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Obesity, dietary sugar and dental caries in Australian adults

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Abstract: Objectives: To determine the association of overweight/obesity, dental caries and dietary sugars in Australian adults. **Materials and methods:** The National Survey of Adult Oral Health (NSAOH) 2004–2006 provided data for analysis of dental caries experience. Self-reported body weight and height were used to calculate body mass index (BMI) for a subsample ($n = 3{,}745$, 89.8%) of the NSAOH data. A self-report questionnaire of 13 food items estimated the daily intake of added sugar, total sugars and total carbohydrate, using food composition estimates from the AUSNUT2011–2013. Bivariate analyses (Pearson's Chi-square with Rao–Scott adjustment and Student's *t*-tests) were used to determine the association of overweight/obesity, dental caries, sugar variables and putative confounders. Poisson regression models for the Decayed, Missing and Filled Teeth Index and individual measures of decayed, missing and filled teeth were constructed, with models containing BMI, dietary added sugar, total sugar and total carbohydrate, controlling for putative confounders. **Results:** There was a positive association between dental caries experience and being overweight or obese compared with having normal weight or being underweight as well as between sugar consumption with all four dental caries outcome measures. When controlled for putative confounders where sugar consumption was identified as a key determinant, the statistical significance between dental caries experience and being overweight or obese disappeared. The demographic and socioeconomic factors associated with dental caries experience were age, sex, education, smoking status and usual reason for dental visit. **Conclusion:** Analysis of the relationship between dental caries and obesity must include data about sugar and carbohydrate consumption.

Key words: *Dental caries, dietary sugars, obesity, public health, body mass index*

INTRODUCTION

Dental caries is a reversible, biological process that initiates as a localised demineralisation of hard tissues of the teeth, under an influence of acid derived from food debris or sugar[1]. It is a leading oral chronic condition[2], affecting the permanent dentition of 2.4 billion people (35.3% of the total population) worldwide[3]. The burden of dental caries is also high in Australian adults (25.5%)[4] and children (18.3%–44.0%)[5].

Obesity results from a complex interplay of diet, exercise and other systems[6], leading to an imbalance between energy intake and expenditure during an extended period[7]. An increasing proportion of Australian adults are overweight or obese (63.4%)[8], which significantly contributes to the burden of disease, and is associated with increased rates of cardiovascular diseases, type 2 diabetes, musculoskeletal disorders, cancers and oral diseases[9,10].

Obesity and dental caries are prominent public health problems in Australia, they occur in complex aetiological environments, and are associated with compromised social and physical function, and reduced quality of life[11]. Age, sex, social determinants (income and education), health-related behaviours (smoking, diet, alcohol consumption and healthcare attendance) and water fluoridation are significant moderators of both dental caries and obesity[12,13]. Dietary sugar intake is a common risk factor for dental caries and obesity[14]. A systematic review of the effect of dietary sugars on body weight found that a reduction in body weight was associated with reduced sugar intake, and prospective cohort studies in children found that individuals with increased sugar intake were likely to become overweight or obese[14].

Restricting sugar intake in adults and children also results in a reduction in dental caries experience[15].

Evidence for the association between diet, dental caries and obesity is limited. A systematic review and meta-analysis of dental caries and obesity in children and adolescents reported higher dental caries experience with increase in body weight[12]. However, there remains insufficient evidence to support this association, due to a high degree of heterogeneity between studies and the need for further investigation of the association[16,17]. Considering Australia's increasing levels of obesity and availability of national oral health survey data, opportunity exists to further investigate this interaction.

This study investigated the association of overweight/obesity, dental caries experience and diet in a nationally representative sample of Australian adults using the National Survey of Adult Oral Health (NSAOH) 2004–2006.

MATERIALS AND METHODS

The NSAOH 2004–2006 employed a three-stage, stratified, clustered sampling design to draw a representative sample of Australian population aged 15 years and older[4]. Full details of sampling, examination protocol and survey participation have been described previously[4]. The ethics approval was obtained from University of Adelaide Human Research Ethics Committee, and the study was conducted according to the World Medical Association Declaration of Helsinki (version, 2008). All examined subjects provided a signed, informed consent to participate in the study. The consent procedures were approved by the University of Adelaide Human Research Ethics Committee.

Data extracted from the NSAOH 2004–2006 included the dental caries experience data measured using the Decayed Missing Filled Teeth (DMFT) index. This is a cumulative measure comprising a count of the number of decayed (D), missing (M) and filled teeth (F) and its individual components, more details of the examination protocol have been published previously[4]. Self-reported body weight (kg) and body height (cm) were obtained using a questionnaire completed by survey participant following the oral health assessment. Categorical variables for body mass index (BMI) were created using the World Health Organisation (WHO) BMI classifications for adults[8], specifying underweight/normal BMI as < 25 kg/m^2, overweight/obese ≥ 25 kg/m^2.

The self-reported habitual dietary intake of 13 food items was recorded (Appendix A), with participants reporting the total number of servings consumed on a usual day and in the last hour before bed for each food item. In our study, a nutritionist (KK) calculated added sugar, total sugar and total carbohydrate levels for each food item using the FoodWorks version 8 dietary analysis package[18], with the Australian Food, Supplement and Nutrient Database (AUSNUT) 2011–2013 food composition database[19]. AUSNUT is a set of files that enables food, dietary supplement and nutrient intake estimates to be made from dietary data. Questionnaire and database foods were matched using the most similar generic food item. Serving sizes were generated initially by consulting the NSAOH questionnaire; where these were unclear, a serving size for the selected food or beverage was obtained through the standard portion sizes outlined in the Australian Guide to Healthy Eating (AGHE)[20]. Where foods were not available from the AGHE (e.g. discretionary foods), a value of ~600 kJ was attributed[21].

The estimated consumption of added sugar, total sugar and total carbohydrate from 13 food items for all individuals was calculated by multiplying the number of servings reported by the added sugar, total sugar and total carbohydrate values for each food item. New variables were created for these cumulative totals by calculating the sum of each variable from all 13 food items. Total values of recorded added sugar, total sugar and total carbohydrate were used in our analysis as primary exposure variables.

Variables from the NSAOH data set were selected *a priori* for analysis as potential confounders. These included: socioeconomic factors (income and education); health and lifestyle factors (diabetes and smoking status); alcohol consumption; lifetime fluoridation exposure and oral health behaviours (usual reason for dental visit, time since last visit, mouth rinsing, tooth brushing and flossing). Variables associated with both dental caries and obesity were defined as confounders.

Categorical variables were designated for sex (male, female), diabetes (yes, no), alcohol consumption (≤ 2, > 2 standard drinks per day), usual reason for dental visit (check-up, problem), time since last dental visit (< 12, ≥ 12 months), mouth rinsing (yes, no), tooth brushing ($<$ twice a day, $\geq$ twice a day), flossing (yes, no), age (15–44, 45–59, ≥ 60 years), income ($<$ \$30k, \$30k–\$60k, $\geq$ \$60k), education (high-school or less, trade certificate/diploma, and degree or higher) and smoking (current, previous, never). A standard drink contains 10 g of alcohol is an established metric for estimating alcohol consumption across drink types[22].

The Australian Research Centre for Population Oral Health (ARCPOH) maintains a database of fluoride concentrations in drinking water for 99.4% of the Australian population[23]. Fluoride concentrations were recorded and matched to geographical location by postcode[24]. A record of city or area of residence collected for each individual for each year post-1964 was collected and matched to the ARCPOH water fluoridation database. Fluoride concentrations for each year at each location were summed and divided by the participant age, then multiplied by 100 to give percentage of lifetime water fluoridation exposure[24].

Statistical analysis was undertaken using R version 3.4.1[25]. The complex survey design of the NSAOH was accounted for; data were stratified by metropolitan and rural regions, clustered by post code and weighted for the probability of participants being selected for inclusion in the questionnaire.

Weighted-percentages, means and confidence intervals for population descriptive statistics were calculated. Bivariate analysis was conducted to explore the associations of BMI category, dental caries experience, potential confounders and sugar variables. Pearson's Chi-square with Rao–Scott adjustment and Student's *t*-tests were used to evaluate differences in levels of categorical and continuous variables, respectively. Linear regression was used to examine associations between dental outcomes and the continuous variables for dietary sugars and water fluoridation.

Multiple variable regression models were prepared using the generalised linear modelling function within the SURVEY package[26], accounting for the complex survey design and employing the quasi-Poisson regression family. Dependent variables for models were dental caries experience (DMFT), decayed teeth (D), missing teeth (M) and filled teeth (F), respectively. Models were prepared for each dependent variable by BMI and dietary added sugar (Model 1), total carbohydrate (Model 2) and total sugar (Model 3). Potential confounders that were found to be associated with both dental outcomes and BMI were included in the analysis.

RESULTS

The NSAOH 2004–2006 contained data from 14,123 people interviewed with a computer-assisted telephone interview (CATI). Of these, 5,507 participants underwent clinical examination and 4,170 participants completed the questionnaire[4]. Due to varying response rates between the clinical examination and questionnaire, height and weight data available for the BMI could only be calculated for 3,745 (89.9%) individuals who completed the questionnaire.

The study population was aged between 15 and 91 years, with equal distribution of sexes post-application of population weighting. Most participants were 15–44 years (57%) old. Socioeconomic status was high, with 46.5% having an annual income over $60k and 67% higher than secondary education level. Diabetes (4.3%) and current smoking (15.2%) were uncommon characteristics of the population. Over half of participants (57.7%) reported drinking less than two standard drinks per day. Slightly more than 50% of the population was overweight/obese, and the average lifetime spent with a fluoride concentration of 1 ppm was 53.7%. More than half of the participants had visited their dentist in the last 12 months and had a check-up-based dental appointment (55.7% and 59.7%) at their last dental visit. Mouth rinsing, tooth brushing ≥ 2 times and flossing were reported at 58.1%, 55.5% and 48.5% of the population, respectively (*Table 1*). Mean intake dietary added sugar, total sugar and total carbohydrates were estimated at 71.70, 125.08 and 171.50 g/day, respectively.

Table 2 illustrates the bivariate analysis of BMI and putative confounders. The analysis suggested that overweight/obesity was significantly associated with people aged 60 years and older (< 0.001), males (< 0.001), former smokers ($P < 0.001$) and problem-based dental visit behaviour ($P < 0.001$). Lower total carbohydrate intake was observed in overweight/obese people compared with underweight/normal weight people ($P < 0.05$). Mean DMFT, missing teeth, filled teeth, but not decayed teeth, were significantly higher among overweight/obese individuals than those of underweight/normal weight. No significant differences were observed in the mean values of decayed teeth between the two weight groups (*Figure 1*; *Table 3*).

Table 4 demonstrates a significant association between dental caries experience measures (DMFT, decayed teeth, missing teeth and filled teeth) with

Table 1 Characteristics of the study population

Characteristic	Level	*n*	Weighted percentage %	95% CI
Age	15–44	1,591	56.7	54.2–59.3
	45–59	1,333	25.2	23.3–27.1
	60+	1,246	18.1	16.4–19.7
Sex	Male	1,604	50.0	47.4–52.6
	Female	2,566	50.0	47.4–52.6
Income	< 30k	1,253	24.1	21.7–26.6
	30k to < 60k	567	29.4	26.9–31.9
	60k+	2,093	46.5	43.3–49.8
Education	High-school or less	1,349	32.7	30.1–35.3
	Trade/dip/cert	1,351	32.5	29.8–35.1
	Degree/ teaching/nursing	1,372	34.9	31.9–37.8
Diabetes	Yes	213	4.3	3.2–5.5
	No	3,956	95.7	94.5–96.8
Smoking	Current	578	15.2	13.2–17.1
	Previous	1,315	27.3	25.1–29.5
	Never	2,277	57.5	55.0–60.1
Alcohol	≤ 2 drinks	2,191	57.7	54.5–60.8
	> 2 drinks	1,152	42.3	39.2–45.5
Usual reason for dental visit	Check-up	1,712	55.7	52.6–58.8
	Problem	1,602	44.3	41.2–47.4
Time since last visit	< 12 months	2,630	59.7	57.1–62.4
	> 12 months	1,537	40.3	37.6–42.9
Mouth rinsing	No	2,821	41.9	39.3–44.6
	Yes	1,347	58.1	55.4–60.7
Tooth brushing	< 2 day	1,612	44.5	41.8–47.2
	≥ 2 day	2,535	55.5	52.8–58.2
Flossing	No	1,952	51.5	48.6–54.3
	Yes	2,217	48.5	45.7–51.4
BMI	Underweight/ normal	1,685	48.9	45.9–51.9
	Overweight/obese	2,060	51.1	48.1–54.1
Fluoride	% Lifetime > 1 ppm	3,770	53.7	51.2–56.1

BMI, body mass index; CI, confidence interval.

smoking ($P < 0.05$), alcohol consumption ($P < 0.05$), usual reason for dental visit ($P < 0.05$), time since last visit ($P < 0.05$), flossing ($P < 0.05$), and all three measures of dietary sugars ($P < 0.05$).

Table 5 provides each of the three multiple variable models of added sugars (Model 1), total carbohydrates (Model 2) and total sugars (Model 3), the rate ratios for DMFT were significantly higher in individuals aged 45 years and older, females and participants with problem-based dental visiting behaviour. The number of decayed teeth was significantly associated with added sugars, total carbohydrates and total sugars, with smoking and problem-based dental visits significant across all models. A biological gradient was observed between decayed teeth and smoking status across all three models, with higher rates of decayed teeth observed in current smokers compared with previous smokers, and the lowest rate in those who had never smoked. The number of missing teeth was significantly associated with age, higher education, problem-based dental visits and sugar intake in all models. The number of filled teeth was significantly higher with age, level of education and reason for dental visit in all models.

DISCUSSION

In this study, we determined that there was a positive association between dental caries experience (DMFT), missing (M) and filled teeth (F), and being overweight or obese compared with having normal weight or being underweight as well as between sugar consumption with all four dental caries outcome measures. However, when controlled for putative confounders where sugar consumption was identified as a key determinant, the statistical significance between dental caries experience and being overweight or obese disappeared. The literature on the relationship between dental caries and obesity is unclear, with reports demonstrating increased, decreased and no association as weight increases. This

Table 2 Bivariate analysis of BMI (underweight/normal BMI ≤ 25 kg/m^2, overweight/obese BMI as > 25 kg/m^2), and covariates

Characteristic	Level	Underweight/ normal %	95% CI	Overweight/ obese %	95% CI	*P*-value
Age	15–44	57.5	52.7–62.3	42.5	37.7–47.3	
	45–59	37.8	33.9–41.6	62.2	58.4–66.1	
	60+	37.1	33.3–40.9	62.9	59.1–66.7	< 0.001
Sex	Male	43.2	38.1–48.2	56.8	51.8–61.9	
	Female	54.9	51.7–58.1	45.1	41.9–48.3	< 0.001
Income	< 30k	44.0	37.9–50.2	56.0	49.8–62.1	
	30k to < 60k	47.1	42.7–51.5	52.9	48.5–57.3	
	60k+	49.4	44.3–54.5	50.6	45.5–55.7	0.3686
Education	High-school or less	47.4	42.2–52.7	52.6	47.3–57.8	
	Trade	41.9	36.4–47.3	58.1	52.7–63.6	
	Degree	51.4	46.0–56.8	48.6	43.2–54.0	0.0554
Diabetes	Yes	47.4	42.2–52.7	52.6	46.0–56.8	
	No	41.9	36.4–47.3	58.1	47.3–57.8	0.1222
Smoking	Current	50.2	43.0–57.5	49.8	42.5–57.0	
	Previous	37.1	32.3–41.8	62.9	58.2–67.7	
	Never	54.1	50.2–57.9	45.9	42.1–49.8	< 0.001
Alcohol	≤ 2 drinks	45.9	42.0–49.8	54.1	50.2–58.0	
	> 2 drinks	48.5	42.7–54.3	51.5	45.7–57.3	0.4571
Usual reason for dental visit	Check-up	54.3	50.1–58.5	45.7	41.5–49.9	
	Problem	40.9	36.4–45.4	59.1	54.6–63.6	< 0.001
Time since last visit	< 12 months	47.2	43.6–50.8	52.8	49.2–56.4	
	> 12 months	51.5	46.8–56.2	48.5	43.8–53.2	0.1355
Mouth rinsing	No	47.6	42.9–52.2	52.4	47.8–57.1	
	Yes	49.9	46.1–53.6	50.1	46.4–53.9	0.4447
Tooth brushing	< 2 day	45.4	40.1–50.7	54.6	49.3–59.9	
	≥ 2 day	51.6	48.1–55.0	48.4	45.0–51.9	0.0546
Flossing	No	47.2	42.5–51.8	52.8	48.2–57.5	
	Yes	50.7	47.3–54.2	49.3	45.8–52.7	0.2129
		Underweight/ normal mean		Overweight/ obese mean		*P*-value
Added sugar	g/day	82.2	74.1–90.3	78.5	73.5–83.4	0.4552
Carbohydrates	g/day	190.4	179.3–201.5	176.7	170.2–183.2	< 0.05
Total sugars	g/day	139.4	130.3–148.6	131.3	125.8–136.8	0.1487
Fluoride	% Lifetime 1 ppm	55.5	51.8–59.2	52.7	49.3–56.0	0.2562

Chi-square with Rao–Scott correction test used for categorical predictors, Student's *t*-test for continuous predictors. Significance at $P < 0.05$.CI, confidence interval.

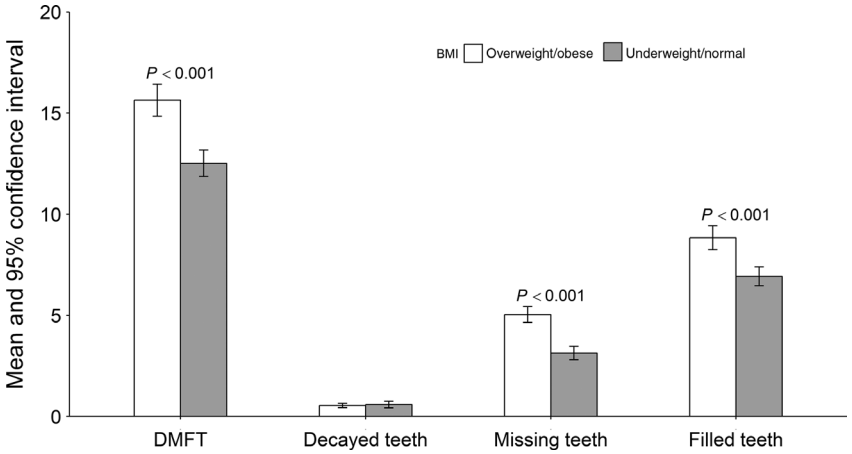

Figure 1. Display of dental outcomes by body mass index (BMI) category, error bars indicating 95% confidence interval. DMFT, Decayed Missing Filled Teeth.

Table 3 Summary measures of dental caries experience by BMI category (underweight/normal BMI ≤ 25 kg/m^2, overweight/obese BMI as > 25 kg/m^2)

	Underweight/normal	95% CI	Overweight/obese	95% CI	*t*-test
Dental caries experience (DMFT)	12.52	11.87–13.17	15.64	14.85–16.42	< 0.001
Decayed teeth (D)	0.59	0.43–0.76	0.54	0.44–0.65	0.609
Missing teeth (M)	3.14	2.81–3.47	5.04	4.65–5.44	< 0.001
Filled teeth (F)	6.93	6.47–7.40	8.84	8.25–9.43	< 0.001

CI, confidence interval; DMFT, Decayed Missing Filled Teeth.

study has demonstrated that any such analysis must include data about sugar and carbohydrate consumption. Similar results were observed in Brazilian adolescents and Korean adults[27,28].

In this study, the dental caries experience was significantly higher in people aged 45 years and older; females; and people with problem-based dental visiting behaviour. Dental caries and obesity share common risk factors and occur in complex socioeconomic and socio-behavioural environments. No association between obesity and dental caries could be a result of influences of other factors on dental caries occurrence and progression. These factors include fluoridated water and beverage consumption, low socioeconomic status, high cost of dental services, having no dental insurance, poorer living conditions, poor health literacy, and elevated psychological stress[29,30].

In this study, dietary sugar intake (added sugars, total sugars and total carbohydrates) was significantly associated with decayed and missing teeth in adults. Supporting this finding, a dose–response relationship was reported between sugar consumption and dental caries experience in Australian adolescents[31]. Sugar intake is an established risk factor for dental caries[15,32]. Population-based approaches targeting reduced sugar consumption, through restricting consumption of sugar-sweetened beverages is required across the life course[33].

This study has some caveats. Firstly, self-reported body height and body weight could have introduced a reporting bias, because of underestimation of their body weights and overestimation of their body heights[34]. While direct measurement of weight and height is preferable when calculating BMI in epidemiological studies, in reality, self-reported weight and height are common substitutes due to the time, cost and data collection constraints[35]. Secondly, a cross-sectional study design is another limitation because it hinders determination of the temporal relationship between the exposure and the outcome. Thirdly, the food frequency questionnaire (FFQ) employed in this study was a self-completed questionnaire, using predetermined serving sizes. These methods are routinely used to determine nutrient intake in large, epidemiological studies when minimising the burden associated with data collection is important. The intrinsic problems related to reported dietary data collection remain unsolved, and therefore readers should be mindful of the limitations of the FFQ data when interpreting the results of this study.

As total daily energy cannot be calculated from the 13 food items in this questionnaire, the results of this analysis cannot be compared with the WHO recommendations for added sugars, which stipulate that added sugars should comprise less than 10% of daily energy intake[36]. The NSAOH dietary questions were primarily included as indicators of risk for dental caries rather than broad measures of nutrition or as specific risk indicators for poor nutrition and obesity. As such, some potentially important carbohydrate-rich food items such as breads and foods particularly high

Table 4 Bivariate analysis of putative confounders and dental outcomes DMFT

Characteristic	Level	DMFT	95% CI	*P*-value	Decayed teeth	95% CI	*P*-value	Missing teeth	95% CI	*P*-value	Filled teeth	95% CI	*P*-value
Age	15–44	9.13	8.63–9.62		0.65	0.51–0.79		1.02	0.87–1.18		4.73	4.36–5.09	
	45–59	19.29	18.82–19.77		0.52	0.39–0.65		6.21	5.79–6.63		12.56	12.13–12.99	
	60+	23.18	22.79–23.56	< 0.001	0.42	0.33–0.50	0.2016	11.65	11.1–12.2	< 0.001	11.11	10.59–11.64	< 0.001
Sex	Male	13.56	12.79–14.34		0.68	0.54–0.82		4.08	3.73–4.43		7.45	6.88–8.01	
	Female	14.89	14.34–15.44	< 0.05	0.48	0.37–0.58	< 0.05	4.42	4.07–4.78	0.159	8.27	7.83–8.69	< 0.05
Income	< 30k	18.12	16.79–19.46		0.71	0.56–0.87		8.22	7.39–9.05		8.41	7.69–9.11	
	30k to < 60k	15.22	14.53–15.91		0.71	0.52–0.89		4.37	3.92–4.82		8.68	8.12–9.25	
	60k+	12.37	11.67–13.07	< 0.001	0.42	0.29–0.54	0.9545	2.56	2.28–2.84	< 0.001	7.69	7.09–8.29	0.5381
Education	High-school or less	15.09	14.34–15.85		0.84	0.65–1.02		5.53	5.03–6.02		7.36	6.84–7.87	
	Trade	15.37	14.49–16.26		0.68	0.48–0.89		4.82	4.35–5.28		8.60	8.01–9.19	
	Degree	13.91	13.0–14.81	0.6421	0.29	0.22–0.35	0.3036	3.36	2.99–3.73	< 0.05	8.75	8.04–9.46	< 0.05
Diabetes	Yes	18.12	14.77–21.48		0.63	0.35–0.91		8.02	5.99–10.06		8.74	6.98–10.49	
	No	14.05	13.57–14.53	< 0.05	0.57	0.48–0.67	0.7079	4.08	3.83–4.33	< 0.001	7.81	7.45–8.18	0.3128
Smoking	Current	14.35	13.34–15.37		1.43	1.04–1.83		4.14	3.47–4.81		6.96	6.26–7.65	
	Previous	16.44	15.59–17.29		0.53	0.38–0.67		5.66	5.16–6.17		9	8.35–9.64	
	Never	13.14	12.51–13.78	< 0.05	0.37	0.31–0.44	< 0.001	3.61	3.29–3.93	< 0.001	7.55	7.07–8.04	< 0.001
Alcohol	≤ 2 drinks	15.68	15.07–16.29		0.44	0.34–0.53		4.83	4.47–5.18		9.06	8.58–9.55	
	> 2 drinks	12.58	11.80–13.37	< 0.001	0.83	0.62–1.04	< 0.05	3.14	2.77–3.51	< 0.001	6.89	6.31–7.47	< 0.001
Usual reason for dental visit	Check-up	13.56	12.87–14.25		0.27	0.19–0.34		3.66	3.27–4.05		7.92	7.38–8.45	
	Problem	17.13	16.4–17.87	< 0.001	0.68	0.51–0.85	< 0.001	5.36	4.92–5.79	< 0.001	9.81	9.27–10.35	< 0.001
Time since last visit	< 12 months	15.72	15.15–16.29		0.44	0.34–0.55		4.62	4.31–4.93		9.23	8.80–9.66	
	> 12 months	12.01	11.29–12.73	< 0.001	0.77	0.62–0.93	< 0.001	3.70	3.33–4.08	< 0.001	5.81	5.32–6.31	< 0.001
Mouth rinsing	No	14.94	14.17–15.70		0.48	0.37–0.59		4.62	4.20–5.03		8.41	7.84–8.98	
	Yes	13.69	13.09–14.28	< 0.05	0.64	0.52–0.77	0.0688	3.96	3.65–4.27	< 0.05	7.46	7.04–7.88	< 0.05
Tooth brushing	< 2 day	13.33	12.62–14.05		0.79	0.62–0.97		4.01	3.64–4.39		6.78	6.29–7.27	
	≥ 2 day	14.92	14.35–15.49	< 0.001	0.39	0.33–0.47	< 0.001	4.42	4.10–4.74	0.0855	8.72	8.28–9.16	< 0.001
Flossing	No	13.46	12.73–14.18		0.77	0.61–0.92		4.54	4.16–4.92		6.68	6.20–7.17	
	Yes	15.04	14.45–15.63	< 0.001	0.38	0.28–0.47	< 0.001	3.94	3.62–4.26	< 0.05	9.09	8.63–9.56	< 0.001
		Linear regression			Linear regression			Linear regression			Linear regression		
Added sugar	Intercept	14.854	14.08–15.63		0.199	−0.01 to 0.41		4.319	3.96–4.68		9.162	8.54–9.79	
	Coef	−0.012	−0.021 to −0.003	< 0.05	0.005	0.002–0.01	< 0.05	−0.005	−0.008 to −0.001	< 0.05	−0.017	−0.024 to −0.01	< 0.001
Carbohydrate	Intercept	15.139	14.01–16.27		0.09	−0.26 to 0.44		4.521	4.06–4.98		9.433	8.62–10.24	
	Coef	−0.007	−0.013 to −0.001	< 0.05	0.003	0.001–0.005	< 0.05	−0.003	−0.01 to −0.001	< 0.05	−0.009	−0.01 to −0.005	< 0.001
Total sugars	Intercept	15.37	14.32–16.42		0.076	−0.23 to 0.38		4.579	4.15–5.01		9.66	8.87–10.44	
	Coef	−0.011	−0.019 to −0.004	< 0.05	0.004	0.001–0.006	< 0.05	−0.005	−0.01 to −0.002	< 0.001	−0.014	−0.02 to −0.01	< 0.001
Fluoride	Intercept	18.623	17.56–19.69		0.49	0.37–0.61		6.483	5.91–7.06		10.86	10.10–11.63	
	Coef	−0.081	−0.098 to −0.06	< 0.001	0.00	−0.002 to 0.002	0.9636	−0.043	−0.05 to −0.03	< 0.001	−0.052	−0.064 to −0.04	< 0.001

Student's *t*-test for difference in means by level of categorical variable, linear regression for continuous variables.
CI, confidence interval; DMFT, Decayed Missing Filled Teeth.

Table 5 Multiple variable regression models for DMFT, decayed teeth, missing teeth and filled teeth with putative confounding variables, added sugar, total carbohydrate and total sugars

Covariate	DMFT	95% CI	*P*-value	Decayed teeth	95% CI	*P*-value	Missing teeth	95% CI	*P*-value	Filled teeth	95% CI	*P*-value
Model 1*												
BMI overweight/obese	1.02	0.97–1.07	0.474	1.01	0.67–1.54	0.949	1.03	0.94–1.13	0.536	1.014	0.94–1.09	0.714
Added sugar	1.0002	0.999–1.004	0.145	1.01	1.00–1.02	< 0.05	1.01	1.00–1.01	< 0.001	0.999	0.996–1.003	0.744
Age												
45–60	1.91	1.78–2.05	< 0.001	0.7	0.48–1.03	0.076	4.84	4.00–5.85	< 0.001	2.26	2.05–2.49	< 0.001
> 60	2.27	2.13–2.42	< 0.001	0.77	0.5–1.18	0.228	8.46	6.95–10.31	< 0.001	2.11	1.91–2.34	< 0.001
Sex												
Female	1.08	1.03–1.14	< 0.05	0.97	0.71–1.34	0.868	1.11	1.01–1.22	< 0.05	1.05	0.97–1.14	0.169
Education												
Trade	1.04	0.98–1.11	0.189	1.01	0.68–1.5	0.957	0.93	0.84–1.02	0.142	1.12	1.03–1.23	< 0.05
Degree	1.01	0.96–1.07	0.71	0.67	0.44–1.03	0.068	0.74	0.66–0.83	< 0.001	1.15	1.06–1.25	< 0.001
Smoker												
Previous	0.98	0.9–1.06	0.617	0.52	0.32–0.86	< 0.05	0.99	0.84–1.16	0.88	1.083	0.96–1.22	0.1821
Never	0.92	0.85–1	0.062	0.37	0.25–0.54	< 0.001	0.89	0.76–1.04	0.151	1.055	0.94–1.19	0.3765
Visit for problem	1.13	1.07–1.19	< 0.001	2.06	1.46–2.91	< 0.001	1.15	1.05–1.26	< 0.05	1.114	1.03–1.20	< 0.05
Model 2†												
BMI overweight/obese	1.02	0.97–1.08	0.371	1.07	0.72–1.58	0.747	1.04	0.94–1.14	0.479	1.00	0.94–1.09	0.641
Total carbohydrate	1.0002	0.999–1.001	0.216	1.002	1.001–1.003	< 0.001	1.001	1.0003–1.001	< 0.05	1.000	0.999–1.001	0.865
Age												
45–60	1.91	1.78–2.05	< 0.001	0.72	0.49–1.06	0.099	4.80	3.96–5.82	< 0.001	2.268	2.05–2.50	< 0.001
> 60	2.26	2.12–2.41	< 0.001	0.77	0.50–1.19	0.238	8.32	6.83–10.15	< 0.001	2.123	1.92–2.35	< 0.001
Sex												
Female	1.09	1.03–1.14	< 0.05	1.00	0.72–1.37	0.978	1.10	1.00–1.21	< 0.05	1.06	0.98–1.14	0.147
Education												
Trade	1.04	0.98–1.11	0.168	0.97	0.66–1.43	0.867	0.92	0.84–1.02	0.13	1.12	1.03–1.23	< 0.05
Degree	1.01	0.95–1.06	0.803	0.67	0.44–1.03	0.07	0.74	0.66–0.83	< 0.001	1.15	1.06–1.25	< 0.001
Smoker												
Previous	0.98	0.9–1.06	0.568	0.53	0.34–0.85	< 0.05	0.99	0.84–1.16	0.874	1.079	0.96–1.22	0.210
Never	0.92	0.84–1.00	0.064	0.37	0.25–0.53	< 0.001	0.88	0.75–1.04	0.138	1.053	0.93–1.19	0.410
Visit for problem	1.13	1.07–1.19	< 0.001	2.04	1.44–2.90	< 0.001	1.15	1.05–1.26	< 0.05	1.11	1.03–1.19	< 0.05
Model 3‡												
BMI overweight/obese	1.02	0.97–1.08	0.398	1.05	0.70–1.56	0.828	1.03	0.94–1.14	0.504	1.02	0.94–1.09	0.646
Total sugar	1.0003	0.99–1.00	0.254	1.003	1.001–1.003	< 0.001	1.001	1.0004–1.002	< 0.05	0.999	0.999–1.001	0.659
Age												
45–60	1.91	1.78–2.05	< 0.001	0.72	0.49–1.06	0.097	4.82	3.98–5.85	< 0.001	2.26	2.05–2.50	< 0.001
> 60	2.26	2.12–2.41	< 0.001	0.78	0.51–1.20	0.263	8.37	6.87–10.21	< 0.001	2.12	1.91–2.35	< 0.001
Sex												
Female	1.09	1.03–1.14	< 0.05	0.99	0.72–1.36	0.934	1.10	1.00–1.21	< 0.05	1.06	0.98–1.14	0.149
Education												
Trade	1.05	0.98–1.11	0.161	0.99	0.67–1.46	0.946	0.93	0.84–1.02	0.138	1.13	1.03–1.23	< 0.05
Degree	1.01	0.95–1.06	0.802	0.68	0.44–1.04	0.075	0.74	0.66–0.83	< 0.001	1.15	1.06–1.25	< 0.05
Smoker												
Previous	0.98	0.90–1.06	0.597	0.53	0.33–0.86	< 0.05	0.99	0.84–1.17	0.949	1.08	0.96–1.21	0.215
Never	0.92	0.85–1.00	0.066	0.37	0.25–0.54	< 0.001	0.89	0.76–1.05	0.166	1.05	0.93–1.19	0.411
Visit for problem	1.13	1.07–1.19	< 0.001	2.05	1.45–2.9	< 0.001	1.15	1.05–1.26	< 0.05	1.11	1.03–1.20	< 0.05

*Model 1: the association of added sugar, putative confounders in relation to DMFT and decayed, missing and filled teeth.
†Model 2: the association of total carbohydrate, putative confounders in relation to DMFT and decayed, missing and filled teeth.
‡Model 3: the association of total sugar, putative confounders in relation to DMFT and decayed, missing and filled teeth.
BMI, body mass index; CI, confidence interval; DMFT, Decayed Missing Filled Teeth.

in dietary fats were not considered, which may have contributed to our understanding of the role of diet in overweight/obesity. The measure of total carbohydrate returned from this survey is likely to under-represent daily carbohydrate intake due to a lack of reporting high-starch foods. Further, the dietary variables are self-reported, and consist of mainly high sugar and discretionary foods. These foods are especially vulnerable to under reporting, particularly by individuals attempting to control their weight[37].

Irrespective of the outlined limitations, profound strengths of this study remain: NSAOH is a nationwide survey; it generated a large sample size; a sophisticated sampling procedure was used; it provided population level prevalence estimates for adult oral health; and there was a negligible non-participation bias[4].

CONCLUSION

There was a positive association between being overweight or obese and dental caries, but the statistical significance disappeared in the regression analysis, where sugar consumption was identified as a key determinant. Analysis on the relationship between dental caries and obesity must include data about sugar and carbohydrate consumption.

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Conflict of interest

The authors declare no conflict of interest.

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Appendix A

Table A1 Food item, weight, carbohydrate, sugar and added sugars from AUSNUT2013

Survey descriptor	AUSNUT2013 descriptor	Qty	Data source	Total carbohydrate (g)	Total sugars (g)	Added sugars (g)
Fruit or natural juice	Fruit, fresh, nfs	150 g	AGHE	18.15	15.60	0
Sweetened fruit drinks	Fruit drink, from dry base, regular, recommended dilution	250 mL	AGHE	23.36	23.36	23.35
Sweetened soft drinks	Soft drink, nfs	1 cup	NSAOH	17.68	17.68	17.79
Lo-cal soft drinks	Soft drink, lemonade, intense sweetened or diet	250 mL	NSAOH	0	0	0
Plain milk	Milk, cow, fluid, unflavoured, nfs	250 mL	NSAOH	14.16	14.16	0
Flavoured milk	Milk, cow, fluid, flavoured, chocolate, nfs	250 mL	NSAOH	24.38	23.10	8.57
Sweetened dairy products	Dairy dessert, flavours other than chocolate, regular fat	1 cup	NSAOH	40.82	31.98	20.8
Breakfast cereal	Breakfast cereal, nfs	1 cup	AGHE	33.35	6.10	3.68
Biscuits, cakes	Muffin, cake-style, commercial, nfs	40 g	AGHE	19.72	10.32	9.02
Table sugar	Sugar, white, fruit sugar (fructose), granulated or lump	1 tsp	NSAOH	4.15	4.15	4.15
Chocolate, confectionery	Chocolate, nfs	30 g	AGHE	17.25	15.93	15.92
Syrups, jams	Jam, nfs	1 tbs	NSAOH	18.40	18.37	18.01
Muesli bars	Bar, muesli or snack, nfs	1 regular bar	AGHE	22.68	8.12	7.01

nfs, not further specified.

Table A2 Justification for selecting the quantity

AusNut2013 descriptor	Qty	Weight/ g	NSAOH	AGHE
Fruit, fresh, not further defined	150 g	150	1 medium piece	1 medium piece of fruit, ~150 g
Juice, fruit, commercial, not further defined	125 g	125	1 medium glass	125 mL juice is 1 serve of fruit
Soft drink not further defined	250 mL	260	1 medium glass	
Soft drink, lemonade, intense sweetened or diet	250 mL	250	1 medium glass	
Milk, cow, fluid, unflavoured, not further defined	250 mL	257.5	1 medium glass	
Milk, cow, fluid, flavoured, chocolate, not further defined	250 mL	265	1 medium glass	
Dairy dessert, flavours other than chocolate, regular fat	1 cup	260	1 cup	
Breakfast cereal not further defined	1 cup	50	1 cup	
Muffin, cake-style, commercial, not further defined	40 g	40		~600 kJ
Sugar, white, fruit sugar (fructose), granulated or lump	1 tsp	4.15	1 teaspoon	
Chocolate not further defined	30 g	30		30 g or ~600 kJ
Jam not further defined	1 tbs	28	1 tablespoon	
Bar, muesli or snack, not further defined	1 regular bar	35	1 bar	~600 kJ