What factors are associated with early childhood dental caries? A longitudinal study of the *Growing Up in New Zealand* cohort.

Simon Thornley,[1,2] Katie Bach,[3] Amy Bird,[4] Rachel Farrar, Sarah Bronte, Bathsheba Turton,[5] Polly Atatoa Carr,[6,7,8] Jacinta Fa'alili-Fidow,[9] Susan Morton,[8-10] Cameron Grant.[10-12]

1. Section of Epidemiology and Biostatistics, University of Auckland, Tamaki Campus, Glen Innes, Auckland, New Zealand.
2. Auckland Regional Public Health Service, Cornwall Complex, Greenlane Clinical Centre, Auckland District Health Board, Auckland, New Zealand.
3. Paediatric Oral Health, Auckland District Health Board, Greenlane Clinical Centre, Auckland, New Zealand.
4. School of Psychology, University of Wollongong, New South Wales, Australia
5. Dental Department, University of Puthisastra, Phnom Penh, Cambodia.
6. National Institute of Demographic and Economic Analysis, Faculty of Arts and Social Sciences, The University of Waikato, Hamilton, New Zealand.
7. Child and Youth Health, Waikato District Health Board, Hamilton, New Zealand.
8. School of Population Health, Faculty of Medicine and Health Sciences, University of Auckland, Tamaki Campus, Glen Innes, Auckland, New Zealand.
9. *Growing Up in New Zealand*, The University of Auckland;
10. Centre for Longitudinal Research – He Ara ki Mua, The University of Auckland
11. Department of Paediatrics: Child & Youth Health, University of Auckland, Grafton, Auckland, New Zealand.
12. General Paediatrics, Starship Children's Hospital, Auckland District Health Board, Auckland, New Zealand.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/IPD.12686

Acknowledgments

We would like to acknowledge the participants and all the members of the *Growing Up in New Zealand* study. We would also like to acknowledge the funders, the New Zealand Ministry of Social Development, supported by the Health Research Council as well as the ongoing support from Auckland UniServices and The University of Auckland. We acknowledge the Starship Foundation for their funding of this oral health project.

Funding

Growing Up in New Zealand has been funded by the New Zealand Ministries of Social Development, Health, Education, Justice and Pacific Island Affairs; the former Ministry of Science Innovation and the former Department of Labour (now both part of the Ministry of Business, Innovation and Employment); the former Ministry of Women's Affairs (now the Ministry for Women); the Department of Corrections; the Families Commission (now known as the Social Policy Evaluation and Research Unit); Te Puni Kokiri; New Zealand Police; Sport New Zealand; the Housing New Zealand Corporation; and the former Mental Health Commission, The University of Auckland and Auckland UniServices Limited. Other support for the study has been provided by the NZ Health Research Council, Statistics New Zealand, the Office of the Children's Commissioner and the Office of Ethnic Affairs. The Starship Foundation provided the funding for the completion of this project on oral health.

Conflict of interest statements

Dr Thornley has nothing to disclose.

Dr Bach has nothing to disclose.

Dr Amy Bird has nothing to disclose.

Dr Farrar has nothing to disclose.

Dr Bronte has nothing to disclose.

Dr Turton has nothing to disclose.

Dr Atatoa-Carr has nothing to disclose.

Jacinta Fa'alili-Fidow has nothing to disclose.

Dr Morton has nothing to disclose.

Dr Grant has nothing to disclose.

DR. SIMON THORNLEY (Orcid ID : 0000-0003-4227-4889)

MS. BATHSHEBA JAEL TURTON (Orcid ID : 0000-0001-5464-9305)

Article type : Original Article

Corresponding author mail id:- : s.thornley@auckland.ac.nz

What factors are associated with early childhood dental caries? A longitudinal study of the *Growing Up in New Zealand* cohort.

Abstract

Background

The relative importance of different strategies to prevent dental caries are not known.

Aim

We explored the relationship between oral health behaviours, diet and the incidence of dental caries.

Design

We conducted a study of children participating in the "Growing Up in New Zealand" cohort. Exposures were oral health behaviours, a food frequency questionnaire and sociodemographic characteristics that were recorded when the child was nine months and two years old. Outcomes were records of dental caries at ages four to seven years.

Results

4111 children had dental examination records from between the ages of four and seven years. High levels of dental caries were reported in children of Pacific, Asian and Māori ethnicity. Food frequency questionnaire information was summarised into two principal components. The major axis of variation was in the intake of food and drinks with high concentrations of sugar and refined starch, with this component strongly associated with caries (multivariable incidence rate ratio of caries 0.48; 95% confidence interval: 0.38 to 0.61, comparing the extreme quintiles of the first principal component).

Conclusions

A diet high in sugar or refined starch was strongly linked to caries. Policies to reduce sugar and refined starch intake should be considered.

Introduction

Early childhood caries is a common and prevalent problem. In New Zealand,[1] it is a leading cause of avoidable hospital treatment[2] and of caries later in life.[3] It is increasingly clear that caries are preventable.[4,5] Improving oral hygiene, with the use of fluoridated toothpaste, and limiting sugar intake are two interventions that are effective in reducing the burden of this disease.[6,7] The evidence for sugar as a driver of the caries process comes from a number of cohort and ecological studies, summarised by Sheiham et al.[4] The health effects of sugar intake are also apparent in cohort studies of people who develop diabetes,[8] and cardiovascular disease.[9] Thus, understanding the characteristics of children who are at high risk of developing dental caries is an

important first step in informing public policy that may improve the health of both children and adults.

With the large burden of caries in New Zealand[1], and a renewed awareness of the potential preventability of caries, we analysed the relationship of sociodemographic, dental hygiene practices, and dietary intake, specifically sugary foods, with the incidence of dental caries within an ethnically and socioeconomically diverse child cohort. With the use of learning Bayesian networks, there is an opportunity to explore the nature of relationships between these various factors.

Methods

Study design and Population

The *Growing Up in New Zealand* cohort is a pre-birth cohort created by the enrolment of 6,822 pregnant women and the 6,853 children born to them in 2009-10.[10] Pregnant women were eligible for enrolment if they resided in Auckland, Counties Manukau and Waikato regions of New Zealand during late pregnancy. There were no exclusion criteria. The cohort at birth was similar to New Zealand's national birth cohort from 2007-10.[11]

A retrospective cohort study design was employed, in which the units of analysis were individual children in the *Growing Up in New Zealand* study. Since dental caries was the outcome of interest, children were selected into the study if they had at least one visit to a dental therapist between the ages of four and seven years.

Exposures of interest

The main likely causes of dental caries are dietary intake, and oral health behaviours such as lack of brushing, restricted duration of breast feeding (recorded at the age of nine months) and snacks before bed. Enrolment with a dental service may also be important.[1] Information about these oral health behaviours was collected at face-to-face

interviews completed with each cohort child's mother when the child was nine months and two years old.

When their child was aged 23 months, mothers were asked about the principal water source of the household. Reticulated supplies in New Zealand are more likely to be fluoridated, with only Christchurch having a reticulated but non fluoridated water supply.

At the two year interview, participants were administered a 58-item food frequency questionnaire (FFQ), which enquired about whether or not each child ate or drank particular food items during the last four week period and, if so, how frequently. The FFQ included questions about the frequency of intake ("none", "one/day", "two/day", "3/day", "4/day", "5-6/day", "1/month" or "2-3/month"), with pictures showing the corresponding food and questions augmented with pictures of portion sizes. Sizes were classed as ¼, ½, 1, or 2 or more "serves". These variables were combined to estimate the total number of servings per week which was ultimately analysed.

Potential confounders

Exposures of interest include sociodemographic characteristics, such as sex, ethnicity, and area based socioeconomic status (NZDep2006). Ethnicity and socioeconomic status were assessed when the baby was 9 months old, from an interview with the mother. Ethnicity was assessed at Statistics New Zealand 'level 1' and 'prioritised' so that in the event of several ethnicities being reported, Māori was prioritised, followed by Pacific, Asian and European or Other.[12] In New Zealand, about 70% of the population identify as European or Other, 16% as Māori, 15% as Asian (primarily Chinese and Indian) and 8% as Pacific.

Outcome

The first dental assessment of the sum of decayed, missing and filled primary teeth between the ages of four and seven years at the Community Oral Health Service was the outcome of interest. This is an integer variable that estimates the burden of dental caries into a score between zero (no caries) and twenty (all primary teeth affected by caries).

Statistical analysis

Relevant records were extracted from the *Growing Up in New Zealand* cohort. These were then matched by national health identifier to dental records. Records of caries were categorized and tabulated by sociodemographics, oral health behaviours, and frequency of food items. Subjects' sociodemographic and oral health-related behaviours were examined by dividing the population into approximately four groups of approximately equal size, by their caries state (zero, one, two or three, and four or more). Kruskal-Wallis and Chi-square tests assessed whether or not these factors were associated with caries status. A two-sided alpha level of 5% was considered significant. Individual food items that showed strong positive or negative correlation with caries were also presented.

Food frequency questionnaires were summarised using principal components analysis. The first two principal components were then included in a quasi-Poisson regression model as independent predictors, with oral health behaviours and sociodemographic factors included as confounders. The outcome of the model was dental caries, measured by the dmft (decayed/missing/filled primary teeth) index. The items in the food frequency questionnaire were summarised into two principal components. The proportion of variation explained from these factors was examined in a scree plot, and these factors were divided into quintiles for regression analysis. The R package, *factoextra*[13] was used to undertake principal components analysis. The number of principal components was selected based on whether or not component loadings had a meaningful interpretation.

To assist in the interpretation of the regression variables and explore their inter-relationship, a learning Bayesian network analysis was carried out. On the basis of the summarized food frequency questionnaire information, and considering only factors that were associated with caries, the *growshrink* algorithm from the *bnlearn* package was used to draw a directed acyclic graph, compatible with the patterns of conditional dependence in the data.[14] The alpha level was set at 0.05 and Monte-Carlo conditional independence tests were used, to reduce error rates associated with sparse tables. In

order to run this algorithm, data had to be categorized and primary teeth caries (dmft) were categorized into four categories: zero, one, two and three, and four or more.

Ethical approval

Ethical approval for the study was granted by the New Zealand Ministry of Health, Health and Disability Ethics committee (number: NTY08-06-055), and written informed consent obtained from the parent or guardian of each child.

Results

Of the 6,853 children in the cohort, 4,111 were available for analysis, with at least one dental record within the four to seven year age group (**Figure 1**). The children who did not have a dental record during the four to seven year age group were more likely to be identified as of Māori or Pacific ethnicity, or live in the most deprived socioeconomic quintile areas (see **supplementary table** 1). The characteristics of the children were then compared by their caries status.

[Insert figure 1]

Table 1 shows the sociodemographic characteristics of the *Growing Up in New Zealand* cohort children, by caries status. Most of the children (3,074/4,111; 75%) had no caries when examined. Ethnicity was strongly associated with caries status, with Pacific children almost four times more likely to be represented in the highest dmft (four or more) group than the no caries group. Māori and Asian children were about 50% more likely to be in the highest dmft group than the no caries group, whereas European and Other children were three times less likely to be in the highest dmft group than the no caries group. Socioeconomic status was similarly strongly associated with caries, with children living in the least deprived quintile about half as likely to be in the highest dmft compared to the no caries group.

[Insert table 1 here]

Table 2 shows the oral health behaviours of the children, along with breast feeding duration, by caries status. The three behaviours that were associated with caries included brushing frequency, parental help with brushing and whether or not the child's teeth were brushed after a snack or drink. Breast feeding duration, fluoride toothpaste use, type of toothpaste, and whether or not the parents reported the child having a snack before bed were not associated with caries status. Water source at the age of two years was not strongly associated with caries status.

[Insert table 2 here]

Table 3 shows selected items from the 2 year food frequency questionnaire which were strongly associated with caries status. The largest proportional increase in intake associated with caries was for sugar sweetened soft drinks, with a median of zero in the no caries group, compared to 0.3 per week in the highest caries group (ratio of values is, therefore, infinite). Overall, however, reported intake of sugar sweetened drinks was low.

The next strongest association with caries status was the frequency of eating white bread. Children who had a dmft score of four or more had a median of 5.5 servings of white bread per week, compared to 1.5 in the no caries group, indicating a 3.7 fold increase in frequency. Fruit juice, and confectionary and cake intake was also strongly associated with caries, with a three-fold difference between the highest and lowest intake groups. Ice-cream, noodles and rice porridge, refined breakfast cereals and takeaways were also positively associated with caries.

Foods and drinks that showed an inverse association with caries prevalence, included increasing frequency of whole meal or whole grain bread intake, and frequency of eating brassicas or cheese.

Principal components analysis was carried out on the food frequency data. 13.4% of the overall variation was captured in the first two components.

Figure 2 shows a biplot of the first two principal components and the loadings of each variable plotted as an arrow. The arrows are coloured by the strength of the contribution of each item to these two components. The name of each variable is plotted by the score

of the first (horizontal axis) and second (vertical axis) principal component. The cosine of the angle between each arrow is proportional to the level of correlation between each of the food categories. This indicates, for example, that parents who report frequent intake of soft drinks, also tend to report frequent intake of white bread, cakes and biscuits, ice cream and confectionery. These parents, conversely, reported low intakes of carrots, brassicas, peppers and tomatoes, indicated by the wide angle between the sugary foods and the vegetable cluster.

[Insert figure 2]

The individual loadings of the items are given in **Supplementary table 2**. The table is ordered by the sum of the two loadings, so that it places items which are farthest toward the bottom left of the plots. Items that have a negative loading on the first and second principal components are heavily weighted toward sugary items (confectionary and cakes, soft drinks, ice cream and fruit juice) and those with refined starches (white bread, snack crisps). Positive loadings for the second principal component, were correlated with higher frequency of intake of 'healthy' food items, such as brassicas, berries, carrots, peas, beans and mushrooms.

Crude and adjusted associations between caries and various exposures are laid out in **table 4**. In the cohort, Asian ethnicity was particularly strongly associated with caries with an incidence rate ratio of caries of 5.57 (95% CI: 4.58 to 6.77) comparing these children to those who identified as 'New Zealand European or Other'. There was a three-fold increase in caries associated with living in households in high compared to low socioeconomic deprivation areas. The lowest, negative quintile of the first principal component was associated with a three-fold higher rate of caries, compared to the highest quintile. The lowest, negative quintile of the second principal component was associated with a doubling of caries incidence, compared to the highest quintile. Brushing at least daily was associated with a halving of the incidence of caries compared to brushing less frequently than this.

In the multivariable analysis, including all variables in the table associated with caries in the model, the strength of all associations diminished, except for Pacific ethnicity. The association between Asian ethnicity and caries reduced by half in the multi-variable analysis. Principal component one, linked to sugary foods, remained strongly associated with caries in the final model.

The pattern of conditional dependence between selected variables in the dataset learned by the grow shrink algorithm is depicted in **figure 3.** It shows an arc indicating conditional dependence between ethnicity and caries, the first principal component and caries as well as between the frequency of tooth brushing and caries. The association between socioeconomic deprivation and caries is depicted as being mediated through the first principal component of the food frequency questionnaire information. The association between the second principal component and caries is depicted as related to the link between ethnicity and caries.

[Insert figure 3]

Discussion

This study showed strong statistical evidence of an association between a high sugar and refined starch diet and incidence of dental caries. In crude analyses, increasing intake of sugary soft drinks, fruit juice, white bread, rice congee and noodles were strongly associated with dental caries. In the principal components analysis, frequency of intake of refined starches and sugars were heavily weighted in the first principal component, which captures the greatest variability in the dietary information recorded. This component was strongly associated with caries severity in both crude and adjusted analyses. Conversely, bread containing unrefined wheat, cheese and brassica intake were negatively associated with caries, indicating a possible causal association.

A strength of this study is the large sample size and extensive data available, including sociodemographic, oral health-related and nutrition-related questions. This provided adequate statistical power to detect differences in exposure groups. The objective evidence of caries from an oral health professional also means less measurement error and therefore less bias than would be expected from a study that incorporated self-report measures of oral health.

Weaknesses in the study conversely relate to missing data, in that about a third of the cohort did not have a dental record available during the ages of four and seven years. This may be due to migration out of the study region or engagement in private dental care. The degree of bias from this source is difficult to assess. Since this was not a designed study, but rather a retrospective analysis of observational data, we are relying on relatively consistent reporting of the extent of caries. Although there is likely to be some inter-observer variation, this is likely to be less than would be expected from self-reported caries.

Our study is largely concordant with the findings of other similar investigations.[15] In a study of children aged two to six years, those with severe caries (three or more smooth surface carious lesions) consumed an average of 100 to 140 mL more sugar-sweetened beverages than children who were caries free. In a Spanish cross-sectional study of six to ten year old children, the authors reported higher mean intakes of sugar sweetened beverages, industrial breads, sweet snacks and craft bakery products in children with caries, compared to those who were caries free.[16] Conversely, intake of cheese, and to a lesser extent nuts, were higher in the no caries group than in those with caries.

In addition to the well-known risks linked to intake of high sugar foods, our study highlights the high burden of caries associated with foods that have a high concentration of refined starches such as white bread, rice congee and noodles. This has implications for oral health promotion practices.

The linkage in this study between ethnicity, socioeconomic status and diet reinforces the findings of other studies. For example, the risk of obesity is increased for children in households in which people experience food insecurity – that is being unable to afford good quality food, levels of nutrition related conditions.[17]

It is well known that ethnicity and socioeconomic deprivation are strongly associated with dental caries.[18] The Bayesian learning analysis indicates that this association is likely to be mediated, at least in part, by dietary intake.

This study is observational, and much of the research which links diet with early childhood caries is from similar or weaker ecological study designs.[4,19] The evidence for sugar reduction is strong enough for the World Health Organization to recommend drastic reductions in intake to less than 5% of overall dietary energy.[20]

Conclusion

Our study highlights the strong association between a diet high in sugar and refined starch and the presence of early childhood caries. These findings strengthen the case to reduce the availability of such foods and drinks to improve the oral health of children.

Funding

Growing Up in New Zealand has been funded by the New Zealand Ministries of Social Development, Health, Education, Justice and Pacific Island Affairs; the former Ministry of Science Innovation and the former Department of Labour (now both part of the Ministry of Business, Innovation and Employment); the former Ministry of Women's Affairs (now the Ministry for Women); the Department of Corrections; the Families Commission (now known as the Social Policy Evaluation and Research Unit); Te Puni Kokiri; New Zealand Police; Sport New Zealand; the Housing New Zealand Corporation; and the former Mental Health Commission, The University of Auckland and Auckland UniServices Limited. Other support for the study has been provided by the NZ Health Research Council, Statistics New Zealand, the Office of the Children's Commissioner and the Office of Ethnic Affairs. The Starship Foundation provided the funding for the completion of this project on oral health.

Bullet points

- Oral hygiene and sugar intake and engagement with oral health professionals are important influences of early childhood caries.
- The relative importance of these factors is not known.
- Children who identify as Māori and Pacific ethnicity and those who live in socioeconomically deprived areas are at high risk of dental caries.
- This study shows that a dietary intake of items with a high concentration of sugar and refined starches are most strongly associated with dental caries.
- Learning Bayesian network analysis showed that the association between ethnicity, socioeconomic status and dental caries is likely to be mediated primarily by dietary factors.

References

1. Ministry of Health. *Our Oral Health: Key findings of the 2009 New Zealand Oral Health Survey.* Wellington: Ministry of Health;2010.

2. Craig E, Adams J, Oben G, Reddington A, Wicken A, Simpson J. *The health status of children and young people in the northern District Health Boards.* Dunedin: NZ Child and Youth Epidemiology Service;2011.
3. Broadbent JM, Thomson WM, Poulton R. Progression of dental caries and tooth loss between the third and fourth decades of life: a birth cohort study. *Caries Res.* 2006;40(6):459–465.
4. Sheiham A, James WP. A new understanding of the relationship between sugars, dental caries and fluoride use: implications for limits on sugars consumption. *Public Health Nutr.* 2014;17(10):2176-2184.
5. Sheiham A. Dietary effects on dental diseases. *Public Health Nutr.* 2001;4(2b):569-591.
6. Thornley S, Marshall R, Reynolds G, Koopu P, Sundborn G, Schofield G. Low sugar nutrition policies and dental caries: A study of primary schools in South Auckland. *J Paediatr Child Health.* 2017;53(5):494-499.
7. Marinho VCC, Higgins J, Logan S, Sheiham A. Fluoride toothpastes for preventing dental caries in children and adolescents. *Cochrane Database Syst Rev.* 2003(1).
8. Malik VS, Popkin BM, Bray GA, Despres JP, Willett WC, Hu FB. Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes: a meta-analysis. *Diabetes Care.* 2010;33(11):2477-2483.
9. de Koning L, Malik VS, Kellogg MD, Rimm EB, Willett WC, Hu FB. Sweetened beverage consumption, incident coronary heart disease, and biomarkers of risk in men. *Circulation.* 2012;125(14):1735-1741, S1731.
10. Morton SM, Atatoa Carr PE, Grant CC, et al. Cohort profile: growing up in New Zealand. *Int J Epidemiol*. 2013;42(1):65-75.
11. Morton SM, Ramke J, Kinloch J, et al. Growing Up in New Zealand cohort alignment with all New Zealand births. *Aust NZ J Public Health*. 2015;39(1):82-87.
12. Ministry of Health. *HISO 10001:2017 Ethnicity Data Protocols.* Wellington: Ministry of Health; 2017 2017.
13. Kassambara A, Mundt F. Factoextra: extract and visualize the results of multivariate data analyses. R package version 1.0. 4. 2017. In:2017.

14. Scutari M. Learning Bayesian networks with the bnlearn R package. *J Stat Softw.* 2009.
15. Evans EW, Hayes C, Palmer CA, Bermudez OI, Cohen SA, Must A. Dietary Intake and Severe Early Childhood Caries in Low-Income, Young Children. *J Acad Nutr Diet.* 2013;113(8):1057-1061.
16. Llena C, Forner LJCR. Dietary habits in a child population in relation to caries experience. *Caries Res.* 2008;42(5):387-393.
17. Utter J, Izumi BT, Denny S, Fleming T, Clark T. Rising food security concerns among New Zealand adolescents and association with health and wellbeing. *Kōtuitui: New Zealand Journal of Social Sciences Online.* 2018;13(1):29-38.
18. Shackleton N, Broadbent JM, Thornley S, et al. Inequalities in dental caries experience among 4-year-old New Zealand children. 2018;46(3):288-296.
19. Peres MA, Sheiham A, Liu P, et al. Sugar Consumption and Changes in Dental Caries from Childhood to Adolescence. *J Dent Res.* 2016;95(4):388-394.
20. Moynihan P. Sugars and Dental Caries: Evidence for Setting a Recommended Threshold for Intake–. *Adv Nutr.* 2016;7(1):149-156.
21. Thornley S, Marshall R. Measures of Association in Epidemiological Studies: How Best to Compare Discrete and Continuous Variables? *J Biom Biostat.* 2012;3:e111.

Table 1. Characteristics of the child cohort (n = 4,111), by dental caries status.

	dmft category					
	0 *n* (row %)	**1** *n* (row %)	**2 or 3** *n* (row %)	**4 or more** *n* (row %)	**Test**	***P*-value**
Total	3074	277	337	423		
Sex					χ^2 (3 df)	0.77
Boy	1556 (74.1)	142 (6.8)	179 (8.5)	224 (10.7)		
Girl	1490 (75.3)	134 (6.8)	158 (8.0)	196 (9.9)		
Ethnicity of mother					χ^2 (9 df)	< 0.001
European or Other	1768 (86.8)	103 (5.1)	84 (4.1)	83 (4.1)		
Māori	571 (66.1)	80 (9.3)	96 (11.1)	117 (13.5)		
Asian	411 (69.5)	40 (6.8)	64 (10.8)	76 (12.9)		
Pacific	259 (50.3)	49 (9.5)	81 (15.7)	126 (24.5)		
Deprivation quintile*					χ^2 (12 df)	< 0.001
1 or 2 (least deprived)	622 (83.2)	49 (6.6)	39 (5.2)	38 (5.1)		
3 or 4	687 (81.4)	53 (6.3)	50 (5.9)	54 (6.4)		
5 or 6	579 (80.2)	49 (6.8)	48 (6.6)	46 (6.4)		
7 or 8	593 (74.8)	52 (6.6)	58 (7.3)	90 (11.3)		
9 or 10 (most deprived)	527 (58.6)	69 (7.7)	130 (14.4)	174 (19.3)		

* NZDep06 measure of area-based socioeconomic deprivation

dmft: Decayed/missing/filled primary teeth, df: degrees of freedom.

Table 2. Oral health behaviours at two years, by dental caries status.

	dmft category					
	0 *n* (row %*)	**1** *n* (row %*)	**2 or 3** *n* (row %*)	**4 or more** *n* (row %*)	**Test stat.**	***P*-value**
Brushing frequency?					χ^2 (9 df)	< 0.001
Never	20	< 10	< 10	< 10		
Less Than Once A Day	267 (58.2)	44 (9.6)	64 (13.9)	84 (18.3)		
Once a day	1228 (73.9)	130 (7.8)	139 (8.4)	165 (9.9)		
Twice a day or more	1499 (80.3)	93 (5.0)	122 (6.5)	153 (8.2)		
Parental help with brushing?					χ^2 (6 df)	< 0.001
No	120 (58.0)	19 (9.2)	26 (12.6)	42 (20.3)		
Yes, sometimes	738 (69.6)	72 (6.8)	109 (10.3)	142 (13.4)		
Yes, most of the time	2135 (78.6)	176 (6.5)	190 (7.0)	217 (8.0)		
Breast feeding duration (months)					KW	0.052
Median (IQR)	4.5 (2.0, 5.7)	4.0 (1.7, 5.0)	4.0 (3.0, 6.0)	4.0 (3.0, 6.0)		
Fluoride toothpaste use?					χ^2 (6 df)	0.192
No toothpaste	23	< 10	< 10	< 10		
Not fluoride	175 (76.1)	13 (5.7)	18 (7.8)	24 (10.4)		
Yes	2305 (76.6)	194 (6.4)	228 (7.6)	281 (9.3)		
See dental therapist?					χ^2 (3 df)	0.228
No	1781 (75.1)	173 (7.3)	187 (7.9)	232 (9.8)		
Yes	1226 (74.7)	97 (5.9)	143 (8.7)	175 (10.7)		
Type of toothpaste?					χ^2 (3 df)	0.512
Adult	342 (73.2)	29 (6.2)	43 (9.2)	53 (11.3)		
Kids	2622 (75.5)	236 (6.8)	277 (8.0)	339 (9.8)		
Snack or drink before bed?					χ^2 (3 df)	0.553
No	1269 (74.7)	117 (6.9)	149 (8.8)	164 (9.7)		
Yes	1725 (75.4)	150 (6.6)	176 (7.7)	237 (10.4)		
Water source?					χ^2 (3 df)	0.082
Reticulated	2692 (75.2)	238 (6.6)	299 (8.3)	352 (9.8)		
Other	340 (73.0)	33 (7.1)	31 (6.7)	62 (13.3)		

dmft: Decayed/missing/filled primary teeth, IQR: interquartile range, KW: Kruskal-Wallis test, df: degrees of freedom.*Unless otherwise indicated.

Table 3. Food frequency categories at age two years (servings per week), by dental caries status for items that were strongly positively or negatively associated with dmft.

	dmft category				
	0	**1**	**2 or 3**	**4 or more**	***P*-value***
Adverse foods					
Sugary soft drinks					< 0.001
Median (IQR)	0 (0.0, 0.1)	0.0 (0.0, 0.4)	0.1 (0.0, 0.9)	0.3 (0.0, 1.5)	
White bread					< 0.001
Median (IQR)	1.5 (0.0, 7.0)	3.5 (0, 7.0)	3.5 (0.1, 14)	5.5 (1.4, 10.8)	
Fruit juice					< 0.001
Median (IQR)	0.4 (0.0, 1.8)	0.9 (0.2, 3.5)	1.5 (0.3, 3.5)	1.5 (0.3, 3.5)	
Confectionary or cakes					< 0.001
Median (IQR)	0.4 (0.2, 1.5)	0.8 (0.4, 1.8)	1.4 (0.4, 1.8)	1.5 (0.4, 3.5)	
Noodles or rice porridge					< 0.001
Median (IQR)	1.8 (1.5, 3.5)	1.8 (1.5, 3.5)	3.5 (1.5, 5.5)	3.5 (1.5, 5.5)	
Ice cream					< 0.001
Median (IQR)	0.4 (0.1, 0.9)	0.6 (0.1, 1.5)	0.8 (0.1, 1.5)	0.8 (0.2, 1.5)	
Refined breakfast cereals					< 0.001
Median (IQR)	0.9 (0.0, 3.5)	1.5 (0.0, 3.5)	1.5 (0.0, 3.5)	1.8 (0.0, 3.5)	
Takeaways					< 0.001
Median (IQR)	0.2 (0.0, 0.6)	0.3 (0.1,0.8)	0.4 (0.1, 1.5)	0.4 (0.1, 1.5)	
Protective foods					
Whole meal or grain bread					< 0.001
Median (IQR)	5.5 (0.8, 11)	3.5 (0.0, 7.0)	1.5 (0.0, 7.0)	1.5 (0.0, 7.0)	
Brassicas					< 0.001
Median (IQR)	0.8 (0.1, 1.4)	0.4 (0.0, 1.4)	0.4 (0.0, 0.9)	0.4 (0.0, 0.9)	
Cheese					< 0.001
Median (IQR)	3.5 (1.5, 7.0)	3.5 (0.9, 7.0)	2.9 (0.6, 7.0)	3.0 (0.4, 7.0)	

*Derived from Kruskal-Wallis, non-parametric test.

dmft: Decayed/missing/filled primary teeth, IQR: interquartile range, KW: Kruskal-IQR: interquartile range. Median and IQR relate to measures within category of dmft.

Table 4. Summary table of regression findings from quasi-Poisson regression model with outcome of count of decayed, missing or filled primary teeth due to caries.

Characteristic	Num. risk	Denom. risk	Crude IRR (95% CI)	Adjusted* IRR (95% CI)
Sex	Girl	Boy	0.89 (0.77 to 1.02)	0.93 (0.81 to 1.07)
Age at visit (years)	4.2†	5.2†	1.25 (1.11 to 1.42)	1.13 (1.01 to 1.27)
Ethnicity	Pacific	NZ Euro/Other	3.12 (2.51 to 3.88)	3.06 (2.45 to 3.83)
	Māori	NZ Euro/Other	3.12 (2.56 to 3.81)	2.13 (1.73 to 2.63)
	Asian	NZ Euro/Other	5.57 (4.58 to 6.77)	2.64 (2.12 to 3.29)
NZ Dep06	3 and 4	1 and 2 (least deprived)	1.28 (0.95 to 1.71)	1.12 (0.84 to 1.49)
	5 and 6		1.28 (0.95 to 1.74)	1.02 (0.76 to 1.37)
	7 and 8		2.00 (1.52 to 2.63)	1.25 (0.95 to 1.63)
	9 and 10 (most deprived)		3.64 (2.84 to 4.68)	1.63 (1.26 to 2.12)
FFQ (age 2 years)				
PC 1 (Sugary food linked to lowest quintile)	4	5 – Lowest quintile	0.55 (0.46 to 0.67)	0.76 (0.63 to 0.93)
	3		0.34 (0.27 to 0.43)	0.54 (0.43 to 0.67)
	2		0.32 (0.26 to 0.41)	0.55 (0.43 to 0.69)
	1 – Highest quintile		0.32 (0.26 to 0.41)	0.48 (0.38 to 0.61)
PC 2 (Vegetable intake linked to highest quintile)	4	5 - Lowest quintile	0.67 (0.54 to 0.82)	1.02 (0.84 to 1.25)
	3		0.54 (0.43 to 0.67)	0.94 (0.76 to 1.17)
	2		0.45 (0.35 to 0.56)	0.77 (0.61 to 0.96)
	1 – Highest		0.47 (0.37 to 0.59)	0.74 (0.59 to 0.94)

	quintile			
Brushing	At least daily	Less than daily	0.50 (0.42 to 0.60)	0.68 (0.57 to 0.81)

* Adjusted for all variables in the table.

† Comparisons taken at the 16th and 84th centiles of the distribution to approximate the comparison of a binary variable [21].

PC: Principal components. Num: numerator. Denom: denominator. FFQ: food frequency questionnaire. IRR: incidence rate ratio.

Figure legends

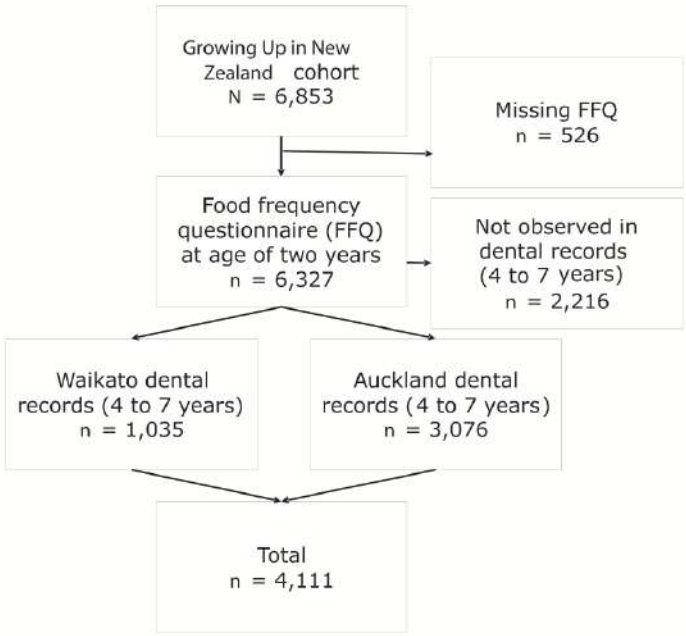
Figure 1. Participant flow.

Contrib: contribution to first and second principal components. Dim: dimension.

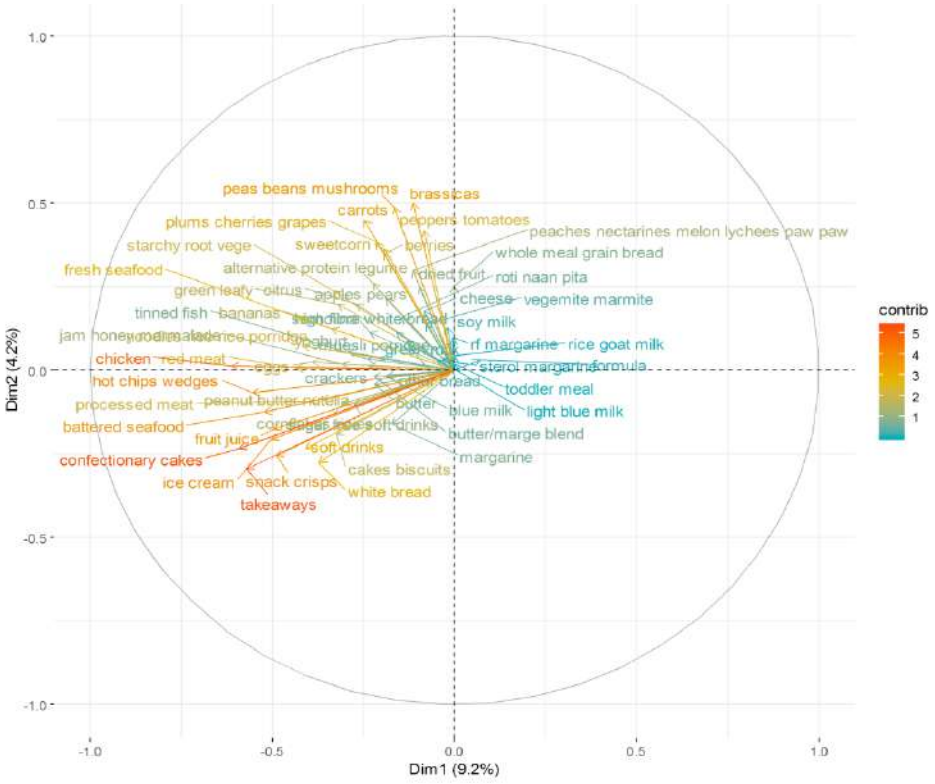
Figure 2. Biplot of contribution of food frequency questionnaire variables to first two principal components.

Figure 3. Directed acyclic graph, 'learnt' using the 'grow-shrink' algorithm.

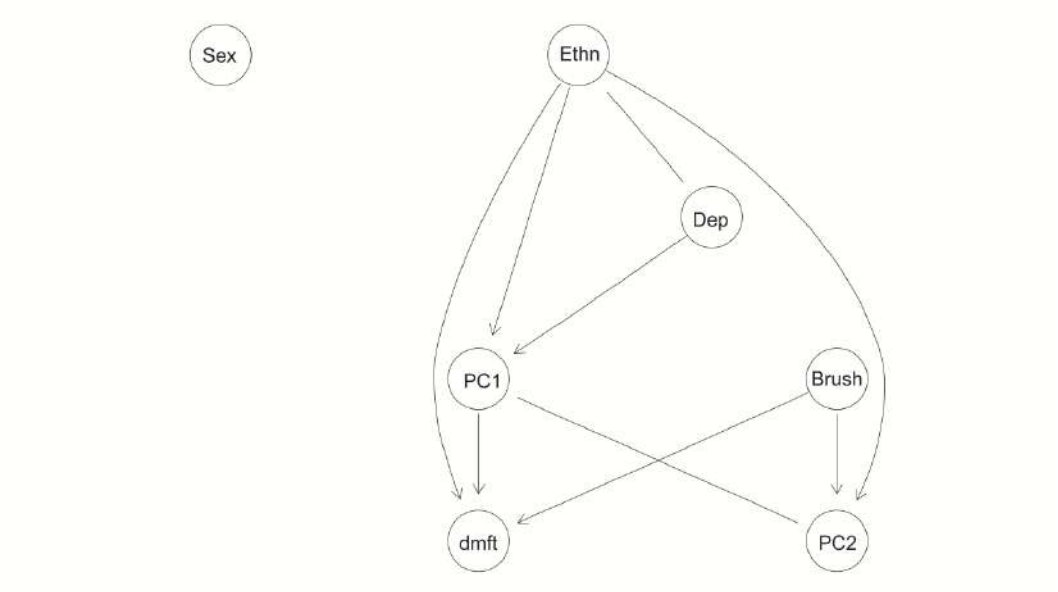
PC 1: principal component 1, PC 2: principal component 2 of food frequency questionnaire data. dmft: decayed, missing or filled primary teeth due to caries. Dep: area-based socioeconomic status. Brush: brushing teeth at least once per day.



ipd_12686_f1.tif



ipd_12686_f2.tif



ipd_12686_f3.tif