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Abstract:

Background: Diet cariogenicity plays a major role as both a protective and risk factor in the development of Early Childhood Caries (ECC).

Aim: Develop a scale measuring the cariogenicity of foods and beverages and employ it to describe the cariogenicity of young children's diets and predict dental caries outcomes.

Design: Scores of cariogenicity and consumption frequency were applied to food frequency questionnaire (FFQ) collected from an Australian Cohort study with three time-points of data. One-way ANOVA, with post hoc Tukey test compared mean cariogenic scale measured at 18 months between the subsample of children with caries classification at age 5 years.

Results: At 6 months children's mean cariogenic score was 10.05, increasing to 34.18 at 12 and 50.00 at 18 months. Mean cariogenic scale score at 18 months was significantly higher in children with advanced disease at 5 years (mean scale score: 59.0 ±15.9) compared to those that were healthy (mean score 47.7 ±17.5, p =0.007) or had mild-moderate disease (mean score 48.2 ±17.3, p =0.008).

Conclusions: The cariogenic diet scale provides a useful indication of the increasing cariogenicity of children's diets with age and highlights the incorporation of discretionary choice foods and beverages into the diets of young children much earlier than nutritionally recommended.

Introduction:

The cariogenicity of a food or beverage is defined as its ability to foster caries in humans under conditions conducive to caries formation. Numerous studies have assessed the cariogenicity of a range of food and beverages in recent years however a cariogenic diet scale to measure a diet's worth of food and beverages is yet to be devised. This research intends to firstly create a cariogenic diet scale and apply it to the VicGen birth cohort and subsequently apply the scale using caries outcomes of the cohort at a later age.

A food or beverage's cariogenicity is determined by physical properties including processing and refinement, acidic properties, type and content of carbohydrates and presence of protective factors like calcium, phosphate and casein (1). Cariogenicity is also determined by the way the food or beverage is consumed: the quantity, time of day, and frequency of consumption. Human trial studies have been conducted and strong causal evidence found (2-4), however these occurred over 35 years ago and would not be considered to be ethical by contemporary standards, therefore measures of cariogenicity must be determined through laboratory measures and population observation. Several methods exist for scientifically assessing the cariogenicity of foods/beverages; namely animal models, plaque pH, and intra-oral cariogenicity tests (5). Various studies have utilised these methods, however to our knowledge no published work has developed an evidence-based scale assessing cariogenic and anti-cariogenic nutrient properties, able to measure the cariogenicity of a diets worth of food and beverages. Most dietary studies look exclusively at associations between dental caries and on food sugar content without taking into account the contributions of other cariogenic and anti-cariogenic nutrient properties. A further limitation of past work has been a lack of methodological detail and dietary information collected from birth (6-8).

The VicGen birth cohort study has been collecting dietary data and conducting dental examinations from approximately 450 children from birth to 6 years of age. Dietary and dental data were collected at 1, 6, 12 and 18 months and 3, 4 and 5 years of age, thereby enabling tracking and examination of the diet's cariogenicity over this early period of life with supporting dental caries data (9).

The cariogenicity of the diet plays a major role as both a protective and risk factor in the development of Early Childhood Caries (ECC), defined as the presence of one or more decayed (non-cavitated or cavitated lesions), missing (due to caries) or filled tooth surfaces in children between birth and 71 months of age (3). ECC is one of the most common chronic childhood diseases. In the state of Victoria, Australia, 26.6% of children aged 5-12 years have had a tooth filled, 11.7% a tooth extracted and 7.1% have under-gone a general anesthetic for dental treatment (10).

Consequences of ECC include faltered growth and nutrition, restricted activities and long-term growth and developmental implications. Furthermore, ECC is the best predictor of future caries development (3) and there is overlap between many risk factors for dental caries and the development of overweight and obesity. Therefore preventing the development of ECC is important not only for individual children and families but to improve overall population health and wellbeing.

Dental caries is a dynamic disease process, taking place in the dental plaque on the surface of the tooth resulting in a loss of the equilibrium between the tooth enamel and surrounding plaque fluid, producing a loss of calcium and phosphate from the tooth. Soon after this initial carious challenge there is a gradual re-establishment of equilibrium and calcium and phosphate are replaced. However, if there is a net loss of these minerals over time irreversible tooth surface cavitation can occur. Four factors are necessary for dental caries development; a susceptible host or tooth surface, acidogenic and aciduric oral plaque bacteria, fermentable dietary carbohydrates, and time (11). The intention of this work is to give a greater understanding of all dietary factors, in addition to fermentable carbohydrates, and the role they play in the demineralisation of tooth surfaces.

The aims of this paper are to

1) Describe the development of a cariogenic diet scale using the evidence base on anti-cariogenic and cariogenic properties and

2) Apply the scale to dietary data to describe the cariogenicity of children's diets from 6-18 months of age and

3) Compare the cariogenic diet scale score at age 18 months to presence of caries at age 5 years.

Material and Methods:

Review of current evidence base for developing the Cariogenic Scale:

We conducted a comprehensive literature search and review to identify the cariogenic and anti-cariogenic properties of individual nutrients, presented in Table 1. Studies using methods approved by the Scientific Consensus Conference for Methods for the Assessment of the Cariogenic Potential of Foods held in 1985 (5), incorporating animal models, enamel slab experiments and plaque pH testing were included. These study types provide evidence that cannot be collected from epidemiological studies and although not taking place in vivo, provide strong insight into cariogenicity. Literature reviews, human trial studies and longitudinal studies that highlighted clear relationships between dietary factors and caries development measuring habits and disease progression over time to monitor change were included. Also selected for inclusion were government documents, position statements and nutritional/oral health textbook. Cross-sectional studies were excluded due to their inherent limitation in that caries is a progressive disease in which dietary habits pre-dating those captured in surveys are causal factors. Only studies published in English were considered and no publication date restrictions were applied.

Additional properties of food affecting cariogenicity.

Evidence suggests form, consistency, retention time and frequency of consumption of food/beverages significantly affects cariogenicity and dental caries (3, 12-14). When fermentable carbohydrates are ingested, the pH of the dental plaque fluid at the surface of the tooth drops and the retention time of a food/beverage in the oral cavity affects both how long the pH remains lowered and the amount of acid produced. Therefore, sticky and retentive products have a higher cariogenicity compared to foods/beverages that are eliminated quickly from the oral cavity. Frequency of consumption is the most closely related factor to the incidence of dental caries (1, 3, 15-17). All foods/beverages containing fermentable carbohydrate display cariogenicity however when frequent ingestion of fermentable carbohydrates occurs this results in an extended period of low plaque pH and increased demineralization.

Additional food/beverage properties affecting cariogenicity include food acids and food fortification. Foods/beverages fortified with nutrients that aid in the re-mineralising of teeth, including calcium and phosphorus, can reduce the original cariogenicity of a food or beverages nutritional composition (18, 19). Acids acting as erosive agents, alone are not cariogenic, however prolonged exposure to acids can permanently damage teeth by causing erosion and demineralization through a chemical pathway not involving bacteria. Acidic foods/beverages facilitate pH to drop below 5.5 and over time weaken tooth's structure. Foods/beverages that are acidic and contain sugars are particularly concerning, as they are both acidic and cariogenic concurrently being deleterious to tooth surfaces. (17, 20)

Creating the cariogenic diet scale:

Based on the literature review, ten scored categories were created and descriptions including nutritional composition parameters defined. See below for descriptions and refer to Table 2 for nutritional composition details and food/beverage allocation.

Cariostatic (value =0): These foods/beverages contain no fermentable carbohydrates and are primarily composed of fat and protein.

Anti-cariogenic potential (value=0): Do not contain starches (processed or unprocessed) and contain less than 5 grams of sugar per 100grams, primarily lactose. The majority of their composition is protein and/or fat and they are a significant source of at least one of these protective nutrients; calcium, fluoride, phosphorus or casein.

Low cariogenic potential – milk based (value=1): Contain minimal starches and between 6-10gram of sugar per 100 grams. Majority of their composition is protein and/or fat and they contain moderate to high amounts of protective nutrients; calcium, fluoride, phosphorus or casein.

Low cariogenic potential – non-milk based (value=1): Comprised mostly of unprocessed starch with no processed starches and minimal amounts of fat and protein. Contain between 1-10grams of sugar and minimal amounts of protective nutrients.

Moderate cariogenic potential -fresh (value =2): Contain moderate amount of un-processed starch, no processed starch, 11-20grams of sugar with minimal amounts of protective nutrients. Have moderate retention on teeth.

Moderate cariogenic potential –processed and added sugars (value =2): Contain low to moderate amounts of processed and un-processed starches, between 11-20grams of sugars and low to moderate source of protective nutrients.

High cariogenic potential- liquids (value=3): These liquids contain between 10-15grams/100grams of sugar and minimal starches, protective nutrients, fat and protein. They are not retentive (however wash over all teeth surfaces as they are liquids) and contain moderate to high amounts of acids.

High cariogenic potential- foods (value=3): contain high amounts of processed starch with 1-5 grams of sugar. Contain minimal amounts of un-processed starch and protective nutrients and low to moderate amounts of fat and protein. These foods are highly retentive.

Severe cariogenic potential – very high sugar (value=4): contain over 50grams/100grams of sugar and have high retention on teeth. Low amounts of both processed and un-processed starches, trace to minimal amounts of protective nutrients, fat and protein.

Severe cariogenic potential- high sugar highly processed starch (value=4): contain a mix of highly processed starches and at least 20grams/sugar per 100grams, which are highly retentive on teeth. Contain low to moderate amounts of fat and protein and minimal protective nutrients.

Supplementary material with the allocation of each of the food and beverages into their scored measure of cariogenicity is available with this article and is titled the rationale for allocating cariogenicity to food and beverages for the development of a cariogenic diet scale. This allows those wishing to utilize this scale to see the rationale behind each individual food and beverages potential cariogenic rating.

Participants

Child data was collected from the VicGen birth cohort study, which began in 2008. VicGen was established as a longitudinal, multi-dimensional study to investigate the factors involved in the development of early childhood caries (ECC) within a socio-ecological model of health. Families with newborn infants (2-4 weeks of age) were recruited from Maternal and Child Health (MCH) Centres in seven local government areas (LGA) in Victoria, Australia. MCH nurses invited eligible women (not intending to move in the next 12 months, no severe illness in family, children did not require specialist care, no parental mental illness) with newborn children to participate at their child's health and wellbeing visit. The research team then contacted women who were interested, with 466 of 915 invited women who completing the baseline study visit. The LGA's were purposely selected to provide a higher level of disadvantage and cultural diversity and were in a mix of metropolitan, regional and rural areas. This study was approved by the University of Melbourne Human Research Ethics Committee (HREC 0722543) and its protocol (9) and cohort profile have been published (21).

Measures

Parent-reported child dietary data was collected at child age 6, 12 and 18 months via a 44-item food frequency questionnaire (FFQ). Parents reported their child's usual consumption of 32 food items with eight response options ranging from 'never' to '4 or more times per day'. Parents were also asked about their child's daily, weekly or monthly consumption of 12 beverages. This FFQ had been piloted for feasibility and acceptability, and examined for its reliability and validity (22). Child and family socio-demographic variables were collected at each time-point.

Creating the overall scored cariogenic diet scale measure:

The Australian Guide to Healthy Eating (AGTHE) and the Australian Infant Feeding Guidelines (IFG) (23, 24) recommend what foods and beverages are necessary for a healthy diet, referred to as 'core' and those that are not recommended being referred to as 'discretionary' foods and beverages. In creating the cariogenic diet scale, we have only scored discretionary foods and beverages. Although some core food and beverages display a scored level of cariogenicity, they are recommended for consumption in the National Guidelines so are not included into the scored scale. This has been incorporated to not discourage the consumption of core foods necessary for a healthful diet. Table 3 displays all the core foods measured in our FFQ and the frequency consumption is based on the daily serves recommended in the AGTHE and IFG (23, 24) There was one exception, with dried fruit included as part of the cariogenic potential scale, as the nutritional composition of this fruit could have significant influence on dental decay.

Table 4 shows all the scored discretionary choice foods. Never, low, moderate, high and very high intake of foods and beverages was determined by weekly frequency of consumption and allocated a value between 0 (never) and 4 (severe). Clinical judgment by a dietitian along with the AGTHE and IFG recommendations was used to allocate consumption frequency rating, as consumption frequency is cited as the most closely related factor to the incidence of dental caries. A score for each discretionary food and beverage was generated by multiplying the cariogenicity weighting (2-moderate, 3-high or 4-severe) by the consumption frequency (0, 1, 2, 3 or 4), see details in Table 4 for the value of consumption frequency of discretionary choice foods. For example eating donuts three times a week would warrant a score of 8, cariogenicity weighting value of 4 (severe) multiplied by a consumption frequency value of 2. The scores for all discretionary food and beverages were summed to produce an overall cariogenicity score between 0 and 276 for each child at each 6, 12 and 18 months of age. Where ≥50% of the food and beverage items measured in each cariogenicity weighting were present, the average score of the other items in the cariogenic group was used to address missing data. Participants with >50% of the variables missing for one cariogenicity weighting group were excluded from analysis. Nutella and peanut butter were combined as one item in the FFQ, and as the cariogenicity of these items differs markedly, this item was excluded from the analysis.

Caries Classification

Clinical oral examinations of children in the VicGen cohort were completed at 18 months and 3, 4 and 5 years of age (21). Modified International Caries Detection and Assessment System criteria (ICDAS II) were used for caries assessment. ICDAS II is validated for use with children and has been shown to be of acceptable validity and reproducibility for epidemiological and cohort studies (25, 26). In total 259 children completed the final visit at 5 years of age (21). For the current study a series of inclusion criteria were applied to those 259 children, including non-contradictory clinical data collection over all four visits and no missed data collection visits. After completion of data cleaning, a final cohort of 170 children was available for analysis. These children were classified into three groups based on their ICDAS II scores at 5 years of age: A Healthy group who had no early childhood caries as determined by ICDAS scores of 0; a Mild-moderate disease group who had one or more lesions with an ICDAS score of 4 or below; and an Advanced disease group who had one or more ICDAS scores of 5 or above.

Analysis

Simple descriptive statistics (mean, range, standard deviation) were produced for the cariogenic scale score for all children with data available at age 6, 12 and 18 months.

A one-way ANOVA, with post hoc Tukey test was used to compare the mean cariogenic scale measured at 18 months between the subsample of children with a caries classification available at age 5 years (healthy, mild-moderate disease, advanced disease).

Results

Four hundred and sixty-six mother-child dyads were recruited into the study at baseline, and retention of participants varied across the second, third and fourth time-points of data collection. A cariogenic scale score was created for 364, 321 and 367 participants at time-points 6, 12 and 18 months respectively. Table 5 shows the characteristics of those children included in the analysis. Reasons for non-participation across time-points included participants moving from the area, loss to follow up, electing to miss a time-point and withdrawal due to time constraints (21).

At age five years, 170 children were classified into one of three caries groups: Healthy (n=67), Mild-moderate disease (n=75), Severe disease (n=33). Table 6 outlines the characteristics of these three groups. The mild-moderate disease group had a higher proportion of children from disadvantaged areas than the healthy or advanced disease groups.

Cariogenic potential of the diet

The mean cariogenic scores of the diets of children increased across each time-point: 6 months: 10.05 (sd: ±12.93, range 0-78); 12 months: 34.18 (sd: ±18.74, range 0-117) and 18 months: 50.00 (sd: ±18.31, range 8-126). The cariogenicity score was positively skewed at the 6 month time-point. At the 12 and 18 month time-points the children had a normal population distribution. Figures 1, 2 and 3 show the frequency distribution of cariogenic scores across the three waves of data collection.

Cariogenicity and caries outcome

The mean cariogenic scale score at age 18 months was significantly higher in children at age 5 years in the Advanced disease group who had a mean cariogenic scale score of 59.0 ± 15.9 compared to those in the Healthy group who had a mean score of 47.7 ± 17.5 ($p = 0.007$) or those in the Mild-moderate disease group who had a mean score of 48.2 ± 17.3 ($p = 0.000$). There was no difference in mean cariogenic scale score between the Healthy and Mild-moderate disease groups ($p = 0.985$).

Discussion

This paper has created an evidence informed cariogenic diet scale through a review of current literature of anti-cariogenic and cariogenic nutrient properties to enable classification of food and beverages into ten scored categories of cariogenicity. Through combining these scores of cariogenicity with food and beverages consumption frequency we were able to produce an overall cariogenic potential score (0-276) for each child in the VicGen birth cohort study across three time-points; 6, 12 and 18 months and map the score at 18 months to caries outcome at 5 years of age.

This scale has built upon previous work in that it takes into account the combined influences of nutritional composition, frequency and the anti-cariogenic and cariogenic properties of foods, which previous cariogenic work has not. Previous research has not collated a diet's worth of food and beverages and the methodology regarding the creation of scales and literature included is limited. Additionally, these studies did not record if they had used validated dietary measures and had not followed participants from birth therefore lacked longitudinal data, particularly of early dietary habits (6-8).

This scale provides a method for tracking how children's diets change in relation to their cariogenicity from birth into early childhood. It was expected the diets of these children would became increasingly cariogenic with age, as a wider variety of foods and beverages are introduced. At six months when foods are first introduced, the cariogenicity of children's diets was low and positively skewed, explained by the relatively small variety of foods and beverages children were consuming. By 12 and 18 months the scores produced a normal population distribution and the curve increased in cariogenicity from the 12 month to the 18 month time-points. As the score of cariogenicity only measures discretionary food and beverages, those not recommend for a healthful diet, this supports previous research findings that have shown the introduction of discretionary foods and beverages is occurring from a very young age, in the case of our work, as early as age 6 months and is increasing quickly (12, 27-29).

Children who developed advanced disease by age five years, had a mean scale score approximately 10 points higher at age 18 months than those children who were either healthy or had mild/moderate disease at age five years. Interestingly, those that were deemed healthy and those with mild/moderate disease had a similar scale score at age 18 months. These results suggest that the scale may be more useful as a predictor of children on a path to severe disease, rather than mild disease.

Evidence relating to the timing of children's diets becoming cariogenic and the specific foods and beverages being consumed is important for population health interventions as it helps to identify the time-point(s) at which health promotion information and intervention should be targeted for optimum effectiveness. As seen in this work, diet cariogenicity increases between 6 and 12 months of age and by age 18 months there is a much higher intake of discretionary foods and thus cariogenicity. This highlights the need for intervention prior to the age of 12 months of age in order to combat the effect these foods may have on current and future oral health.

This work has focused on giving a deeper exploration into dietary factors and their role in caries development outside the generally well known 'dental decay promoting' foods like soft drinks and lollies. This work has provided a picture of the distribution of the cariogenicity of the diet across a population and how increasingly cariogenic children's diets are becoming at a very young age.

In conclusion the scale provides a useful advance to the assessment and analysis of the cariogenicity of the diet within the context of epidemiological studies, particularly for young children. It does this by offering a continuous diet cariogenicity score with the prediction of dental caries as the outcome measure.

Limitations

This scale is able to give an estimate of the cariogenicity of certain foods, but within the context of a diet where foods are consumed together it is possible that there will be some combinations that will exert a protective effect. If cheese, an anti-cariogenic food, is consumed at the same time as muffins, a severe cariogenic food, then the cheese will exert its protective effects thereby reducing the demineralization that would have occurred by just eating a muffin alone. However we have only collected information on frequency rather than the time of day and combination of foods and beverages. Additionally milk, infant formula and breast milk while being anti-cariogenic to low cariogenicity, if left to pool in the mouth when a child goes to bed with a bottle or falls asleep on the breast can become highly cariogenic. With a slowed saliva flow rate and although only containing lactose, this is still a sugar which will promote decay. Again as we have not collected when foods and beverages have been consumed it is behind the scope of this paper to include.

The dietary measures included in the scale do not include fats and oils however as they are not involved in the direct caries process this has little to no impact. In this study, peanut butter and Nutella were grouped together and chocolate and lollies were grouped together however the cariogenicity of each product varies. As a result we excluded nutella and peanut butter from the analysis, however included chocolate and lollies and allocated them as 'severe' based on the nutritional profile of lollies, therefore we may be slightly over-estimating the contribution of this combined item to the index score.

Importance for paediatric dentists

- This cariogenic diet scale provides a useful non-invasive method to predict the development of early childhood caries by measuring consumption of "discretionary" foods and beverages providing a useful indication of the increasing cariogenicity of children's diets with age.
- As the score of cariogenicity only measures "discretionary" food and beverages, this supports previous research findings that have shown the introduction of discretionary foods and beverages is occurring from a very young age.
- Evidence highlighting the timing of children's diets becoming cariogenic and the specific foods and beverages being consumed is important for population health interventions as it helps to identify the time-points at which health promotion information and intervention should be targeted for optimum effectiveness. Paediatric dentists are in an optimal position to provide information and intervention prior to the

development of caries and to combat the effect these foods may have on current and future oral health.

References:

1. Firestone AR, Schmid R, Muhlemann HR. Effect of the Length and Number of Intervals between Meals on Caries in Rats. Caries Res. 1984;18(2):128-33.
2. Scheinin A, Makinen KK, Ylitalo K. Turku sugar studies. V. Final report on the effect of sucrose, fructose and xylitol diets on the caries incidence in man. Acta Odontol Scand. 1976;34(4):179-216.
3. Gustafsson BE, Quensel CE, Lanke LS, Lundqvist C, Grahnen H, Bonow BE, et al. The Vipeholm dental caries study; the effect of different levels of carbohydrate intake on caries activity in 436 individuals observed for five years. Acta Odontol Scand. 1954;11(3-4):232-64.
4. Harris R. Biology of the Children of Hopewood House, Bowral, Australia. 4. Observations on Dental-Caries Experience Extending over Five Years (1957-61). Journal of Dental Research. 1963;42(6):1387-99.
5. Hefferen JJ. Proceedings of the Scientific Conference on methods for assessment of the cariogenic potential of foods. San Antonio, Texas. J Dent Res Sp issue. 1986;65:1473-544.
6. MacKeown JM, Faber M. Frequency of consumption of cariogenic food items by 4-month-old to 24-month-old children: comparison between two rural communities in KwaZulu-Natal, South Africa. International journal of food sciences and nutrition. 2005;56(2):95-103.
7. Evans EW, Hayes C, Palmer CA, Bermudez OI, Naumova EN, Cohen SA, et al. Development of a pediatric cariogenicity index. Journal of public health dentistry. 2013;73(3):179-86.
8. Giacaman RA, Fernandez CE, Diaz SN. Fermentable carbohydrate dietary consumption measured by a cariogenicity scoring system and caries experience in youth and adults. Revista chilena de nutricion. 2012;39(4):116-28.
9. de Silva-Sanigorski AM, Calache H, Gussy M, Dashper S, Gibson J, Waters E. The VicGeneration study--a birth cohort to examine the environmental, behavioural and biological predictors of early childhood caries: background, aims and methods. BMC public health. 2010;10:97.
10. Australian Department of Education and Early Childhood Development. The State of Victorias Children. . 2010.
11. Marsh PD, Martin MV, Lewis MAD, Williams DW. Oral Microbiology 5th ed. Livingstone C, editor: Elsevier; 2009.

12. Webb K, Rutishauser I, Knezevic N. Foods, nutrients and portions consumed by a sample of Australian children aged 16-24 months. Nutrition & Dietetics. 2008;65(1):56-65.

13. Edmondson EMS. Food Composition and Food Cariogenicity Factors Affecting the Cariogenic Potential of Foods. Caries Res. 1990;24(Suppl 1):60-71.

14. Mundorff SA, Featherstone JD, Bibby BG, Curzon ME, Eisenberg AD, Espeland MA. Cariogenic Potential of Foods I. Caries in the Rat Model. . 24. 1990;5(344-55).

15. Firestone AR, Schmid R, Muelemann HR. Cariogenic effects of cooked wheat starch alone or with sucrose and frequency-controlled feedings in rats. Arch Oral Biol. 1982;27:759-63.

16. Diet, nutrition and the prevention of chronic diseases. Geneva: World Health Organization. 2003. WHO Technical Report Series, No 916. 2003.

17. Sheiham A. Dietary effects on dental diseases. Public Health Nutrition. 2007;4(2b).

18. van Loveren C, Broukal Z, Oganessian E. Functional foods/ingredients and dental caries. European journal of nutrition. 2012;51 Suppl 2:S15-25.

19. Wang X, Lussi A. Functional foods/ingredients on dental erosion. European journal of nutrition. 2012;51 Suppl 2:S39-48.

20. Lussi A, Jaeggi T, Zero D. The Role of Diet in the Aetiology of Dental Erosion. Caries Res. 2004;38(Suppl 1):34-44.

21. Johnson S, Carpenter L, Amezdroz E, Dashper S, Gussy M, Calache H, et al. Cohort Profile: The VicGeneration (VicGen) study: An Australian oral health birth cohort. International journal of epidemiology. 2017;46(1):29-30.

22. Carpenter L, Boak R, Porter J, Flood V, Waters E. Reliability and validity of a food frequency questionnaire with six month to six year old children Journal of Nutrition and Intermediary Metabolism. 2014;1:28-9.

23. National Health and Medical Research Council. Australian Dietary Guidelines. [press release]. National Health and Medical Research Council2013.

24. Infant Feeding Guidelines: Information for health workers in Australia Australia: National Health and Medical Research Council 2012.

25. Braga MM, Oliveira LB, Bonini GA, Bonecker M, Mendes FM. Feasibility of the International Caries Detection and Assessment System (ICDAS-II) in epidemiological surveys and comparability with standard World Health Organization criteria. Caries Res. 2009;43(4):245-9.

26. Shoaib L, Deery C, Ricketts DN, Nugent ZJ. Validity and reproducibility of ICDAS II in primary teeth. Caries Res. 2009;43(6):442-8.

27. Chan L, Magarey AM, Daniels LA. Maternal feeding practices and feeding behaviors of Australian children aged 12-36 months. Maternal and child health journal. 2011;15(8):1363-71.

28. Webb KL, Lahti-Koski M, Rutishauser I, Hector DJ, Knezevic N, Gill T, et al. Consumption of 'extra' foods (energy-dense, nutrient-poor) among children aged 16-24 months from western Sydeny, Australia. Public Health Nutrition. 2005;9(8):1035-44.
29. Lioret S, McNaughton SA, Spence AC, Crawford D, Campbell KJ. Tracking of dietary intakes in early childhood: the Melbourne InFANT Program. European journal of clinical nutrition. 2013;67(3):275-81.
30. Vacca-Smith AM, Venkitaraman AR, Quivey RGJ, Bowen WH. Interactions of streptococcal glucosyltransferases with alpha-amylase and starch on the surface of saliva-coated hydroxyapatite. Arch Oral Biol. 1996;41(3):291-8.
31. Leme AFP, Koo H, Bellato CM, Bedi G, Cury JA. The Role of Sucrose in Cariogenic Dental Biofilm Formation--New Insight. Journal of Dental Research. 2006;85(10):878-87.
32. Schachetele CF. Dental caries: prevention and control. In: Stallard RE, ed. A textbook of preventative dentistry. 2nd ed. Philiadelphia: W.B. Saunders, 1982: 241-531982.
33. Moynihan P. Update on the nomenclature of carbohydrates and their dental effects J Dent 1998;26(3):209-18.
34. Moynihan P. The interrelationship between diet and oral health. Proceedings of the Nutrition Society. 2007;64(04):571-80.
35. Moynihan PJ. The role of diet and nutrition in the etiology and prevention of oral diseases Public Health Nutrition. 2004;7(1A):201-26.
36. Rugg-Gunn A, Woodward M. Milk and Oral Health 2011.
37. Grenby TH, Andrews AT, Mistry M, Williams RJ. Dental caries-protective agents in milk and milk products: investigations in vitro. J Dent. 2001;29(2):83-92.
38. Warner EA, Kanekanian AD, Andrews AT. Bioactivity of milk proteins: 1. Anticariogenicity of whey proteins. Int J of Dairy Tech. 2001;54(4):151-3.
39. Curzon MEJ. Food and dental caries - recent developments on testing the cariogenic potential of foods. Nutrition Bulletin. 1989;14(1):36-45.
40. Edgar WM. Extrinsic and intrinsic sugars: a review of recent UK recommendations on diet and caries. Caries Res. 1993;27(Suppl 1):64-7.
41. Department of Health. Dietary Reference Values for Food and Energy and Nutrients for the United Kingdom. Committee on Medical Aspects of Food Policy. COMA. Report No 41. London: H.M. Stationery Office, 1991.
42. Moynihan P, Petersen PE. Diet, nutrition and the prevention of dental diseases. Public Health Nutrition. 2007;7(1a).

43. Lingstrom P, Holm J, Birkhed D, Bjorck I. Effects of variously processed starch on pH of human dental plaque. Scand J Dent Res. 1989;97(5):392-400.

44. Lingstrom P, vanHoute J, Kashket S. Food Starches and Dental Caries Crit Rev Oral Biol Med. 2000;11(3):366-80.

45. Brudevold F, Goulet D, Tehrani A, Attarzadeh F, Van Houte J. Intraoral Demineralization and Maltose Clearance from Wheat Starch. Caries Res. 1985;19(2):136-44.

46. Kashket S, Zhang J, Van Houte J. Accumulation of Fermentable Sugars and Metabolic Acids in Food Particles that Become Entrapped on the Dentition. Journal of Dental Research. 1996;75(11):1885-91.

47. Brudevold F, Goulet D, Attarzadeh F, Tehrani A. Demineralization Potential of Different Concentrations of Gelatinized Wheat Starch. Caries Res. 1988;22(4):204-9.

48. Grenby TH, Paterson FM. Effect of sweet biscuits on dental caries in rats. Br J Nutr. 1972;27:195-99.

49. Rugg-Gunn AJ. Nutrition and Dental Health. Oxford: Oxford Medical Publications.1993.

50. World Health Organization and Food and Agriculture Organization of the United Nations. Diet, nutrition and prevention of chronic diseases: report of a joint WHO/FAO expert consultation. WHO Technical Report Series 916. Geneva: World Health Organization. . 2003.

51. Reynolds E. Nutritional and Oral Health- Promoting Properties of Dairy Products: Caries Prevention and Oral Health In: Roginski H, editor. Encyclopedia of Dairy Sciences. 3. 2nd ed2002.

52. Rugg-Gunn AJ, Edgar WM, Geddes DA, Jenkins GD. The effect of different meal patterns upon plaque pH in human subjects. Br Dent J. 1975;139(9):351-6.

53. Schuster GS. Anticaries and antiplauque potential of free fatty acids in vitro and in vivo. Pharmaceutical Therapeutics in Dentistry. 1980;5((1-2)):25-33.

54. Mahan K, Escott-Stump S. Krause's Food and Nutrition Therapy 12th 12th ed. Thurlow JP, editor: Elsevier Health Services 2006 September 2007.

55. Peres RC, Coppi LC, Volpato MC, Groppo FC, Cury JA, Rosalen PL. Cariogenic potential of cows, human and infant formula milks and effect of fluoride supplementation. . Br J Nutr. 2009;10(3):376-82.

56. Rugg-Gunn AJ, Do L. Effectiveness of water fluoridation in caries prevention. Community dentistry and oral epidemiology. 2012;40 Suppl 2:55-64.

57. Fluorides and oral health. Geneva: World Health Organization; 1994. WHO Technical Report Series, No. 846.

58. Nutrient Reference Values for Australia and New Zealand Including Recommended Dietary Intakes Australia: National Health and Medical Research Council Australia 2006.

Table 1: Cariogenic and anti-cariogenic properties of macro and micronutrients influencing the development of dental caries

Nutrient	**Description**	**Cariogenicity status**	**Cariogenic or anti-cariogenic properties**	**Types of foods**
Dietary sugars: Sucrose, Fructose and Glucose	All dietary carbohydrates (CHO) • Sucrose is made up of fructose and glucose. Can be naturally found or added to foods. • Fructose also known as fruit sugar • Glucose is also referred to as blood sugar	Cariogenic	• These are fermentable CHOs, metabolised by oral bacteria studies however indicate sucrose is the preferred source for MS (17, 30, 31) • Sucrose is a specific substrate for the synthesis of glucans which promote attachment of MS to teeth and is readily fermented by saccharolytic plaque bacteria (17, 30-32) • All these sugars facilitate the adherence of dental plaque to the enamel of teeth (3)	Sucrose is added to baked goods lollies, roll ups, soft drink. Sucrose is found naturally in fruit and vegetables. Fructose is found naturally in fruit and honey. Glucose is found in all CHO foods
Lactose	Also known as milk-extrinsic sugar, most commonly found in dairy products.	Cariogenic	• Least cariogenic of the common CHO (33-35) • In dairy products becomes of lower carcinogenicity due to the protective components of calcium, phosphate and casein (36-39)	Milk, yoghurt and cheese

Extrinsic sugars	Found freely in food or are added during cooking and processing	Cariogenic	• More readily available to be fermented by oral bacteria thus are more cariogenic than intrinsic sugars (16, 40, 41) • Can be released from foods through cooking and processing making them more cariogenic.	Cakes, biscuits, stewed and dried fruits, fruit juice, lollies
Intrinsic sugars	Sugars naturally found within the cellular structure of foods	Cariogenic	• Evidence suggests these sugars pose little threat towards development of caries (16, 40-42) • They are within the cellular structure of foods thereby are less bioavailable to oral bacteria than extrinsic sugars	Fruit, vegetables
Starches (processed)	Plant cells store glucose as starches which are long, branched and unbranched chains of glucose molecules	Cariogenic	• Starch undergoes gelatinization through cooking or processing increasing fermentability. Gelatinized starches are more susceptible to breakdown by enzymes and therefore bio-available for bacterial acid production (33, 43, 44). • Trapped food particles on teeth undergo rapid hydrolysis, resulting in the substrates maltose and maltotriose which contribute to bacterial acid production (45, 46)	Cakes, biscuits, puddings, muffins, potato chips, savoury crackers spreads and bread.

			• The combination of sucrose and starches can induce rapid and prolonged pH drops. Starches increase the availability of fermentable carbohydrates as a result of starch itself acting as a co-cariogen through promoting the retention of foods with lower levels of sugar to the teeth (1, 13, 15, 34, 46-48)	
Starches (unprocessed)			• Non-processed and raw starches have little to no effect on the development of dental caries (13, 34, 42, 45, 49, 50)	Grains (wheat, rice) legumes and root vegetables (potato, sweet potato)
Protein	Proteins are a vital structural and working substance in all cells	Anti-cariogenic	• Display anti-cariogenic properties and are protective against demineralization (38, 49) • Many oral bacteria can metabolise some amino acids in protein to produce alkali, thereby raising plaque pH (11) • Casein, milks most abundant protein stabilises calcium and phosphate producing a saturated solution that prevents demineralisation and promotes remineralisation of tooth enamel (36, 51)	Eggs, meat, nuts, milk, yoghurt, cheese

Fat	Fat refers to the class of nutrients known as lipids. This include triglycerides (fats and oils), phospholipids and sterols	Cariostatic	• Free fatty acids (FFA) may coat teeth, physically decreasing amount of fermentable carbohydrate. • Fats may also accelerate oral clearance of food particles thereby reducing the time available for bacterial metabolism to occur (52, 53)	Oil, butter, nuts, meat, dairy products
Water		Cariostatic	• Helps wash away particles of food and reduces the amount of substrate that bacteria can ferment (54)	Water
Calcium	The most abundant mineral in the body and one of the most important components of teeth	Anti-cariogenic	• Critical in development of tooth enamel in children and diffuses into the enamel of the tooth and re-mineralizes it (54) • Increases calcium concentration in plaque which inhibits demineralization. Calcium in milk exhibits protective effects even in the absence of proteins, lactose, fat and casein (36, 37)	Milk, cheese, yoghurt, almonds, soy products
Fluoride	A protective mineral involved in tooth health	Anti-cariogenic	• During the mineralization of teeth, calcium and phosphate form crystals called hydroxyapatite. Fluoride replaces the hydroxyl (OH) ions of hydroxyapatite crystal forming fluorapatite which makes teeth more	Fluoridated tap water, infant formula, tea

			resistant to acid challenge (42) . Fluoride inhibits bacterial metabolism of sugars thus decreasing acid production by bacteria and decreasing enamel demineralization (16, 42) • Fluoride supplementation has been shown to reduce the cariogenic effect on foods/beverages (55) and public water fluoridation has been proven to reduce caries prevalence worldwide (56, 57).	
Phosphate	A protective mineral in tooth health	Anti-cariogenic	• Calcium requires phosphate to maximise its ability to form hydroxyapatite or fluorapatite (54, 58)	Meat, eggs, milk and fish.
Alternative sweeteners also known as sugar alcohols	Main ones are xylitol, sorbitol, mannitol maltitol, lactitol and hydrogenated starch hydrolysates	Cariostatic or anti-cariogenic	• These sweeteners are slowly metabolised by oral bacteria and so are usually considered non cariogenic (2, 13) • Xylitol however is not fermented by oral bacteria and has anti-cariogenic properties. In the Turku studies caries increment reduced in relation to xylitol consumption (2)	Chewing gum, sugar free drinks, sweets, gum

Table 2: Grouping of Food Frequency Questionnaire foods by cariogenic rating, nutrient and other properties

Foods in the Food Frequency Questionnaire[1]	Cariogenic score and rating	Nutrient Composition					Additional properties: Retention (R) and Acid content (A)
		Un-processed starch	Processed starch	Sugar per 100g	Fat and Protein	Protective nutrients; Calcium (Ca), Fluoride (F), Phosphorus (P)[2]	
Eggs, Nuts, Luncheon meats, Meat/Fish, Water, Tea or coffee, Herbal drinks/tea, Non fluoridated water	0-Cariostatic	These foods don't contain starch		None	Majority of composition	Minimal amounts < 50mg/100grams - Ca < 0.1mg/L-F	R- low A- low
Milk, Cheese, Fluoridated water	0-Anti-cariogenic	These foods don't contain starch		Primarily lactose and <5g	Majority of composition	Significant source: >120mg/100grams – Ca and/or > 300mg/100gram – P	R-low A- low

						and/or >0.6-mg/L- F	
Infant formula, Breast milk, Yoghurt (unsweetened)	1-Low (milk based)	Minimal	Minimal	6-10g	Majority of composition	Moderate to high: 30-120mg/100grams – Ca and/or > 100mg/100gram – P and/or >>0.6mg/L - F	R-low A-low
Vegetables, Potato Noodles/Pasta, Rice/Couscous, Fresh Fruit, Soup, Peanut butter, Cereals (unsweetened)	1-Low (non-milk based)	Low to high	None	1-10g	Low to high amounts	Minimal amounts: < 50mg/100grams - Ca < 0.1mg/L- F <100mg/100grams -P	R-low to moderate A- low to moderate
Banana	2-Moderate (fresh)	Moderate	None	11-20g	Low amounts	Minimal amounts: < 50mg/100grams - Ca < 0.1mg/L -F	R-moderate A-low

						<100mg/100grams -P	
Bread, Cereals (sweetened), **Ice-cream, Custard**, *Baked beans, Soup, Ready to eat baby foods,* **Flavoured milk, Hot chips** , *Stewed fruit* , *Yoghurt (sweetened)*	2- Moderate (processed and added sugars)	Low to moderate	Low to moderate	11-20g	Low to moderate amounts	Low to moderate sources of calcium and phosphate[3] 0-120mg/100grams of Ca 0-200mg/100grams P	R-low to moderate A- low
Fruit juice, Cordial , Soft drink, Sports drinks , Jelly	3- High (liquids)	Minimal		10-15g	Very low fat and protein	Trace amounts: <10mg/100gram for Ca and P.	R-low A-moderate to high
Potato chips, Savoury biscuits	3- High (foods)	Minimal	High amount >50% starch	1-5g	Low to moderate amounts	Minimal amounts < 50mg/100grams - Ca < 0.1mg/L -F <100mg/100grams -P	R-high A-low

Jam , Nutella, Lollies/ chocolate, Dried fruit[5] Roll ups , Sweetened condensed milk	4- Severe (very high sugar)	Low		>50g	Minimal amounts	Trace to minimal amounts : <50mg/100gram for Ca and P[4]	R- high A-low to moderate
Muesli bars, Puddings, Cakes/ muffins, Donuts, Sweet biscuits	4- Severe (high sugar highly processed starch)	Unlikely to contain these	>15g	>20g	Low to moderate amounts	Minimal amounts < 50mg/100grams - Ca < 0.1mg/L -F <100mg/100grams -P	R- very high A- Low

[1]Bold indicates a discretionary choice food/beverage and italics a core food/beverage [2]Foods high in phosphate also need to be high in calcium to exert the protective effects. [3] Dairy and cereal based products; Custard, ice-cream, flavoured milk, sweetened yoghurt, cereals and bread/rolls will be a moderate source 70-120mg/100grams of Ca and 50-200mg/100grams P however due to higher sugar content they are placed as moderate cariogenicity. [4]Nutella contains 130mg/100grams and phosphorus 190mg/100grams however normal serving size is 20grams – adhering to these ranges.[5]AGTHE recognises dried fruit should not be consumed everyday recommending to only have this occasionally therefore has been included in the scored scale.

Table 3: Cariogenic Diet Scale non-scored core foods and beverages recommended by the Australian Guide to Healthy Eating (AGTHE) (23) and Infant Feeding Guidelines (24) for a Healthful diet

Level of cariogenicity	Weight	Included foods	Consumption frequency of Core Foods based National Nutrition Guidelines
Cariostatic	0	Eggs, Nuts, Luncheon meats, Meat/ fish, non-fluoridated water	7/week
Anti-cariogenic	0	Fluoridated Water	All day
		Cheese Milk (full and low fat)[1] Un-sweetened yoghurt[2]	7-14/week
Low cariogenicity (milk based)	1	Infant formula[b][1] Breast milk[1]	Determined by mother

Low cariogenicity (non-milk based)	1	Vegetables, Potato	7-14/week
		Noodles/ pasta, Rice/Couscous, Unsweetened cereal[2]	14-21/week
		Fresh fruit	7-14/week
		Peanut butter, Soup	Determined by mother
Moderate cariogenicity (fresh)	2	Banana[3]	7-14/week
Moderate cariogenicity (processed and added sugar)	2	Sweetened cereals[2] Bread	7-14/week
		Baked beans, Ready to eat baby food, stewed fruit	7-14/week
		Sweetened yoghurt[2]	7/week

[1]Milk, breast milk and infant formula are anti to low cariogenicity however if left to pool in the mouth when saliva flow is low in the case of taking a bottle to bed or falling asleep on the breast these can be highly cariogenic. As we do not measure when foods are consumed it is behind the scope of this paper to incorporate this into the scale; [2]Yoghurt and cereals were not defined as sweetened or unsweetened in our FFQ. The sweetened varieties are more cariogenic due to the sugar content so have been separated into different scores of cariogenicity. The AGTHE recommends choosing low sugar varieties. [3]Banana has been defined as moderate cariogenicity compared to fresh fruit due to its sugar composition and creamier texture increasing its cariogenicity

Table 4: Cariogenic Diet Scale scored discretionary foods and beverages not recommended by the Australian Guide to Healthy Eating and Infant Feeding Guidelines

			Consumption frequency of discretionary choice foods				
Level of cariogenicity	Weight	Included foods	Never (0)	Low (1)	Moderate (2)	High (3)	Severe (4)
Moderate cariogenicity (processed and added sugar)	2	Ice cream, Custard, Flavoured milk , Hot chips	Never	>0-6/ week	7-13/ week	14-21/ week	≥22/ week

High cariogenicity (liquids)	3	Fruit juice, Cordial, Soft drink, Jelly	Never	>0-1/ week	2-3/ week	4-6/ week	≥7/ week
High cariogenicity (foods)	3	Potato chips, Savoury biscuits/ crackers	Never	>0-2/ week	3-6/ week	7-13/ week	≥14/ week
Severe cariogenicity (very high sugar)	4	Jam/honey, Lollies/ chocolates[1], Dried fruit, sweetened condensed milk	Never	>0-2/ week	3-6/ week	7-13/ week	14+/ week
Severe cariogenicity (high sugar highly processed starch)	4	Muesli bars/ fruit sticks/ roll ups, puddings, cakes/muffins, donuts, sweet biscuits					
TOTAL SCORE			0				276

[1] Chocolate /Lollies are grouped together in the FFQ therefore they were allocated to the higher level of cariogenicity

Table 5: Demographic profile of participants in the VicGen cohort study across three time-points of data collection.

	6 months	**12 months**	**18 months**
n	377	330	387
Data available for creation of scale score	364	326	367
Child age in months (mean, ± sd)	7.64 (±1.26)	13.08 (±1.30)	19.85 (±2.34)
Child Female	48.35%	47.24%	47.14%
Location			
Metropolitan	63.19%	58.28%	61.58%
Regional	12.64%	14.11%	13.08%
Rural	24.18%	27.61%	25.34%
SEIFA[a] disadvantage			
Quartile 1	58.79%	57.36%	56.40%
Quartile 2	23.90%	23.93%	24.80%
Quartile 3	14.29%	14.42%	14.71%
Quartile 4	3.02%	4.29%	4.09%
Mother speaks language other than English at home	21.15%	18.718%	21.25%

Possess health care card[b]	35.16%	30.67%	33.51%
Mothers highest post school qualification			
None	19.56%	17.79%	18.31%
Certificate or apprenticeship or diploma	41.05%	39.96%	40.44%
Degree or postgraduate degree	39.39%	43.25%	41.26%

[a]Socio-Economic Index for Areas - lower score most disadvantaged, higher least disadvantaged (based on baseline responses); [b]Means tested card for low-income earners entitling holder to concessions on certain services.

Table 6. Participant characteristics by disease classification

	Healthy	**Mild-moderate disease**	**Advanced disease**
n	67	75	33
Child age in years, mean [sd]	5.02 [0.09]	5.03 [0.09]	5.02 [0.08]
Child Female, n (%)	28 (42.4)	38 (50.7)	11 (34.4)
Location, n (%)			
Metropolitan	40 (59.7)	42 (56.0)	15 (45.5)
Regional	12 (17.9)	15 (20.0)	8 (24.2)
Rural	15 (22.4)	18 (24.0)	10 (30.3)
SEIFA[a] disadvantage			
Quartile 1 (most disadvantaged)	40 (59.7)	35 (46.6)	19 (57.6)
Quartile 2	18 (26.9)	24 (32.0)	9 (27.3)
Quartile 3	6 (9.0)	12 (16.0)	4 (12.1)
Quartile 4 (least disadvantaged)	3 (4.5)	4 (5.3)	4 (3.0)
Mother speaks language other than English at home	14 (20.9)	7 (9.3)	4 (12.2)
Possess health care card[b]			

Yes	15 (22.4)	22 (29.3)	10 (30.3)
No	51 (76.1)	53 (70.7)	22 (66.7)
Missing	1 (1.5)	-	1 (3.0)
Mothers highest post school qualification			
None	11 (16.4)	7 (9.3)	4 (12.1)
Certificate or apprenticeship or diploma	23 (34.3)	33 (44.0)	11 (33.3)
Degree or postgraduate degree	32 (47.8)	35 (47.0)	17 (51.5)
Missing	1 (1.5)	-	1 (3.0)
Cariogenic scale score at age 18 months			
Data present, n (%)	65 (97.0)	72 (96.0)	33 (100)
Data missing, n (%)	2 (3.0)	3 (4.0)	-
Scale score, mean [sd]	47.7 [17.5]	48.2 [17.3]	59.0 [15.9]

[a]Socio-Economic Index for Areas - lower score most disadvantaged, higher least disadvantaged (based on baseline responses); [b]Means tested card for low income earners entitling holder to concessions on certain services.

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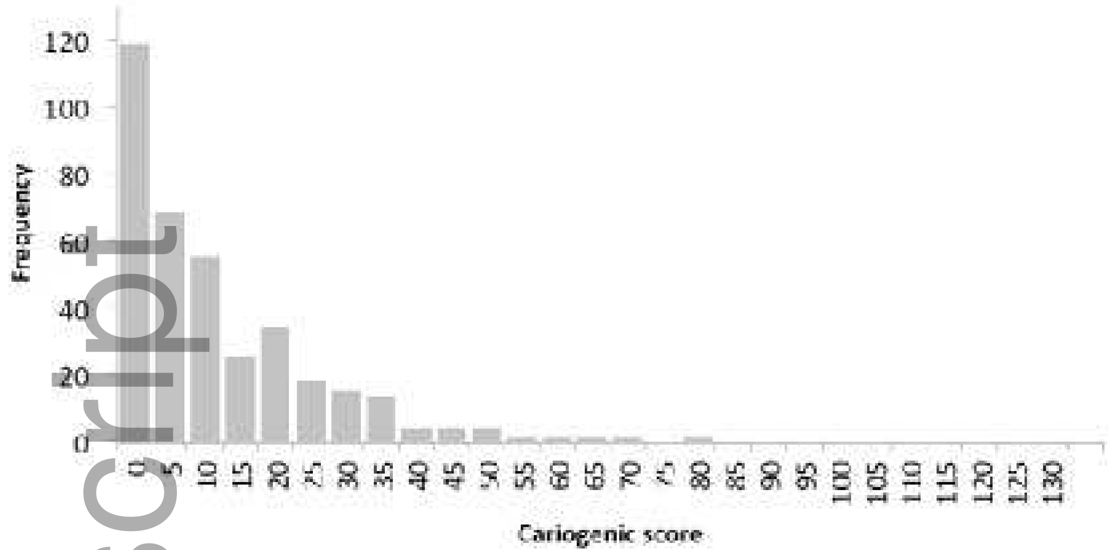

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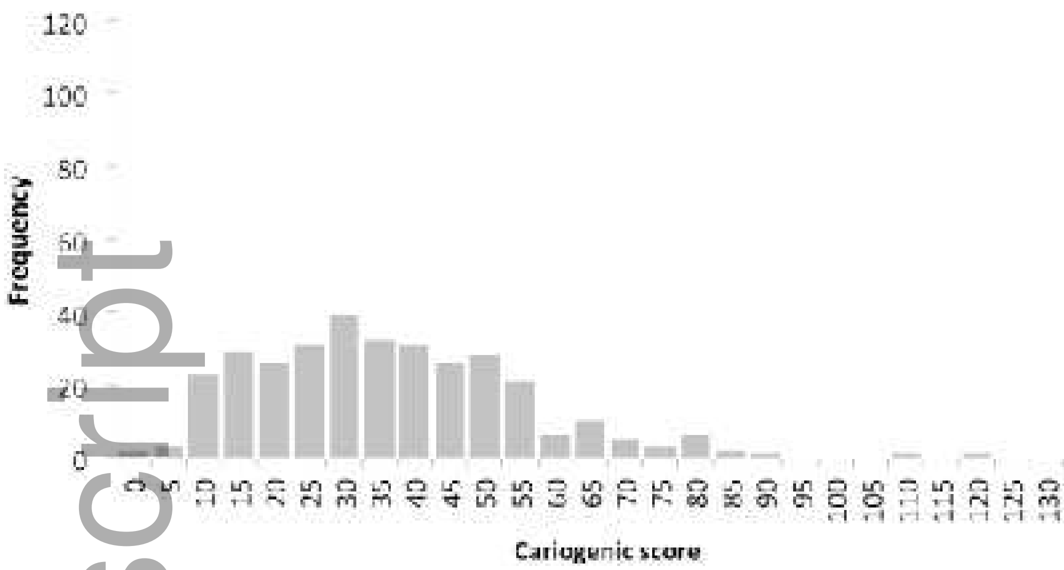

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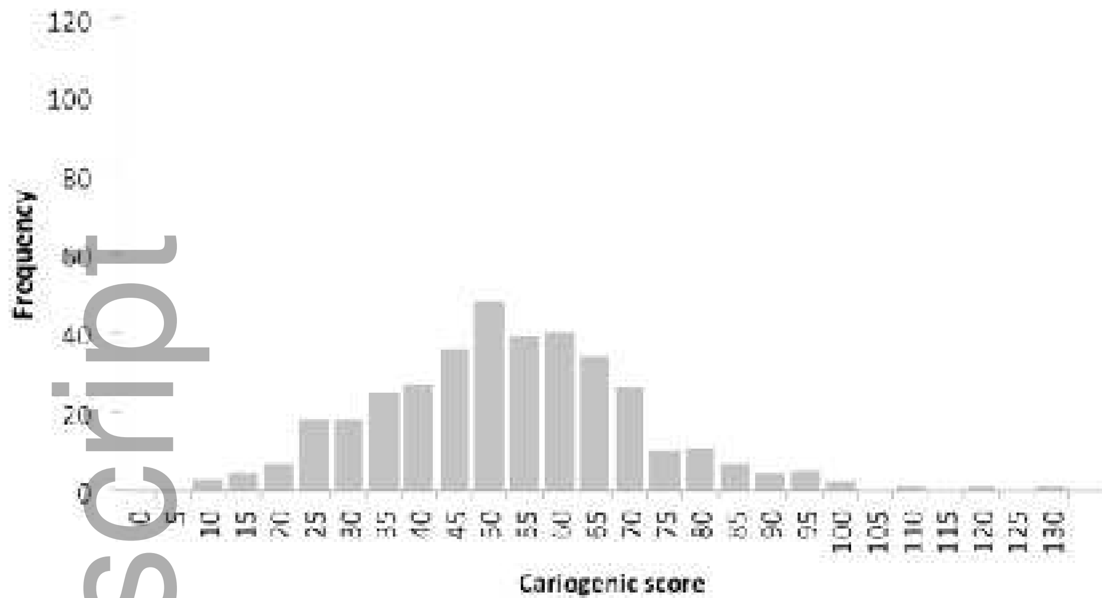

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