SUGAR CONSUMPTION AND CARIES RISK: A SYSTEMATIC REVIEW

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ABSTRACT:

This systematic review addresses the question: In the modern age of extensive fluoride exposure, do individuals with a high level of sugar intake, measured either as total amount or a high frequency of consumption, experience greater caries severity relative to those with a lower level of intake? The MEDLINE and EMBASE databases were searched for English-language papers published between 1980 and 2000 using a search expression developed in conjunction with an experienced librarian. There were 809 papers located in the initial search. A review of titles and abstracts to identify clearly irrelevant papers reduced this number to 134. Two readers each read one half of these papers, and application of predetermined inclusion/exclusion criteria reduced this number of papers to 69. Quality criteria were established for scoring each of these papers on evidence tables. The maximum score for each paper was 100, the 69 papers rated scored between 12 and 79. Final judgment of results was limited to those 36 papers which scored 55 or higher on the evidence tables, and which reported on studies carried out in countries where there is moderate-to-extensive fluoride exposure. Results showed that only two papers found a strong relationship between sugar consumption and caries development, 16 found a moderate relationship, and 18 found weak-to-no relationship. It was concluded that the relationship between sugar consumption and caries is much weaker in the modern age of fluoride exposure than it used to be. Controlling the consumption of sugar is a justifiable part of caries prevention, if not always the most important aspect.

Key words: caries, sugars, systematic review, fluoride.

The recognition that sugars have an etiological role in dental caries has been with us for centuries. Research in more recent decades has done much to define that role. It is now understood that sugar is a favored substrate for the cariogenic bacteria that reside in dental plaque, notably the mutans streptococci, and that the acid by-products of this metabolic process induce demineralization of the enamel surface. Bacterial invasion can follow. Whether this initial demineralization proceeds to clinically-detectable caries, or whether the lesion is remineralized by plaque minerals depends on a number of factors, one of which is the amount and frequency of further sugars consumption. The evidence that sugars (and other fermentable carbohydrates such as highly-refined flour) play a fundamental role in the initiation and progression of caries can be described as overwhelming (1-6). The relationship between sugar consumption and caries in high-income countries like the United States was long viewed as being virtually linear: the more sugar a population consumed, and the greater the frequency of that consumption, the greater the prevalence and severity of caries was presumed to be.

In more recent years, however, this seemingly linear relationship has come to be questioned. For one thing, per capita consumption of all sugars in the United States has risen over the last 25 years or so, and seems to be still rising, while caries experience in the permanent dentition has declined (7). Probably the greatest single influence on caries experience in the United States over recent decades has been extensive exposure to fluoride, once confined only to relatively few persons who received fluoridated water in their homes. Over recent years, however, fluoride exposure has become widespread not only through drinking water, but also through toothpaste, professional applications, and by fluoride's presence in processed foods and drinks. In view of that, it is reasonable to think that the ecological relationship just stated, i.e., rising sugar consumption and declining caries experience, has been affected by the extensive exposure to fluoride.

This report is a systematic review of the literature (8) to examine the relationship between sugar consumption and dental caries experience at a time when fluoride exposure is so widespread. The specific question to be examined is: In the modern age of extensive fluoride exposure, do individuals with a high level of sugar intake, measured either as total amount or a high frequency of consumption, experience greater caries severity relative to those with a lower level of intake?

MATERIALS AND METHODS

The review consisted of a search of the MEDLINE and EMBASE databases for papers published between January 1980 and July 2000. The year 1980 was chosen arbitrarily as a reasonable starting point for the era of population-wide fluoride exposure. Reports to be considered for inclusion in the review were those in the English language and which used cohort, case-control, or cross-sectional research designs with human subjects. The exclusion criteria we used to reject papers from consideration are shown in Table 1. Search terms included: populations, sugar, sucrose, fructose, glucose, disaccharides, monosaccharides, high-fructose corn syrup, HFCS, corn syrup, diet history, diet interview, diet questionnaire, dietary interview, dietary questionnaire, sweets, confectionery, honey, candy, candies, sportsdrinks. A set of search terms for caries was drawn up by an experienced librarian (the full search expression is available from the authors by request).

Table 2 shows the results of the search and its subsequent use. The initial search produced a total of 809 reports. There were two readers on this project; the set of references was divided into two halves alphabetically and each of the two readers examined one half. The first assessment made was by title and abstract, with clearly-irrelevant articles discarded at this point. This process reduced the original 809 reports to 134. These 134 papers were then read in full, again with the task divided alphabetically between the two readers. Another 65 papers were eliminated at this stage because they did not satisfy all inclusion-exclusion criteria, which left 69 papers for scoring and recording in the evidence tables. These papers consisted of 26 cohort studies, 4 case-control studies, and 39 cross-sectional studies.

Categories for scoring the quality of the individual papers were established by the two readers, and a maximum score and scoring criteria were set for each category. The maximum score for any paper was 100. The categories and maximum scores are shown in Table 3 (shown for cross-sectional studies only, as an illustration). To illustrate the scoring method, it can be seen that in the category *Methods for Quantifying Sugars Intake* the maximum score was 8. In this category, the highest grade of 6-8 was given to those studies that used a structured interview for either a 24-hour recall or a food frequency questionnaire, or for a three-day food diary. A score of 4-5 was given for a self-report on food intake that was validated by an interviewer. Reports that referred to an interview but without further details received a score of 3, self-reports that were not validated were scored as 2, and if the method for quantifying sugars intake was not described or not clear the score was zero. All of the categories had criteria for scoring that were based on a similar scoring gradient.

The 69 papers for scoring in the evidence tables were again divided equally between the two readers. To assess between-reader reliability in scoring, five papers from the set were randomly chosen for duplicate scoring. Each reader scored these five papers independently.

The scores for each of the 69 papers on the evidence tables ranged from 12 to 79, and the distribution of the scoring is shown in Figure 1. In order to keep the final results restricted to papers of good quality, we included only those papers which scored 55 or higher, a total of 36. The evidence table for the 33 papers omitted with scores of 54 or less is shown as Table 4.

In the final group of 36 articles being judged to answer the initial question, we rated the risk of sugar-associated caries according to the risk ratio (odds ratio, relative risk) stated in the report. Not all papers stated a risk ratio. Two gave a correlation coefficient for relating sugars intake to caries experience, and three provided a beta coefficient for sugar consumption as a predictor of caries experience. The most common risk measure provided was an odds ratio in the cross-sectional design. For any relationship of caries (e.g., total DMF/dmf, proximal caries only, radiographic diagnoses only) to sugars intake (e.g., frequency of bedtime snacks, frequency of sugar intakes, total amount consumed) we judged that an OR of 2.5 or higher would be counted as a strong association, ORs of 1.5 to 2.4 would be scored as moderate, and ORs of 1.4 or lower as weak or none. For correlation coefficients, we judged that an $r < 0.4$ constituted a weak relationship (both papers giving only a correlation coefficient were at this level). For the three papers citing a beta coefficient, we converted this measure to either an odds ratio (if the authors used logistic regression) or a relative risk if they used linear regression, by using the exponent of beta. A quantitative meta-analysis was not appropriate because of the heterogeneity of the studies assessed. This is true not only for study design and measurement procedures, but because the studies came from a number of different countries with differing social conditions.

RESULTS

The two readers achieved a good degree of uniformity in their scoring for the quality of papers, as shown in Table 5. Correlations were high (Pearson's $r = 0.87$), and there was no significant difference in mean scores ($p = 0.56$).

The evidence table for the 36 articles considered to address the question is shown as Table 6. Table 7 shows the distribution of reports which found strong, moderate, and weak relations between sugars intake (any measure) and caries experience, and displays these relations by type of study design. By our criteria, there were only two reports which showed a strong relationship. There were 16 papers which found a moderate strength of relationship between sugars intake and caries development, and another 18 where the relationship was weak-to-none.

DISCUSSION

The study of sugar/caries relationships has some inherent difficulties, a statement which is probably true for any diet-related condition. For example, there is no consensus on the most valid methods of measuring dietary intake in free-living humans: 24-hour recall interviews, 3-day diaries and food frequency questionnaires are all used in research studies (9), and measurement bias is likely to be present in all of them. The extent to which the results found were dependent upon the measurement procedure used cannot be determined.

In this review, the predominant study design was cross-sectional (23 of the 36 final papers; Table 7). This is the weakest study design with which to address the question, because cross-sectional studies frequently relate current dietary practices to past caries experience. The problems of seeking an accurate retrospective record of sugar exposure in past years would also affect the validity of case-control studies, of which there was just the one in the final 36 studies assessed.

There were 16 of the 23 cross-sectional reports which studied the permanent dentition, while only five of the 12 cohort studies did so. Among the cohort studies, eight of the 12 were conducted for periods of two years or less, which may hardly be long enough to permit the true relationship to be discerned.

Overall, the quality of the evidence regarding the relationship between sugar consumption and caries was sufficient to justify the relationships found. All but two papers found the relationship to be moderate or weak. While there is no question that fermentable carbohydrates are a necessary link in the causal chain for dental caries (10), the findings of this review differ from the strong relationships found in studies from the pre-fluoride era, the most notable of which was Vipehölm (3). Conducted in a Swedish mental institution between 1945 and 1952, the Vipehölm study by today's standards would be unethical because it provided high quantities of sugars to people unable to give their consent to this regimen. Residents in the institution were divided into groups with controlled consumption of refined sugars which varied in amount, frequency, physical form, and whether they were taken with or between meals. The extremes of intake were (a) no added sugars at all, and (b) daily between-meal consumption of 24 sticky toffees. Caries was diagnosed at the incipient level through to cavitation, and the differences in caries incidence between the groups were pronounced. In retrospect, the Vipehölm study was always of dubious external validity because of the nature of the studied population. With the advent of fluoride since that time it is even less applicable to present-day circumstances.

Only two studies of the final 36 dealt with root caries, and both were small-scale studies. Both concluded that the diet which promotes coronal caries also promotes root caries. With an aging population and greater retention of teeth, root caries is likely to grow as a public health issue in the future. The question of diets which promote root caries need to be elucidated better in a larger-scale study, as does the likely protective effect of daily fluoride supplements for older persons at risk of root caries. These two factors could probably be included in the one prospective trial, which would need to be of larger scope than the studies so far conducted.

Nearly all studies dealt with relationships between *mean* caries status and sugars exposure, rather than *distributions*. It seems likely that while the reduced risk from sugar consumption in the fluoride age is measurable for a population, there are still some identifiable subgroups who do not benefit. Further research could focus on these differences.

In terms of relevance to the Consensus Questions, the findings of our review are relevant to questions 2, 3, and 5 of the six listed questions. Taking each in turn:

2. What are the best indicators for an increased risk of dental caries infection?

Persons with high sugar consumption, whether measured in frequency or amounts, usually have higher counts of cariogenic bacteria than people who have low consumption. However, this relationship is not linear, what constitutes “high” and “low” consumption is poorly defined, and high bacterial counts do not necessarily lead to an outcome of clinical caries. Sugar consumption is likely to be a more powerful indicator for risk of caries infection in persons who do not have regular exposure to fluoride.

3. What are the best methods available for the primary prevention of dental caries initiation throughout life?

Where there is good exposure to fluoride, sugar consumption is a moderate-to-mild risk factor for caries in most people. Hence efforts to control excessive consumption of sugar is a justifiable part of caries prevention, if not always the most important aspect.

5. How should clinical decisions regarding prevention and/or treatment be affected by detection methods and risk assessment?

A patient assessed to be at high risk for caries needs to be aware that sugar consumption increases the risk. The clinician can therefore conduct a dietary assessment with the purpose of identifying where sugar consumption can reasonably be curtailed. For a patient assessed to be at low risk of caries, this procedure is probably unnecessary.

In conclusion, our findings in this review are consistent with the view that restriction of sugar consumption still has a role to play in the prevention of caries, but that this role is not as strong it was in the pre-fluoride era.

FURTHER RESEARCH NEEDS

- Dietary risk factors for root caries, and the effect of daily fluoride supplements in preventing root caries in older people.

- Sugar consumption in high frequency and amounts still appear to be a risk factor for caries among some children, but not all. Research is needed to identify the factors that render some children more likely than others to develop caries in the presence of a high-sugar diet. It may be that such individuals are not well-exposed to fluoride, or the reason may be more complex than that.

- Studies are needed of how best to bring the benefits of caries prevention enjoyed by the majority to the parents and caregivers of high-risk children (the poor, the deprived, and racial/ethnic minorities).

REFERENCES QUOTED IN TEXT

1. Bibby BG. The cariogenicity of snack foods and confections. J Am Dent Assoc 1975; 90:121-32.

2. Finn SB, Glass RB. Sugar and dental decay. World Rev Nutr Dietet 1975; 22:304-26.

3. Gustaffson BE, Quensel CE, Lanke LS *et al*. The Vipeholm dental caries study. The effect of different levels of carbohydrates intake on caries activity in 436 individuals observed for five years. Acta Odont Scand 1954; 11:232-364.

4. Newbrun E. Dietary carbohydrates: their role in cariogenicity. Med Clinics North Am 1979; 63:1069-86.

5. Rugg-Gunn AJ, Edgar WM. Sugar and dental caries: a review of the evidence. Community Dent Health 1984; 1:85-92.

6. Shaw JH. The role of sugar in the aetiology of dental caries. 6. Evidence from experimental animal research. J Dent 1983; 11:209-13.

7. Burt BA. Trends in caries prevalence in North American children. Int Dent J 1994; 44(4 Suppl 1):403-13.

8. Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS. Evidence based medicine: what it is and what it isn't [editorial]. Br Med J 1996; 312:71-2.

9. Lee RD, Nieman DC. Nutritional assessment. 2nd ed. New York: McGraw Hill, 1996.

10. Scheinen A, Makinen KK. Turkü sugar studies; an overview. Acta Odont Scand 1976;34:405-8.

REFERENCES CITED IN THE REVIEW

11. Aaltonen AS, Tenovuo J. Association between mother-infant salivary contacts and caries resistance in children: a cohort study. Pediatr Dentistry 1994; 16:110-6.

12. Angelillo IF, Torre I, Nobile CG, Villari P. Caries and fluorosis prevalence in communities with different concentrations of fluoride in the water. Caries Res 1999; 33:114-22.

13. Arnadottir IB, Rozier RG, Saemundsson SR, Sigurjons H, Holbrook WP. Approximal caries and sugar consumption in Icelandic teenagers. Community Dentistry Oral Epidemiology 1998; 26:115-21.

14. Beighton D, Adamson A, Rugg-Gunn A. Associations between dietary intake, dental caries experience and salivary bacterial levels in 12-year-old English schoolchildren. Arch Oral Biol 1996; 41:271-80.

15. Bergendal B, Hamp SE. Dietary pattern and dental caries in 19-year-old adolescents subjected to preventive measures focused on oral hygiene and/or fluorides. Swed Dent J 1985; 9:1-7.

16. Bjarnason S, Finnbogason SY, Noren JG. Sugar consumption and caries experience in 12- and 13-year-old Icelandic children. Acta Odont Scand 1989; 47:315-21.

17. Bruening KS, Gilbride JA, Passannante MR, McClowry S. Dietary intake and health outcomes among young children attending 2 urban day-care centers. J Am Dietet Assoc 1999; 99:1529-35.

18. Burt BA, Eklund SA, Morgan KJ *et al*. The effects of sugars intake and frequency of ingestion on dental caries increment in a three-year longitudinal study. J Dent Res 1988; 67:1422-9.

19. Cleaton-Jones P, Richardson BD, Sinwel R, Rantsho J, Granath L. Dental caries, sucrose intake and oral hygiene in 5-year-old South African Indian children. Caries Res 1984; 18:472-7.

20. Eronat N, Eden E. A comparative study of some influencing factors of rampant or nursing caries in preschool children. J Clin Pediatr Dentistry 1992; 16:275-9.

21. Faggiano F, Di Stanislao F, Lemma P, Renga G. Role of social class in caries occurrence in 12 year olds in Turin, Italy. Eur J Public Health 1999; 9:109-13.

22. Faine MP, Allender D, Baab D, Persson R, Lamont RJ. Dietary and salivary factors associated with root caries. Special Care Dentistry 1992; 12:177-82.

23. Freeman R, Breistein B, McQueen A, Stewart M. The dental health status of five-year-old children in north and west Belfast. Community Dent Health 1997; 14:253-7.

24. Frostell G, Birkhed D, Edwardsson S *et al*. Effect of partial substitution of invert sugar for sucrose in combination with Duraphat treatment on caries development in preschool children: the Malmo Study. Caries Res 1991; 25:304-10.

25. Garcia-Closas R, Garcia-Closas M, Serra-Majem L. A cross-sectional study of dental caries, intake of confectionery and foods rich in starch and sugars, and salivary counts of Streptococcus mutans in children in Spain. American Journal of Clinical Nutrition 1997; 66:1257-63.

26. Gibson S, Williams S. Dental caries in pre-school children: associations with social class, toothbrushing habit and consumption of sugars and sugar-containing foods. Further analysis of data from the National Diet and Nutrition Survey of children aged 1.5-4.5 years. Caries Res 1999; 33:101-13.

27. Gizani S, Vinckier F, Declerck D. Caries pattern and oral health habits in 2- to 6-year-old children exhibiting differing levels of caries. Clinical Oral Investigations 1999; 3:35-40.

28. Godson JH, Williams SA. Oral health and health related behaviours among three-year-old children born to first and second generation Pakistani mothers in Bradford, UK. Community Dent Health 1996; 13:27-33.

29. Grindefjord M, Dahllof G, Nilsson B, Modeer T. Prediction of dental caries development in 1-year-old children. Caries Res 1995; 29:343-8.

30. Grindefjord M, Dahllof G, Nilsson B, Modeer T. Stepwise prediction of dental caries in children up to 3.5 years of age. Caries Res 1996; 30:256-66.

31. Grytten J, Rossow I, Holst D, Steele L. Longitudinal study of dental health behaviors and other caries predictors in early childhood. Community Dentistry Oral Epidemiology 1988; 16:356-9.

32. Hausen H, Heinonen OP, Paunio I. Modification of occurrence of caries in children by toothbrushing and sugar exposure in fluoridated and nonfluoridated areas. Community Dentistry Oral Epidemiology 1981; 9:103-7.

33. Holbrook WP, Arnadottir IB, Takazoe I, Birkhed D, Frostell G. Longitudinal study of caries, cariogenic bacteria and diet in children just before and after starting school. Euro J Oral Sciences 1995; 103:42-5.

34. Holbrook WP, de Soet JJ, de Graaff J. Prediction of dental caries in pre-school children. Caries Res 1993; 27:424-30.

35. Holt RD. Foods and drinks at four daily time intervals in a group of young children. Br Dent J 1991; 170:137-43.

36. Holt RD, Winter GB, Downer MC, Bellis WJ, Hay IS. Caries in pre-school children in Camden 1993/94. Br Dent J 1996; 181:405-10.

37. Honkala E, Nyyssonen V, Kolmakow S, Lammi S. Factors predicting caries risk in children. Scand J Dent Res 1984; 92:134-40.

38. Ismail AI. Food cariogenicity in Americans aged from 9 to 29 years assessed in a national cross-sectional survey, 1971-74. J Dent Res 1986; 65:1435-40.

39. Jones C, Woods K, Whittle G, Worthington H, Taylor G. Sugar, drinks, deprivation and dental caries in 14-year-old children in the north west of England in 1995. Community Dent Health 1999; 16:68-71.

40. Karjalainen S, Sewon L, Soderling E, Lapinleimu H, Seppanen R, Simell O. Oral health of 3-year-old children and their parents after 29 months of child-focused antiatherosclerotic dietary intervention in a prospective randomized trial. Caries Res 1997; 31:180-5.

41. Kleemola-Kujala E, Rasanen L. Relationship of oral hygiene and sugar consumption to risk of caries in children. Community Dentistry Oral Epidemiol 1982; 10:224-33.

42. Kwon HK, Suh I, Kim YO *et al*. Relationship between nutritional intake and dental caries experience of junior high students. Yonsei Med J 1997; 38:101-10.

43. Lachapelle D, Couture C, Brodeur JM, Sevigny J. The effects of nutritional quality and frequency of consumption of sugary foods on dental caries increment. Canad J Public Health 1990; 81:370-5.

44. Lai PY, Seow WK, Tudehope DI, Rogers Y. Enamel hypoplasia and dental caries in very-low birthweight children: a case-controlled, longitudinal study. Pediatr Dentistry 1997; 19:42-9.

45. Larsson B, Johansson I, Ericson T. Prevalence of caries in adolescents in relation to diet. Community Dentistry Oral Epidemiol 1992; 20:133-7.

46. MacEntee MI, Clark DC, Glick N. Predictors of caries in old age. Gerodontol 1993; 10:90-7.

47. Maiwald HJ. Correlation between the consumption of sugar, acid solubility of the tooth enamel and caries attack in children. J Internat Assoc Dentistry for Children 1981; 12:3-7.

48. Marcenes WS, Sheiham A. Composite indicators of dental health: functioning teeth and the number of sound-equivalent teeth (T-Health). Community Dentistry Oral Epidemiol 1993; 21:374-8.

49. Masalin K, Murtomaa H. Work-related behavioral and dental risk factors among confectionery workers. Scand J Work, Environ Health 1992; 18:388-92.

50. Masalin KE, Murtomaa HT, Sipila KP. Dental caries risk in relation to dietary habits and dental services in two industrial populations. J Public Health Dentistry 1994; 54):160-6.

51. Mathiesen AT, Ogaard B, Rolla G. Oral hygiene as a variable in dental caries experience in 14-year-olds exposed to fluoride. Caries Res 1996; 30:29-33.

52. Mattila ML, Paunio P, Rautava P, Ojanlatva A, Sillanpaa M. Changes in dental health and dental health habits from 3 to 5 years of age. J Public Health Dentistry 1998; 58:270-4.

53. Mattila ML, Rautava P, Sillanpaa M, Paunio P. Caries in five-year-old children and associations with family-related factors. J Dent Res 2000; 79:875-81.

54. Mattos-Graner RO, Zelante F, Line RC, Mayer MP. Association between caries prevalence and clinical, microbiological and dietary variables in 1.0 to 2.5-year-old Brazilian children. Caries Res 1998; 32:319-23.

55. McMahon J, Parnell WR, Spears GFS. Diet and dental caries in preschool children. European J Clin Nutrition 1993; 47:794-802.

56. Papas AS, Joshi A, Palmer CA, Giunta JL, Dwyer JT. Relationship of diet to root caries. American J Clin Nutrition 1995; 61:423S-9S.

57. Peng B, Petersen PE, Fan MW, Tai BJ. Oral health status and oral health behaviour of 12-year-old urban schoolchildren in the People's Republic of China. Community Dent Health 1997; 14:238-44.

58. Persson LA, Holm AK, Arvidsson S, Samuelson G. Infant feeding and dental caries--a longitudinal study of Swedish children. Swed Dent J 1985; 9:201-6.

59. Petridou E, Athanassouli T, Panagopoulos H, Revinthi K. Sociodemographic and dietary factors in relation to dental health among Greek adolescents. Community Dentistry Oral Epidemiol 1996; 24:307-11.

60. Petti S, Tarsitani G, Panfili P, Simonetti D'Arca A. Oral hygiene, sucrose consumption and dental caries prevalence in adolescent systemic fluoride non-users. Community Dentistry Oral Epidemiol 1997; 25:334-6.

61. Ravald N, Hamp SE, Birkhed D. Long-term evaluation of root surface caries in periodontally treated patients. J Clin Periodontol 1986; 13:758-67.

62. Rodrigues CS, Watt RG, Sheiham A. Effects of dietary guidelines on sugar intake and dental caries in 3-year-olds attending nurseries in Brazil. Health Promotion Internat 1999; 14:329-35.

63. Rodriguez-Contreras Pelayo R, Delgado Rodriguez M, Galvez Vargas R. Prevalence of dental caries in school children of the province of Granada (Spain). Euro J Epidemiol 1989; 5:193-8.

64. Roeters J, Burgersdijk R, Truin GJ, van 't Hof M. Dental caries and its determinants in 2-to-5-year-old children. J Dentistry Children 1995; 62:401-8.

65. Rugg-Gunn AJ, Hackett AF, Appleton DR, Jenkins GN, Eastoe JE. Relationship between dietary habits and caries increment assessed over two years in 405 English adolescent school children. Arch Oral Biol 1984; 29:983-92.

66. Serra Majem L, Garcia Closas R, Ramon JM, Manau C, Cuenca E, Krasse B. Dietary habits and dental caries in a population of Spanish schoolchildren with low levels of caries experience. Caries Res 1993; 27:488-94.

67. Silver DH. A longitudinal study of infant feeding practice, diet and caries, related to social class in children aged 3 and 8-10 years [published erratum appears in Br Dent J 1988 Jan 9;164(1):21]. Br Dent J 1987; 163:296-300.

68. Soderholm G, Birkhed D. Caries predicting factors in adult patients participating in a dental health program. Community Dentistry Oral Epidemiol 1988; 16:374-7.

69. Stacey MA, Wright FA. Diet and feeding patterns in high risk pre-school children. Austral Dent J 1991; 36:421-7.

70. Stecksen-Blicks C, Gustafsson L. Impact of oral hygiene and use of fluorides on caries increment in children during one year. Community Dentistry Oral Epidemiol 1986; 14:185-9.

71. Stecksen-Blicks C, Holm AK. Between-meal eating, toothbrushing frequency and dental caries in 4-year-old children in the north of Sweden. Internat J Paediatr Dentistry 1995; 5: 67-72.

72. Steyn NP, Albertse EC, van Wyk Kotze TJ, van Wyk CW, van Eck M. Sucrose consumption and dental caries in twelve-year-old children of all ethnic groups residing in Cape Town. J Dent Assoc South Africa 1987; 42:43-9.

73. Sundin B, Birkhed D, Granath L. Is there not a strong relationship nowadays between caries and consumption of sweets?. Swed Dent J 1983; 7:103-8.

74. Sundin B, Granath L, Birkhed D. Variation of posterior approximal caries incidence with consumption of sweets with regard to other caries-related factors in 15-18-year-olds. Community Dentistry Oral Epidemiol 1992; 20:76-80.

75. Tubert-Jeannin S, Lardon JP, Pham E, Martin JL. Factors affecting caries experience in French adolescents. Community Dentistry Oral Epidemiol 1994; 22:30-5.

76. Vidal OP, Schroder U. Dental health status in Latin-American preschool children in Malmo. Swed Dent J 1989; 13:103-9.

77. Weissenbach M, Chau N, Benamghar L, Lion C, Schwartz F, Vadot J. Oral health in adolescents from a small French town. Community Dentistry Oral Epidemiol 1995; 23:147-54.

78. Wendt LK, Birkhed D. Dietary habits related to caries development and immigrant status in infants and toddlers living in Sweden. Acta Odontol Scand 1995; 53:339-44.

79. Wilson RF, Ashley FP. Identification of caries risk in schoolchildren: salivary buffering capacity and bacterial counts, sugar intake and caries experience as predictors of 2-year and 3-year caries increment. Br Dent J 1989; 167:99-102.

CAPTION FOR FIGURE:

Figure 1: Distribution of scores for 69 papers relating sugar consumption to caries. The arrow indicates the cutoff for papers scoring 55 or higher, which were used to reach conclusions.