable) and caries (outcome) with adjusted common risk factors as confounders (in white) and unadjusted other variables (in grey). Statistical interactions between outcomes and age were examined, and the subgroup analyses were stratified by age (WHO suggested cut-off point of 65 years) since there are indications that age may modify the associations [10–15].

Results

Participant characteristics

The study sample consisted of 886 (67%) females, mean age 55.2 (SD 11.7) years, and 441 (33%) males, mean age 54.0 (SD 12.1) years, who had complete registrations of study outcomes (caries experience), height and weight. Obese males were older than normal-weight or overweight participants, they had lower sugar-containing diet, and refined carbohydrates and starch-containing diet scores (Table 1). In females, there was observed older age of participants, less years of education, lower rates of urban residence and lower rates of brushing twice a day with higher BMI category. In addition, sugar-containing diet, and refined carbohydrates and starch-containing diet scores seemed to decrease with higher BMI category (Table 1).

In males, the mean D_3MFS was 70.6 (SD 38.9), mean D_3S – 4.6 (SD 8.9), mean FS – 23.4 (SD 18.8) and mean MT – 6.5 (SD 7.2), and in females the corresponding values were 80.7 (SD 35.5), 2.3 (4.7), 34.4 (20.3) and 6.3 (6.9). Among participants, there were 12 (3%) males and 20 (2%) females who were edentulous. The distribution of D_3MFS index and its components by BMI categories are presented in Figs. 1 and 2.

Sex-specific association between caries and body mass index

In males, after the adjustment for common risk factors, the inverse association between overweight and D_3S

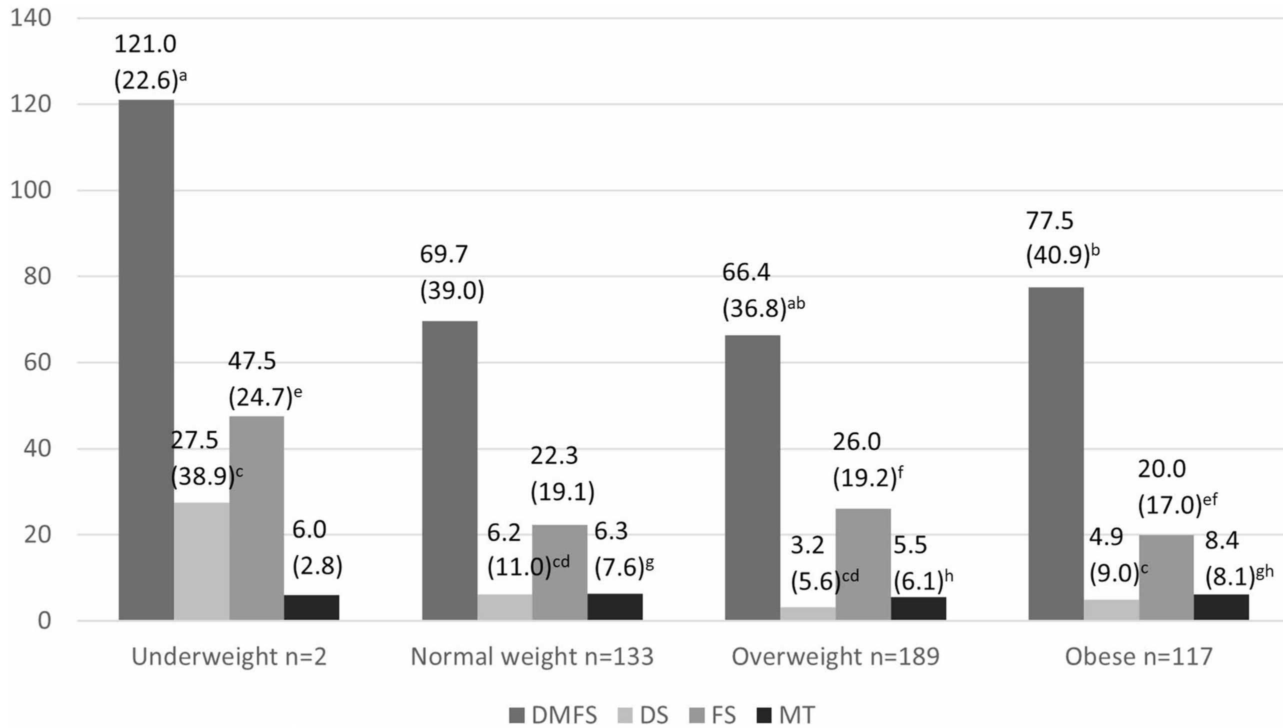

Fig. 1 Caries experience by body mass index (BMI) groups among male participants ($n = 441$). Mean values with standard deviations (SD) are shown separately for each component of caries experience: decayed surfaces (D_3S), filled surfaces (FS), missing teeth (MT), and total caries experience (D_3MFS). Within each caries experience component, BMI groups sharing the same letter differ statistically significantly ($p < 0.05$) according to one-way ANOVA with LSD post-hoc tests. For example, the D_3MFS score differed statistically significantly between underweight and overweight males (indicated by the letter '**a**') and between overweight and obese males (indicated by the letter '**b**')

(adjusted RM (adRM) 0.59; 95% CI 0.39, 0.86), and the positive association between obesity and MT remained significant (adRM 1.37; 95% CI 1.01, 1.85) (Table 2). This indicates that male participants with overweight had an average of 41% fewer D_3S, and those with obesity 37% more MT compared to participants with normal weight. In females, the associations between overweight, obesity and MT (adRM 1.33; 95% CI 1.10, 1.61 and adRM 1.74; 95% CI 1.43, 2.15, respectively) were significant and suggested a MT gradient across overweight and obesity groups. The positive association between obesity and D_3MFS was also observed (adRM 1.14; 95% CI 1.05, 1.24), indicating that female participants with obesity had a mean decayed, missing or filled surfaces that was 14% higher compared to those with normal weight. The crude significant inverse association between obesity and FS disappeared after the adjustment for common risk factors (Table 3). Age seemed to modify the associations (interaction terms $p < 0.05$). Age-stratified adjusted subgroup analyses indicated significant inverse association between overweight, obesity and D_3S (adRM 0.53, 95% CI 0.35, 0.81 and adRM 0.57 (0.35, 0.93, respectively) only in males < 65 years age (Supplementary Table 1). In females, significant associations were observed between obesity and D_3MFS (adRM 1.14; 95% CI 1.03, 1.26) and between overweight, obesity and MT (adRM 1.31; 95% CI 1.05, 1.64 and adRM 1.81; 95% CI 1.43, 2.30, respectively) also only in age group < 65 years (Supplementary Table 2).

Discussion

The main finding of the current cross-sectional study was the sex-specific associations between overweight/obesity and dental caries; in females the observed associations were between caries experience, tooth loss and overweight/obesity, while in males untreated caries was inversely associated with overweight and tooth loss was associated with obesity. In addition to a stronger and more pronounced association between tooth loss and BMI in females than males, we observed missing teeth gradient in overweight and obese female participants. The other finding was that some sex-specific crude associations between caries and BMI diminished after adjusting for common risk factors, therefore our results partly support common risk factor approach.

Acknowledging the complexity of the relationship between caries and BMI, we adopted a common risk factors approach, encompassing not only health-related behaviors common to both conditions but also a broader spectrum of social risk factors. Even after the adjustment for common risk factors, a significant association between tooth loss and BMI persisted. This finding was

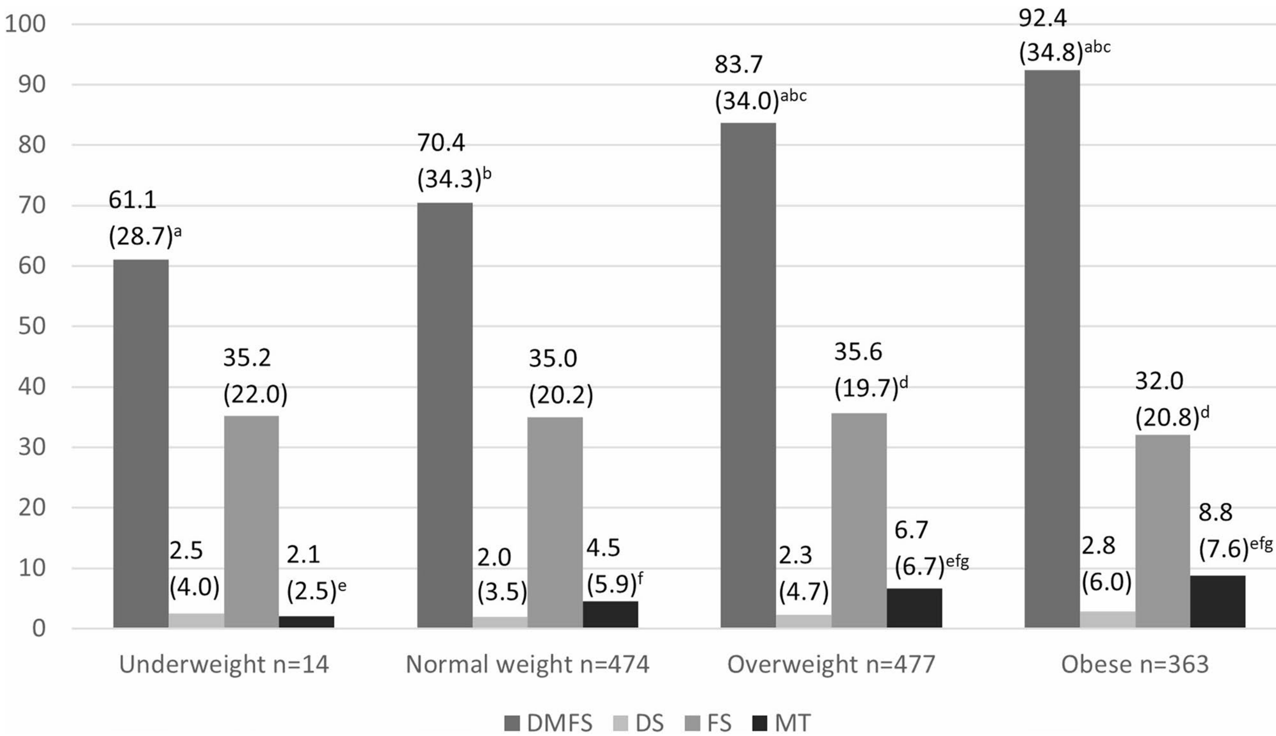

Fig. 2 Caries experience by body mass index (BMI) groups among female participants ($n = 886$). Mean values with standard deviations (SD) are shown separately for each component of caries experience: decayed surfaces (D_3S), filled surfaces (FS), missing teeth (MT), and total caries experience (D_3MFS). Within each caries experience component, BMI groups sharing the same letter differ statistically significantly ($p < 0.05$) according to one-way ANOVA with LSD post-hoc tests. For example, the D_3MFS score differed statistically significantly between underweight, overweight and obese females (indicated by the letter **a**), between normal-weight, overweight and obese females (indicated by the letter **b**), and between overweight and obese females (indicated by the letter **c**)

common for both sexes and was in line with the systematic review, including only cross-sectional studies, which demonstrated bi-directional association between tooth loss and obesity [32]. One possible explanation for this finding may be that individuals with tooth loss, which leads to reduced masticatory function, change their diet; it has been previously demonstrated that tooth loss was associated with lower diet quality, i.e., increased carbohydrate consumption and reduced intake of other nutrients [33]. Possibly, diet choices including soft processed food, rich in saturated fats may lead to overweight and obesity. On the other hand, a systematic review of longitudinal studies suggested that there was no strong evidence that tooth loss influenced changes in diet and nutrition [34]. Dietary preferences particularly for sugar- and/or starch-containing foods may contribute to the concomitant development of dental caries and overweight or obesity as unhealthy diet is a recognized common risk factor [35, 36]. Our results are in contrast to recent studies from Australia and Brazil which found that the association between tooth loss and obesity was no longer significant after adjusting for confounders, with sugar consumption also identified as a key factor [14, 37]. These inconsistencies may be related to differences in methodology or socio-cultural contexts.

This study found an independent association between caries and obesity even after the adjustment for our selected shared risk factors. Although we accounted for key health-related behaviors such as diet and oral hygiene, as well as social determinants like education and place of residence in the analyses, it is important to acknowledge the potential influence of additional unmeasured common risk factors, including social, psychosocial, environmental factors and biological predisposition [38, 39] that may confound the observed associations. For example, income as a proxy for socioeconomic position was not included in the present study. Future research examining the relationship between dental caries and obesity should incorporate a comprehensive set of potential confounding variables to ensure more accurate and reliable findings. Regarding genetics, it has been shown that salivary protein salivary α-amylase coding gene, amylase alpha 1, copy number, was associated with dental caries and obesity [40, 41]. Future studies could also test genetical biomarkers as potential common risk factors.

In our study, the association between tooth loss and general obesity was stronger in females with a gradient of increasing tooth loss observed across those with overweight and obesity. The association between tooth loss and obesity may be influenced by the choice of adiposity

Table 2 Ratios of means (RM) and their 95% confidence intervals (CI) for the association in males ($n = 304$) between decayed-, missing- and filled-surfaces index, its components and body mass index categories according to univariable (crude RM) and multivariable (adjusted RM) negative binomial regression analyses with the natural logarithm (LN) of age as an offset variable to account for different observation times. Statistically significant associations ($p < 0.05$) are marked in bold

Outcomes	Crude RM (95% CI)	Adjusted RM (95% CI)	Crude RM (95% CI)	Adjusted RM (95% CI)	Crude RM (95% CI)	Adjusted RM (95% CI)	Crude RM (95% CI)	Adjusted RM (95% CI)
	Decayed$_3$MissingFilled Surfaces		**Decayed$_3$ Surfaces**		**Filled surfaces**		**Missing teeth**	
Body Mass Index								
-Normal weight (reference category)								
-Overweight	0.95 (0.85, 1.06)	0.98 (0.86, 1.13)	0.51 (0.35, 0.74)	0.59 (0.39, 0.86)	1.11 (0.90, 1.37)	1.09 (0.86, 1.39)	0.89 (0.71, 1.12)	1.08 (0.80, 1.46)
-Obese	1.04 (0.92, 1.18)	1.06 (0.91, 1.24)	0.72 (0.48, 1.09)	0.69 (0.43, 1.10)	0.81 (0.64, 1.02)	0.93 (0.70, 1.24)	1.32 (1.03, 1.70)	1.37 (1.01, 1.85)
Education	0.97 (0.96,0.99)	0.98 (0.95,0.99)	0.91 (0.87,0.95)	0.93 (0.88,0.98)	1.05 (1.02,1.08)	1.05 (1.01,1.08)	0.91 (0.88,0.93)	0.91 (0.87,0.94)
Residence								
-Suburban/rural (reference category)								
-Urban	0.96 (0.85,1.08)	0.95 (0.82,1.11)	1.23 (0.83,1.81)	1.56 (1.01,2.53)	1.32 (1.06,1.64)	1.36 (1.04,1.78)	0.71 (0.56,0.90)	0.63 (0.48,0.84)
Sugar-containing diet score	1.01 (1.01,1.02)	1.01 (0.99,1.02)	1.02 (0.99,1.05)	1.03 (0.99,1.07)	1.01 (0.99,1.03)	1.01 (0.99,1.04)	1.02 (0.99,1.04)	0.99 (0.98,1.02)
RCS -containing diet score	1.02 (1.01,1.04)	1.02 (0.99,1.04)	1.0 (0.95,1.05)	0.94 (0.87,1.01)	1.01 (0.98,1.05)	1.01 (0.97,1.04)	1.03 (0.99,1.07)	1.04 (1.00,1.09)
Brushing frequency								
-≥Twice a day (reference category)								
-≤Once a day	1.12 (1.01,1.24)	1.06 (0.92,1.21)	2.23 (1.60,3.11)	2.05 (1.37,3.09)	0.80 (0.66,0.96)	0.92 (0.72,1.16)	1.47 (1.20,1.81)	1.18 (0.91,1.53)
McFadden's R^2		0.322		0.315		0.320		0.365

RCS refined carbohydrates and starch

Table 3 Ratios of means (RM) and their 95% confidence intervals (CI) for the association in females (*n* = 595) between decayed-, missing- and filled-surfaces index, its components and body mass index categories according to univariable (crude RM) and multivariable (adjusted RM) negative binomial regression analyses with the natural logarithm (LN) of age as an offset variable to account for different observation times. Statistically significant associations ($p < 0.05$) are marked in bold

Outcomes	Crude RM 95% CI	Adjusted RM 95% CI	Crude RM 95% CI	Adjusted RM 95% CI	Crude RM 95% CI	Adjusted RM 95% CI	Crude RM 95% CI	Adjusted RM 95% CI
	Decayed$_3$MissingFilled Surfaces	**Decayed$_3$ Surfaces**	**Filled surfaces**	**Missing teeth**				
Body Mass Index								
-Normal weight (reference category)								
-Overweight	1.06 (0.99, 1.13)	1.04 (0.96, 1.13)	1.06 (0.81, 1.40)	1.20 (0.86, 1.66)	0.89 (0.80, 1.01)	0.96 (0.84, 1.11)	1.38 (1.19, 1.62)	1.33 (1.10, 1.61)
-Obese	1.12 (1.05, 1.20)	1.14 (1.05, 1.24)	1.22 (0.92, 1.62)	1.03 (0.73, 1.47)	0.77 (0.68, 0.87)	0.87 (0.74, 1.01)	1.78 (1.51, 2.08)	1.74 (1.43, 2.15)
Education	0.99 (0.98, 0.99)	0.99 (0.98, 1.01)	0.94 (0.90,0.98)	0.97 (0.93,1.02)	1.05 (1.03,1.06)	1.04 (1.02,1.06)	0.91 (0.89,0.93)	0.92 (0.89,0.95)
Residence								
-Suburban/rural (reference category)								
-Urban	0.96 (0.89, 0.99)	0.96 (0.89, 1.03)	0.77 (0.60, 0.99)	0.82 (0.60, 1.12)1	1.13 (1.02, 1.26)	1.08 (0.95, 1.24)	0.76 (0.66, 0.88)	0.80 (0.67, 0.96)
Sugar-containing diet score	1.01 (0.99, 1.01)	1.01 (1.00, 1.02)	1.02 (0.99, 1.04)	1.01 (0.98, 1.04)	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	1.01 (0.99, 1.03)
RCS-containing diet score	1.00 (0.99, 1.01)	0.99 (0.98, 1.01)	1.02 (0.98, 1.05)	1.03 (0.98, 1.08)	1.01 (0.99, 1.03)	1.01 (0.99, 1.03)	0.98 (0.96, 1.01)	0.98 (0.95, 1.01)
Brushing frequency								
-≥Twice a day (reference category)								
-≤Once a day	1.08 (1.02, 1.14)	1.05 (0.98, 1.13)	1.63 (1.29, 2.06)	1.29 (0.96, 1.73)	0.87 (0.79, 0.96)	0.94 (0.83, 1.07)	1.35 (1.18, 1.54)	1.20 (1.02, 1.42)
McFadden's R^2		0.339		0.363		0.334		0.387

RCS refined carbohydrates and starch

measure, with studies showing that central obesity (measured by waist-hip ratio) is more strongly associated with tooth loss in females, while general obesity (measured by BMI) shows a stronger association in males – patterns that may reflect sex-specific impact of adiposity on inflammatory responses such as periodontal disease and consequently tooth loss [37, 42]. In our study the specific cause of tooth loss could not be confirmed, and it could be that teeth were missing also due to periodontal diseases. In the present study we used BMI, which is known to have limitations to indicate sex-related adiposity differences [43], therefore, future research should incorporate both general and central adiposity measures to more accurately assess their respective sex-specific associations with dental caries. Our result of more pronounced association between tooth loss and BMI in females is in line with another longitudinal Brazilian study that found general obesity was linked to tooth loss, but only in females [44]. The relationship between tooth loss, obesity and sex is complex and may be influenced by both biological and socio-behavioral factors associated with being female, many of which are recognized risk factors for tooth loss and obesity [45].

In the present study, caries experience was associated with obesity only in females. This finding may be explained by the higher caries experience rates observed in females than males in our population, and the difference was primarily attributed to a greater number of missing teeth [24].

Our study showed that males with overweight, on average, had fewer teeth with untreated caries compared to normal-weight male participants. In general, it has been suggested that males tend to ignore their oral health, have worse oral health-related behaviors and less frequent dental visits [46] which may result in higher rates of untreated caries compared to females also observed in our study. Our finding of the inverse association between overweight and untreated caries in males most likely could be linked to socio-behavioral mechanism. Previous research in Lithuania has shown that higher socioeconomic position is associated with increased BMI in males [25]. In our study, overweight male participants had fewer untreated surfaces. This may indicate that males with higher socioeconomic position are more likely to be overweight and also more likely to have better health-related behaviors, resulting in less untreated caries.

We observed inverse crude association between dental restorations and obesity in females. The initially significant crude association was no longer present after adjusting for common risk factors suggesting that it was attributed to these social and health-related behavioral confounders. Common social risk factors and health-related behaviors seem to be the primary contributors to both conditions. This finding supports the common risk factor approach, emphasizing the need to address dental caries and overweight/obesity as interrelated conditions influenced by shared determinants. Caries prevention should be integrated into systemic non-communicable disease management strategies to enhance the effectiveness of public health strategies and alleviate the overall burden of non-communicable diseases [47]. Implementation of common strategies should address also commercial determinants of health and span from individual to global levels, including individual (such as modifying health-related behaviors, e.g., counseling on reducing the frequency of free sugars and education campaigns), societal (e.g., reducing accessibility and creating safe environments, such as workplaces/schools not serving foods/drinks containing added sugar), national (e.g., implementing health policies, such as sugar taxation, front-of-package labeling, regulating marketing and advertising), and global (e.g., supporting research for non-communicable disease prevention strategies) interventions, with a specific emphasis on reducing health inequalities [48]. For example, following the implementation of alcohol taxation in Lithuania, educational inequalities in all-cause mortality decreased by 18% among males and 14% among females [49]. Although modest, this intervention demonstrated sex-differences in responsiveness. To effectively reduce sex-specific health inequities in obesity and dental caries, and maximize the impact of interventions simultaneously targeting both conditions, it is important to identify sex-specific association between overweight/obesity and different dimension of caries disease. This knowledge can inform gender- and sex-responsive public health strategies.

The present study revealed the modifying effect of age on associations between BMI and caries. The results from the sub-group analyses showed significant associations between caries and BMI only in the age group < 65 years. This could be explained by cumulative exposure to risk factors, or differences in health behaviors over time, such as fluoride exposure history. Caries experience index becomes saturated with increasing age due to its cumulative nature, making it less sensitive. Another explanation could be the smaller sample size in the older age group, which may have resulted in an underpowered analysis. Our findings are in line with the Swedish study reporting the association between tooth loss and obesity also only in younger age group (< 60 years) [50]. This result was explained by potentially reduced masticatory function in elderly and related weight loss attenuating the association. A UK study in participants ≥ 65 years demonstrated an association between lower number of teeth and obesity, while edentulous participants were more likely to be underweight [51]. In our study, edentulous participants were also included, but none of them were in the underweight group (*data not shown*). Future studies exploring age-specific associations should also include age-stratified analyses and ensure sufficiently powered sample sizes.

This study analyzed a national sample of Lithuanian adults aged between 34 and 78 years, of whom almost two-thirds were either overweight or obese and exhibited high rates of dental caries experience. The present study had a cross-sectional design with its inherent limitations. Information on common risk factors and BMI was self-reported. Dietary information was collected using the WHO questionnaire, supplemented with additional questions on refined carbohydrates and starch-containing foods. Dietary intake was not assessed using food record forms, which are considered to be a more valid method for collecting dietary information. Therefore, the possibility for recall bias, misclassification of dietary intake, and underestimation of prevalence of overweight/obesity cannot be ruled out. Summing ordinal variables depicting diet frequency to create a continuous composite score was chosen for simplicity reasons implicitly assuming equal weighting and spacing between ordinal levels. Education and residence represented broader social common risk factors, however, data about income were not available. Edentulous participants were included in this study. This may have inflated the MT component and, consequently, the overall D_3MFS score, while reducing the relative share of the FS and D_3S components. Because missing data were not imputed, cases with missing values were excluded from the multivariable analyses. This may have resulted in the sub-group analyses being underpowered, therefore these results should be interpreted with caution. The response rate of 53% and slight over-representation of females in the study sample may limit the generalizability of our study results to the broader Lithuanian population. However, low response rates do not necessarily introduce substantial bias in estimates of associations. The exclusion of underweight participants from the analysis due to their small sample size may limit the generalizability of the findings to the entire BMI spectrum, therefore future studies should include larger numbers of underweight participants.

Conclusions

In this cross-sectional study, sex-specific associations between caries and overweight/obesity were observed. The associations were stronger and more pronounced in females, with a notable BMI-related gradient in tooth loss. Some sex-specific associations diminished after adjusting for the common risk factors, partly supporting the common risk factor approach. Our findings may inform gender- and sex-responsive public health strategies simultaneously targeting overweight/obesity and caries to reduce their overall burden in Lithuania. Future studies should confirm our findings, including a more comprehensive set of common risk factors and performing sufficiently powered age-stratified sex-specific analyses.

Supplementary Fig. 1. The analytical strategy and the relationship between variables used in the analyses presented by a directed acyclic graph. BMI (independent variable) and caries (outcome) with adjusted common risk factors as confounders (in white) and unadjusted other variables (in grey).

Abbreviations

CI	Confidence interval
D_3S	Decayed surfaces
D_3MFS	Decayed, missing and filled surfaces
FS	Filled surfaces
MT	Missing teeth
NCDs	Noncommunicable diseases
RM	Ratio of means
WHO	The World Health Organization

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

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Clinical trial number

Not applicable.

Authors' contributions

LS-M, IS, JA, VB, AP and RS-R made substantial contributions to the conception of the current work. LS-M, RS-R, IS and AP contributed to the design of the study. IS collected the data. LS-M performed statistical analyses and together with RS-R and AP interpreted them. LS-M and RS-R drafted the manuscript, and all co-authors substantially revised the manuscript.

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Data availability

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request. Data are located in controlled access data storage at Vilnius University, Lithuania.

Declarations

Ethics approval and consent to participate

This study was performed in compliance with Good Clinical Practice and the Declaration of Helsinki. The Ethics approval was obtained from the Lithuanian Bioethical Committee (reference number 158200-17-920-426). Participation was voluntary and based on a signed written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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