Title: A systematic review of dietary acids and habits on dental erosion in adolescents

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A systematic review of dietary acids and habits on dental erosion in adolescents

Abstract

Background: Dental erosion is the dissolution of dental hard tissues caused by acids of a non-bacterial origin. Dietary acids are considered the predominant and most controllable factor.

Aim: To synthesise the literature on the effects of dietary acids and habits on dental erosion in the permanent dentition of 10- to 19-year-old adolescents.

Materials and Methods: An electronic literature search was undertaken in Cochrane, Medline, Cinahl, Dentistry & Oral Science Source via EBSCOhost and Embase with no restriction on the date of publication.

Results: The initial search identified 449 articles, 338 remained after removal of duplicates. Seventy-seven articles remained after screening of titles and abstracts, 52 were eligible for the full-text review. A considerable variety of beverages, food and dietary habits were reported as risk factors for dental erosion. The most consistent findings implicated the erosive potential of carbonated beverages and the consumption of acidic drinks at bedtime.

Conclusions: Although results were not consistent between cohort and cross-sectional studies, this review suggests certain dietary risk factors may contribute to dental erosion in adolescents. There is a need for more high quality cohort studies to establish more conclusive evidence on the role of dietary acids and habits on dental erosion.

Keywords

dental erosion, adolescents, permanent dentition, diet, habits, systematic review

1 INTRODUCTION

Dental erosion (DE), defined as a pathological, chronic and irreversible dissolution of dental hard tissues caused by acids of a non-bacterial origin,[1] has been identified as a globally emerging oral health problem.[2] The estimated global prevalence of DE is 30% in adolescents, 25% in Australia.[3] Understanding of risk factors and early diagnosis are essential to prevent and manage DE.[4] When allowed to progress it can lead to dentinal hypersensitivity, aesthetic concerns and loss of vertical dimension, all of which affect oral health related quality of life.[3,5] Management of advanced DE often requires costly and invasive functional and aesthetic rehabilitation.[6]

DE is multifactorial and is caused by a complex interaction between environmental factors and tooth enamel.[7] Dietary acids are not only considered the predominant factor, but also the easiest to control.[8-10] Such acids can arise from a number of sources including soft drinks, sports/energy drinks, teas, fruit and fruit juice, alcoholic beverages, vinegar/pickled food, sauces and confectionary.[11,12]

Dietary habits, referring to the manner by which these acids are consumed, similarly play an important role.[13] Driven by changes in lifestyle, nutritional habits and increased availability of dietary acids, dietary habits have gradually changed over the past decades.[14]

Some studies associate acidic fruit, carbonated and fruit drinks with DE in children and adolescents,[15,16] while others have shown no such association.[17,18]

This systematic review aims to synthesise the literature on the effects of dietary acids and habits on DE in the permanent dentition of 10- to 19-year-old adolescents. It provides an update on the two most recently published systematic reviews,[10,19] includes incidence, prevalence and progression data and focusses on adolescents.

2 METHODS

The review was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[20]

2.1 Data sources

An electronic search of the literature was undertaken in March 2019 in Cochrane, Medline, Cinahl, Dentistry & Oral Science Source via EBSCOhost and Embase. In addition, bibliographies of included articles were scanned manually to identify any additional relevant articles. The search strategy is shown in Table 1.

The predetermined eligibility criteria were: (a) observational cross-sectional and cohort studies; (b) published in English in a peer-reviewed journal; (c) conducted on 13- to 18-year-olds as defined by Medical Subject Headings (MeSH); (d) investigation of DE as well as dietary acids and/or habits as associated factors; (e) examination of permanent teeth only and (f) no restriction on the publication date. Articles for 10- to 12-year-old children and young adults aged 19 were also considered, consistent with the World Health Organization (WHO) definition.[21]

The exclusion criteria were: (a) case reports, case series, or pilot studies; (b) articles that did not distinguish between DE in permanent and deciduous teeth; (c) clinical data or participants that were reported in other included articles; (d) previous systematic reviews; (e) conference abstracts; and (f) *in vitro* studies.

2.2 Screening and selection

All titles and abstract were independently screened by two researchers (AC & SL). Discrepancies were resolved by a third researcher (TT). The level of agreement was calculated using Cohen's kappa and was set at 0.85.[22] Following selection a full-text analysis was performed independently by two researchers (TT & SH). For multiple articles from the same cohort only the most relevant paper was included. If relevant, data from the other articles were extracted and incorporated into the selected record.

2.3 Data extraction

Data extraction was independently conducted by three researchers (SL, TT, & SH) based on the Cochrane Checklist of items.[23] The accuracy of the collected data was confirmed by a fourth researcher (AC) who resolved discrepancies by re-performing the data extraction.

2.4 Risk of bias and quality of evidence

The quality of included studies was assessed according to the Newcastle-Ottawa Scale (NOS) for cohort and case-control studies[24] and a modified version of this tool for cross-sectional studies.[25] NOS evaluates selection, exposure and comparability. A score of eight or higher indicated a low risk of bias, six to seven a medium risk and a score of less than or equal to five a high risk of bias.[26] Two reviewers independently rated and compared the scores for each study (AC & TT). Disagreements were resolved by consensus.

2.5 Frequency effect size

Frequency effect size (FES) of extracted risk factors was calculated by dividing the number of studies reporting either a positive or negative association with DE following bivariate or multivariable analysis by the total number of included studies assessing this risk factor, expressed as a percentage.[27]

3 RESULTS

3.1 Study selection

The initial literature search identified 449 articles of which 338 remained after removal of duplicates. Seventy-seven articles remained after screening of titles and abstracts of which 52 were eligible for the full-text review. The results of the screening and search process are presented in Figure 1.

3.2 Descriptive analysis

A summary of included articles is reported in Table 2. Of the included articles five were cohort studies with durations ranging from 18 months to four years, three were case-control and 44 were cross-sectional studies. Two of the cohort studies also reported on the progression of DE.[16,28] Studies were conducted in 26 different countries, with one study undertaken across two countries.[29]

The common indices used were the Basic Erosive Wear Examination (BEWE) (n=11),[30] Tooth Wear Index (TWI) (n=14)[31] and O'Sullivan (n=9).[32] Either self-administered questionnaires (n=46) or structured interviews (n=5) were used to analyse dietary patterns and habits, with one study utilising a single application 24-hour food recall.[33] Of these questionnaires were validated for adolescents in only 11 studies,[28,34-43] whereas the types of food/beverages evaluated were validated in five studies.[44-48] Ten studies validated for both.[49-58] Bivariate or multivariate analysis was conducted in all studies to determine statistical significance.

3.3 Risk of bias and quality of evidence

Twelve studies were of low, 38 of medium and two (both cross-sectional) of high risk of bias (Table 2). One high risk of bias study did not utilise a validated measurement tool [41] whilst the other applied weak statistical analysis and had a poor justification of sample size and non-respondents.[59]

3.4 Beverages and dental erosion

All studies described the influence of beverages on DE, with carbonated drinks, sports/energy drinks and fruit juice and most commonly reported. Carbonated drinks were significantly positively associated with DE in 22 of the 42 (52%) studies that investigated this beverage.[28,36,38,39,41-44,51,53,56,58-68]

Seven of 25 (28%) studies that investigated the consumption of sports/energy drinks reported a significant positive association with DE.[36,40,42,46,51,53,62]

Twelve of 36 (33%) studies reported that a higher intake of fruit juice significantly increased DE prevalence.[18,38,41,42,46,51,53,54,59,62,69,70] The majority of these studies did not specify the type of fruit juice.

Various types of tea were also examined with 11 studies reporting no significant link with DE, seven supported a significant increase in risk[36,40,51,53,54,57,68] and one study reported a protective effect of tea following bivariate analysis.[58]

Three cohort studies considered the intake of milk with two reporting that a higher frequency of intake could significantly reduce the progression of existing erosive lesions.[16,71]

The majority of the limited studies that examined water, coffee, alcohol, flavoured milk and/or flavoured drinks found no association with DE.

3.5 Food and dental erosion

Fruit, sour food, confectionery and dairy products were the most commonly investigated food. Citrus fruits such as lemons, oranges and grapefruit were assessed in 20 studies of which six (30%) demonstrated a significant positive relationship.[40,44,49,51,53,69] Other types of fruit including apples, grapes, mangoes and those not otherwise specified were investigated in 28 studies. Of these only seven (25%) identified a significant positive association with DE.[40,51,53,54,62,67,69]

In two cohort studies sour vegetables[28] and sour candies[16] both showed a significantly positive association with DE. Four cross-sectional studies observed that DE was significantly increased by the frequent consumption of sour candies.[42,53,55,66] A 3-year study identified yogurt/dairy products to be significantly negatively associated with DE incidence and progression following multivariate analysis.[28] Vinegar, pickles and/or yoghurt were assessed in 20 cross-sectional studies.[34,36,38,41,42,49-51,53,58,61-63,65,68,72-76] Two of these (10%) showed a significant positive association for both vinegar and pickles[41,53] and one (5%) a positive association for yoghurt.[51]

Six studies reported a significant directly proportional relationship between ketchup, mayonnaise, sour dip and DE.[36,38,49,51,53,69] Chewing gum, spicy foods, vegetables, acidic additives and vitamin C tablets were investigated in only a small number of studies with the majority reporting no significant association.

3.6 Dietary habits and dental erosion

Dietary intake habits were examined in three cohort and 33 cross-sectional studies. One cohort study reported that individuals with a high progression of tooth erosion had a statistically significant higher intake of drinks between meals and a 'retaining' drinking technique.[16] Despite immediate swallowing showing a protective effect in bivariate analysis, no correlation was identified in multivariate analysis between swishing, immediate swallowing, or straw use and the incidence of DE.[71] Sixty percent of cross-sectional studies found no association with swishing, retaining, or swallowing drinks immediately and DE. Two studies reported a directly proportional relationship in only selective teeth,[47,52] while four others identified this in all examined teeth.[53,55,62,76] Using a straw[39] and direct intake methods from bottles[42] or cups[53] were all shown to be significantly positively associated with DE prevalence. Straws reducing the odds of DE in bivariate analysis was reported in four cross-sectional studies.[42,44,53,69]

Rinsing after carbonated drink consumption, the consumption of chilled/higher temperature drinks and the consumption of chilled fruits were rarely reported. One study reported that rinsing after carbonated drink consumption significantly reduced DE prevalence,[53] while higher temperature of fruits was found to significantly increased DE in another.[77]

No significant associations were identified between DE incidence and timing of dietary acid intake at bedtime, before or after brushing.[78] Five cross-sectional studies found a directly proportional relationship between the consumption of acidic drinks or foods at bedtime and DE.[45,52,53,59,62] One of these identified lemon juice, carbonated drinks, lemon and sour candy to be the most harmful.[53]

In summary, apart from carbonated beverages, no other beverages, food or dietary habits have shown an overwhelming conclusive or significant association with DE.

3.7 Frequency effect size

Following bivariate or multivariable analysis, 32 identified risk factors were either positively or negatively associated with DE. Their calculated FES are presented in Table 3.

The highest FES for risk factors where more than 5 studies showed an association with DE were carbonated drinks (51%), fruit juice (29%), sports/energy drinks (29%) and tea (29%) for beverages; confectionary (43%), sauces (43%), citrus fruits (26%) and vinegar/pickles (26%) for food; and a swishing drinking habit/retaining drinks in the mouth (41%) and consumption of acidic drinks/food/beverages at bedtime (29%) for dietary habits.

4 DISCUSSION

While several studies have reported on the association between various risk factors and DE, no comprehensive qualitative summary of the impact of diet has as yet been published for adolescents.

Cognisant that publication bias may result in overestimation of true dietary impact, this was reduced through a systematic search protocol including hand searching through references of relevant studies, trial registries and omitting publications conducted on the same cohort.[79] Selection bias was minimised by the duplicate screening of study eligibility by independent researchers.

Most studies investigated dietary intake and habits used food frequency questionnaires or a brief dietary assessment. Retrospective assessment of diet is subject to recall bias with validation studies tending to show an overestimation of frequently consumed foods and underestimation of rarely consumed foods.[80] In addition, diet is known to vary according to season and day of the week, indicating the importance of multiple dietary assessments.[81] Two cohort studies conducted a dietary assessment only once over the duration of the study, risking an inaccurate representation of the eating habits within the population.[78,82] The use of more reliable and precise dietary assessment tools, such as multiple-day food records, and an improved understanding of the advantages, limitations, and characteristics of each, are recommended.[83,84]

Indices differed considerably in regard to the tooth subtypes, clusters of teeth and scoring systems. This was further complicated by the difficulty in diagnosing dentine exposure under field conditions.[85] Fewer significant associations between diet and DE were observed in the studies that used tooth indices with full mouth assessment, e.g. TWI[31], O'Sullivan[32] and Lussi.[86] Indices which converted individual observations to one score, e.g. BEWE[30] and Simplified Erosion Partial Recording System (SEPRS),[64] can overestimate the severity of DE.[87] Some studies elected to combine or average erosive tooth wear scores, while others used the presence or absence of dentine exposure to determine which risk factors were significantly associated. Tools used to quantify DE need to be revised as the lack of standardized indices present a limitation in the quantitative synthesis of epidemiological

studies and understanding of disease severity.[88,89] Current indices should be rigorously tested and refined to attain more homogenous findings in future studies.

Low to moderate sampling bias was present in three cohort and 12 cross-sectional studies. A small sample size has a higher likelihood that results are due to chance, whilst a too large sample size may exacerbate results which are not clinically relevant. Non-response bias was comparatively less common, however, still present in nine studies which omitted descriptions of the response rate and the characteristics of non-responders. Attrition bias was applicable to only one cohort study which failed to provide a description of dropouts and featured an attrition rate of 21%.[78]

Cross-sectional studies were more likely to establish a significant association with DE compared to cohort studies given that active and past erosion was not distinguished, increasing the likelihood of overestimation of associations in studies lacking temporal sequence. Contrary to this lifestyle factors must persist over time to lead to DE.[90]

For carbonated beverages only results for cross-sectional data are comparable to a previous review which concluded that especially carbonated drinks increased the risk of DE.[10] For sport/energy drinks and fruit juice results were inconclusive with approximately 25% of studies for each identifying a positive and significant association with DE. For beverages FES was found to be the highest for carbonated drinks (51%).

Citrus fruit was marginally more likely to be associated with DE. The impact of sour candies was particularly notable as recent incidence and prevalence data both supported a significant positive association. Due to a limited number of studies correlations could not be established with many food items including sauces, biscuits, chewing gum, spicy food, vegetables, acidic additives and vitamin C. This review was unable to find strong evidence advocating the protective effect of dairy products against DE and progression. For food FES was found to be the highest for confectionary and sauces (43% each).

The mixed results for tea, yogurt and chewing gum may be a consequence of the levels of acidic additives which vary depending on the manufacturer and flavour of the product.[58,91]

Limited evidence was found to link dietary habits and DE. One cohort study reported that DE progressed significantly more in those with a higher drink intake between meals and retaining drinks in the mouth.[16] The impact of prolonged retention of beverages was only supported in 40% of cross-sectional studies. Significant relationships with DE associated with consumption of fruit at higher temperatures[77] and rinsing after carbonated drink consumption[53] justifies a need for further investigation. The acidic potential of acidic drinks, exacerbated by xerostomia from dehydration following exercise, was confirmed in one

study.[92] For dietary habits FES was found to be the highest for a swishing drinking habit/retaining drinks in the mouth (41%).

FES scores should be interpreted with caution as values do not reflect the importance of each factor but rather the relative magnitude of extracted results which is dependent on how often it was mentioned.

Several risk factors favoured both a positive and negative correlation with DE (tea, milk, dairy products, straw use and brushing after eating/drinking), highlighting potential complex contributing factors which require further investigation. The conflicting results found with various consumption modalities such as using a straw and direct intake from bottles or cups may be related to the overall low specificity of survey questions which were unable to distinguish what type of food or beverages was involved with each behaviour.

There were inconsistent associations between DE and the timing of brushing after acidic intake since the complex interactions of confounding factors, such as the abrasiveness of the toothpaste and the mechanical action of the toothbrush, potentially influenced the results.[93]

This review included an additional 39 papers since the last systematic review on DE was conducted[10] of which approximately half were published in the last 5 years, which strengthens the findings by reducing the chance of omitting relevant information, accounting for different study designs and building a more solid foundation for causal inferences. Despite our intention to reflect the full range of results, the dichotomous reporting of associations as either significant or not, may not represent the true distribution or severity of association and is a limitation of this review. The review was further limited by formulating results based on pooled information from a diverse range of study methodologies and indices, which affected the heterogeneity of the data.[10] Lack of association between wear patterns and their respective aetiology could be ascribed to variations in terminology and subsequent interpretation.[94]

Although the strength of evidence provided by both cohort and cross-sectional studies are of low quality, it was still considered sufficient to implicate dietary factors in the widespread and increasing problem of DE. There was a poor level of agreement in prevalence compared to incidence and progression data and as such further long-term prospective studies are needed. The inconsistency of results suggests that although dietary factors and behaviours are contributing factors towards DE in adolescents, their influence is highly variable depending on the co-existence of other significant risk factors. Given that the erosive potential of food and beverages are likely moderated by habits and the ways in which they

are consumed, this should be further investigated. Since DE is a chronic process, long term studies with a consistent body of evidence are recommended to validate the current findings.

Results from this qualitative assessment should be interpreted with consideration of the various confounding factors associated with DE beyond the scope of this review. Even though experimental control of confounders is preferred in order to deliver robust conclusions, this review draws attention to the impact of various dietary factors and habits on DE in adolescents.

Within the limitations of our review, certain dietary risk factors may contribute to dental erosion in adolescents. It is important that health professionals are aware of the erosive potential of diet and diet-related behaviours and the accentuated impact it may have on susceptible groups.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

WHY THIS PAPER IS IMPORTANT TO PAEDIATRIC DENTISTS

- Dental erosion in adolescents is a globally emerging oral health problem
- Management of advanced dental erosion often requires costly and invasive functional and aesthetic rehabilitation
- Health professionals should be aware of the erosive potential of diet and diet-related behaviours

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Tables legend

TABLE 1 Search strategy

TABLE 2 Information of included studies

TABLE 3 Frequency effect size of extracted risk factors from cross-sectional, case-controlled, and longitudinal studies

TABLE 1 Search strategy

#	Search term
#1	dental erosion [All Fields]
#2	erosive tooth wear [All Fields]
#3	tooth erosion [All Fields]
#4	(#1 or #2 or #3)
#5	adolescent* [All Fields]
#6	teen* [All Fields]
#7	(#5 or #6)
#8	diet [All Fields]
#9	acids [All Fields]
#10	dietary acid [All Fields]
#11	dietary [All Fields] AND acid [All Fields]
#12	aetiology [All Fields]
#13	food [All Fields]
#14	beverage* [All Fields]
#15	(#8 or #9 or #10 or #11 or #12 or #13 or #14)
	Final search term: #4 and #7 and #15

TABLE 2 Information of included studies

Author (country)	Age (years)	Sample size	Direction of significance in bivariate and multivariate analysis for:			Clinical index	Risk of bias
			Beverages	**Food**	**Dietary habits**		
Cohort studies (n=5)							
Brusius et al (Brazil)[82]	12	801	Carbonated drinks Juice	Orange Lemon	N/A	BEWE	Medium
Chadwick et al (UK)[78]	11-13	197	Flavoured fizzy drinks Fizzy water Fruit juice Sports drinks Herbal teas Alcohol	Fruit Yoghurt Salad creams, dressings or vinegar	Drinking method Consumption of drinks at bedtime	Ryge system & surface matching and difference detection algorithm (SMADDA)	Medium
Dugmore & Rock (UK)[95]	12	1149	Fizzy pop (+m) Fruit juice Coffee/tea Fruit squash Chocolate	Apples and citrus fruits Fruits other than apples and citrus fruits (–m) Chips with vinegar or tomato sauce	N/A	O'Brien Index modified by Dugmore	Medium

			Milk Water	Chocolates Sweets			
El Aidi et al (The Netherlands)[28]	10-12	572	Acidic whey-based drinks (+b) *Acidic whey-based drinks (+b)* Carbonated drinks (+b) Fruit juice Energy/sports drinks *Energy/sports drinks (+b)* Ice tea Tea Fruit lemonade Lemonade squash Milk products *Milk products (–m)* Water Alcoholic mixed drinks (+m)	Fruits Acidic fruits Yoghurt products (–m) *Yoghurt products (–m)* Cheese Pickled vegetables Sour candy Sauces Chewing gum Curry Chilli sauce Vitamins *Vitamins (+m)* Sour vegetables (+m)	Swishing drinking habit Direct swallow (–b) Straw use	Lussi Index modified by Van Rijkom	Medium
Hasselkvist et al	13-14	*175*	*Acidic*	*Fresh fruits*	*Retaining drinking habit (+m)*	SEPRS	Medium

(Sweden)[96]			*carbonated drinks* *Juice* *Sports drinks* *Coffee* *Tea (–b)* *Still drinks* *Milk (–b)* *Sour milk (–m)* *Water* *Alcoholic beverages* *Sugar containing non-cola drinks (–b)*	*Dried fruits* *Yoghurt* *Cheese* *Ice cream* *Sweets* *Sour sweets (+b)* *Popsicle* *Biscuits* *Snacks* *Chewing gum*	*Consumption of drinks between meals (+m)*		
Case-control studies (n=3)							
Arnadottir et al (Iceland)[97]	15	278	Carbonated drinks Fruit juice Sports drinks	Sugar free gum	Consumption of acidic drinks and fruits between meals	Lussi Index modified by Arnadottir	Medium
Milosevic et al (UK)[37]	15	102	Carbonated drinks Fruit juice	Pickled onions Pickled foods excluding onion Ketchup/sauces	Consumption of chilled beverages Straw use	TWI modified by Bardsley	Low

Saerah et al (Malaysia)[46]	16	576	A total of 17 beverages and foods; not specified. Carbonated sports drink (+m) Orange juice (+m)	A total of 17 beverages and foods; not specified.	N/A	TWI	Medium
Cross-sectional studies (n=44)							
Abu-Ghazaleh et al (Jordan)[49]	15-16	1,602	Carbonated drinks Fresh juice Energy drinks Coffee (+b) Tea Fruit drinks Milk Water	Apples Canned fruit Oranges (+m) Lemons Yoghurt Cheese Vinegar Pickles Olives (+b) Salt and vinegar chips Ketchup (+m) Spicy food Vitamin C tablets	N/A	TWI modified by Bardsley	Medium
Aguiar et al	15-19	675	Carbonated	Yoghurt	N/A	O'Sullivan	Medium

(Brazil)[50]			drinks Natural fruit juice Artificial fruit juice Energy drinks Coffee Ice tea Isotonic beverages Milk/flavoured milk	Vinegar Pickles Mustard Ketchup		Index modified by Aguiar	
Al-Dlaigan et al (UK)[51]	14	418	Carbonated drinks (+b) Fruit (apple and orange) juice (+b) Sports drinks (+b) Coffee/tea (+b) Orange squash (+b) Milk (+b) Alcohol (+b)	Fruits (apples, oranges, bananas, grapes) (+b) Yoghurt (+b) Vinegar (+b) Pickles Ketchup (+b) Salad dressing Vitamin C tablets (+b)	N/A	TWI modified by Millward	Medium
Al-Majed et al (Saudi Arabia)[52]	12-14	851	Coffee/tea Milk Water	Fruits Crisps or savory snacks Confectionary and sweet	Retaining drinking habit (+b maxillary incisors) Consumption of acidic drinks or food at bedtime (+b maxillary incisors)	O'Brien Index modified by	Medium

				snacks Cakes Toast/sweet sandwiches Cereals - sweetened/unsweetened Biscuits - sweetened/unsweetened		Al-Majed	
Alvarez Loureiro et al (Uruguay)[72]	12	1,136	Carbonated drinks	Fruits Yoghurt	Swishing drinking habit Straw use Consumption of beverages immediately after exercise	BEWE	Low
Alves et al (Brazil)[60]	12	1528	Carbonated drinks (+m)	Oranges Lemons	N/A	BEWE	Low
Bardolia et al (Isle of Man)[61]	13-14	629	Carbonated drinks (+b) Fruit juice Flavoured water Milk Water	Fruits Yoghurt Ice-cream Chewing gum	N/A	TWI modified by Bardsley	Medium
Bartlett et al (UK)[73]	11-14	210	Carbonated drinks Fruit juice	Acidic fruits (lemons, oranges, apples, grapes) Vinegar Pickles Curry/spicy foods	N/A	TWI	Medium

				Spices			
Caglar et al (Turkey)[74]	11	153	Carbonated drinks Fresh orange juice Fruit juice Tea Milk Water	Fruits Citrus fruits Fruit flavoured yoghurt Ice cream	Straw use Consumption of beverages over an extended period Consumption of beverages between meals Consumption of beverages at bedtime	O'Sullivan Index	Medium
Caglar et al (Turkey)[75]	12-14	36	Carbonated drinks Fruit juice Tea Nesquik Buttermilk Milk Water	Fruits Fruit yoghurt	Retaining or swishing drinking habit Straw use Consumption of beverages over an extended period Consumption of drinks between meals Consumption of drinks at bedtime	Lussi Index	Medium
Chrysanthakopoulos (Greece)[62]	13-16	770	Carbonated drinks (+m) Fruit juice (+m) Sports drinks (+b) Coffee/tea Milk	Fruits (+b) Yoghurt Vinegar Vegetables	Retaining drinking habit (+m) Consumption of acidic drinks at bedtime (+m)	TWI	Medium

Correr et al (Brazil)[77]	12	389	Carbonated drinks Fruit juice (natural or artificial) Sports drinks Acidic drinks Milk	Acidic fruits Candies	Straw use Consumption of beverages over an extended period Consumption of beverages at higher temperatures Consumption of fruits at higher temperatures (+b)	O'Sullivan Index modified by Correr	Medium
Deery et al (UK & USA)[29]	11-13	254	Carbonated drinks Non-carbonated (fruit/still) drinks	Fruits Spicy foods	N/A	O'Brien Index	Medium
Gonzalez-Aragon Pineda et al (Mexico)[63]	14-19	417	Sweet carbonated drinks (+b) Fruit juice Sports drinks Energy drinks Tea Nectar or juice concentrate Milk Water	Fresh and canned fruits Yoghurt Pickled vegetables Canned/preserved peppers Condiments Spicy foods	Retaining or swishing drinking habit Consumption of beverages over an extended period Immediate brushing of teeth after food or drink consumption Consumption of drinks at bedtime	Lussi Index	Low
Gurgel et al	12 &	414	Carbonated	Fruits	Retaining drinking habit	O'Brien	Medium

(Brazil)[34]	16		drinks Fruit juice Sports drinks Coffee/tea Milk Water	Citrus fruits Yoghurt Vinegar Sweets Ketchup	Consumption of acidic drinks at bedtime	Index	
Hamasha et al (Jordan)[53]	12-14	3812	Carbonated drinks (+b) Fruit drinks (including lemon juice) (+b) Sports drinks (+m) Coffee (+b) Herbal tea (+b) Milk Water	Tinned fruits (+b) Citrus fruits (+m lemon) Yoghurt Cheese Vinegar (+b) Pickles (+b) Sour candies (+m) Mayonnaise (+b) Ketchup Spicy food (+b) Chewable vitamin C (+b)	Retaining drinking habit (+m) Straw use (–b) Immediate brushing of teeth after carbonated drink consumption (+m) Consumption of sports beverages immediately after exercise (+b) Consumption of food or drink at bedtime (+m lemon juice and carbonated drinks) Rinsing after carbonated drink consumption (–m)	TWI modified by Millward	Medium
Hasselkvist et al (Sweden)[64]	13-14; 18-19	474	Carbonated drinks (+b) Fruit juice Sports drinks Still drinks Water	N/A	N/A	SEPRS	Medium

Huew et al (Libya)[54]	12	791	Carbonated drinks Natural fruit juice Sports drinks Squash Fruit-based sugary drinks (+b) Tea with milk (+m) Flavoured milk (+m) Water	Fruits (+m except for bananas) Chewing gum	Consumption of beverages over an extended period (+b) Consumption of acidic food or drink at bedtime	NDNS	Medium
Kirthiga et al (India)[35]	11-16	2000	Carbonated drinks	Fruits (oranges, lemons, grapes) Candy Jelly	Retaining drinking habit Consumption of acidic drinks or food at bedtime	O'Sullivan Index	Medium
Kumar et al (India)[44]	11-14	605	Carbonated drinks (+m)	Fruits Lemons (+m) Jam Sweets (+b) Snacks Biscuit Vitamin C	Straw use (–b) Consumption of acidic beverages between meals Consumption of acidic beverages at bedtime	O'Sullivan Index	Low

Li et al (China)[45]	12&15	720	Carbonated drinks Fruit juice Tea	Acidic foods; not specified	Retaining drinking habit Straw use Consumption of beverages immediately after exercise Consumption of acidic foods or drinks at bedtime (+m)	BEWE	Medium
Milosevic et al (UK)[36]	14	2385	Carbonated drinks (+b) Low-calorie carbonated drinks Fruit juice Sports drinks (+b) Coffee/tea Herbal/lemon tea (+b) Diluted fruit juice/squash Milk Mineral water Still water Alcohol	Fruits Yoghurt Cheese Vinegar (+b) Pickles Baked beans Salt and vinegar chips (+b) Ketchup Sauces (+b) Salad dressings Curry/spicy food	Consumption of drinks at bedtime	TWI	Low
Mulic et al (Norway)[38]	18	1456	Carbonated drinks (+m) Fruit juice (+m) Sports drinks Squash (+b)	Fruits (citrus, apples, kiwis) Yoghurt Vinegar Sour candies/candies	N/A	VEDE	Medium

			Flavoured water Alcopop/wine	containing vitamin C Chips with sour dip (+b) Lettuce with vinegar dressing			
Muller-Bolla et al (France)[55]	14	331	Acidic beverages (+m) Sports/energy drinks	Acidic fresh fruit Acidic sweets (+m) Vitamin C	Retaining drinking habit (+m)	BEWE	Low
Mungia et al (USA)[65]	12-17	307	Carbonated drinks (+b) Juice Milk and Water (+b)	Fruits Pickles Sour candies	N/A	TWI modified by Mungia	Medium
Najmi et al (Pakistan)[39]	12-14	299	Carbonated drinks (+m) Fruit juice Sports drinks Lemon tea	Vitamin C	Straw use (+m)	O'Sullivan Index	Medium
Okunseri et al (USA)[18]	13-19	1,314	Carbonated drinks Apple juice (+m) Grape juice	N/A	N/A	TWI modified by Okunseri	Medium

			Orange/grapefruit juice Tomato/vegetable juice Other juice Fruit drink Milk				
Provatenou et al (Greece)[66]	14	263	Carbonated drinks (+b) Fruit juice	Lemon-flavoured sour candy (+b)	Retaining drinking habit	BEWE	Medium
Ratnayake & Ekanayake (Sri Lanka)[69]	17	1200	Coca cola (+m) Ginger beer (+b) Natural fruit juice (+b)	Apples (+m) Oranges (+b) Sauces (+b) Chewable vitamin C tablets (+m)	Straw use (–b)	TWI modified by Ratnayake	Low
Sanhouri et al (Sudan)[40]	12-14	1138	Carbonated drinks Lemon juice Orange juice Sports drinks (+b) Karkade tea (+b)	Fruits (+m mango) Citrus fruits (lemons, oranges, grapefruits, baobabs, tamarinds) (+b baobab, +m grapefruit)	Immediate brushing of teeth after carbonated drink consumption	TWI modified by Millward	Medium
Septalita et al (Indonesia)[57]	12	487	Fruit juice Citric tea (+m)	Chewing gum Vitamin C supplement	N/A	BEWE	Medium

			Acidic drinks	drinks			
Shahbaz et al (Pakistan)[41]	12-14	385	Carbonated drinks (+b) Lemon and orange juice (+b) Sports drinks	Citrus fruits Vinegar (+b) Pickles (+b)	Immediate brushing of teeth after carbonated drink or juice consumption (–b)	Erosion present or absent	High
Skalsky Jarkander et al (Sweden)[67]	15 & 17	1071	Carbonated drinks (+m) Juice Sports drinks	Fruits (+b) Apples (+b) Citrus fruits Chewing gum	Consumption of juice or sports drinks immediately after exercise (+m)	SEPRS modified by Skalsky	Medium
Sovik et al (Norway)[42]	16-18	795	Carbonated drinks (+b) Diet carbonated drinks (+b) Fruit juice (+b) Sports drinks (+m) Squash Flavoured water	Apples Citrus fruits Yoghurt Sour sweets (+m) Vitamin C fizzy tablet	Retaining or swishing drinking habit Consumption modality (–b glass or straw for diet soft drinks only) Consumption of acidic drinks between meals	VEDE	Medium
Struzycka et al (Poland)[68]	18	1869	Carbonated drinks (+b) Fruit juice Energy drinks	Fruits Pickles	N/A	BEWE	Medium

			Fruit teas (+b) Isotonic drinks				
Talebi et al (Iran)[59]	12	483	Carbonated drinks (+b) Fruit juice (+b) Water (–b)	Fruits	Straw use Consumption of beverages over an extended period Consumption of acidic beverages between meals Consumption of acidic beverages at bedtime (+b)	O'Sullivan Index	High
Van Rijkom et al (The Netherlands)[47]	15-16	400	Carbonated drinks Fruit juice Sports drinks Dairy drinks Acidic drinks (–m) - upper anteriors	Acidic fruits	Swishing drinking habit (+m lower molars)	Lussi Index modified by Van-Rijkom	Medium
Vargas-Ferreira et al (Brazil)[98]	11-14	944	Acidic drinks	N/A	N/A	O'Sullivan Index	Low
Vered et al (Israel)[48]	15-18	100	Carbonated drinks Energy drinks Lemon drinks	Fruits (oranges, apples) Fresh vegetables Acidic food (+m)	N/A	BEWE	Medium
Wang et al (China)[43]	12-13	1499	Carbonated drinks (+m)	Fruits Succade	Retaining drinking habit Straw use	O'Sullivan Index	Low

			Fruit juice Sports drinks Lemon tea	Chewing gum Vitamin C	Consumption of beverages at bedtime		
Waterhouse et al (Brazil)[58]	13-14	458	Carbonated drinks (sugared) (+m) Carbonated drinks (sugar-free) Fruit juice Sports drinks Energy drinks Coffee Tea (–b) Fruit flavoured drinks Milk Water	Fruits Yoghurt Vinegar Pickles Sweets Mustard Ketchup Chewing gum (+b)	Consumption of food and drinks at bedtime	TWI	Medium
Williams et al (UK)[33]	14	525	Acidic drinks; not specified	Acidic fruits; not specified	N/A	O'Brien Index	Medium
Zhang et al (Hong Kong)[70]	12	600	Carbonated drinks Fruit juice (+b)	Chewing gum (+b) Vitamin C supplement drinks	N/A	BEWE	Low

			Citric tea/drinks containing lemon				
Zhang et al (China)[76]	12 & 15	720	Carbonated drinks Fruit juice Vegetable juice Coffee Wine	Fresh fruit Yoghurt Vinegar Pickled vegetables Vitamin C	Retaining drinking habit (+b carbonated drinks and fruit juices) Straw use Consumption of beverages immediately after exercise (+b) Consumption of acidic drink or food at bedtime	BEWE modified by Zhang	Low

Note:

Italics = results for progression data

(+b) or (–b) = respectively positively or negatively associated with DE following bivariate analysis

(+m) or (–m) = respectively positively or negatively associated with DE following multivariable analysis

SEPRS = Simplified Erosion Partial Recording System; BEWE = Basic Erosive Wear Examination; TWI = Tooth Wear Index; VEDE = Visual Erosion Dental Examination; NDNS = National Diet and Nutrition Surveys

TABLE 3 Frequency effect size of extracted risk factors from cross-sectional, case-controlled, and longitudinal studies

Beverages				Food				Dietary habits			
Risk factor	**Studies (n) with a positive correlation with dental erosion**	**Studies (n) assessing the risk factor**	**FES%**	**Risk factor**	**Studies (n) with a positive correlation with dental erosion**	**Studies (n) assessing the risk factor**	**FES%**	**Risk factor**	**Studies (n) with a positive correlation with dental erosion**	**Studies (n) assessing the risk factor**	**FES%**
Carbonated drinks[4,38,39,41,42,44,46,51-53,56,58-66,68,69,71,95]	24	47	51%	Fruit[40,51,53,54,56,62,69]	7	32	22%	Straw use[39]	1	16	6%
Fruit juice[18,38,41,42,46,51,53,54,59,62,69,70]	12	41	29%	Citrus fruit[40,44,49,51,53,56]	6	23	26%	Swishing drinking habit/retaining drinks in the mouth[16,47,52,53,55,62,76]	7	17	41%
Sports/energy drinks[36,40,42,46,51,53,62,71]	8	28	29%	Dairy products (yoghurt, ice-cream, cheese, etc.)[51]	1	20	5%	Consumption of acidic drinks/food/beverages at bedtime[45,52,53,59,62]	5	17	29%
Coffee[49,51,53]	3	12	25%	Vinegar and pickles[36,41,49,51,53]	5	19	26%	Consumption of drinks/acidic drinks and fruit between meals[96]	1	7	14%
Tea[36,40,51,53,54,57,68]	7	24	29%	Confectionary (sweets, lemon-flavoured	6	14	43%	Consumption of chilled beverages	0	1	0%

				candies, sour candies, biscuits, etc.)[42,44,53,55,65,96]							
Acidic beverages[55,71]	2	7	29%	Sauces (ketchup, mayonnaise)[36,38,49,51,53,56]	6	14	43%	Consumption of beverages at higher temperature	0	1	0%
Flavoured drinks including concentrate and squash[38,54]	2	15	13%	Chewing gum[58,70]	2	10	20%	Consumption of beverages immediately after exercise[53,67,76]	3	5	60%
Milk[51,54,65]	3	20	15%	Spicy food[53]	1	7	14%	Consumption of beverages over an extended period[54]	1	6	17%
Water[65]	1	18	6%	Vitamin C supplements[51,53,56,71]	4	14	29%	Consumption of fruit at higher temperature[77]	1	1	100%
Alcohol[51,71]	2	7	29%	Fresh vegetables[71]	1	3	33%	Immediate brushing of teeth after food or drink consumption[53]	1	4	25%
	Beverages				**Food**				**Dietary habits**		
Risk factor	**Studies (n) with a negative correlation with dental erosion**	**Studies (n) assessing the risk factor**	**FES%**	**Risk factor**	**Studies (n) with a negative correlation with dental erosion**	**Studies (n) assessing the risk factor**	**FES%**	**Risk factor**	**Studies (n) with a negative correlation with dental erosion**	**Studies (n) assessing the risk factor**	**FES%**
Tea[58,96]	2	24	8%	Dairy products (yoghurt,	1	20	5%	Straw use[42,44,53,69]	4	16	25%

				ice-cream, cheese, etc.)[71]			
Milk[71,96]	2	20	10%		Direct swallowing[71]	1	1	100%
					Immediate brushing of teeth after food or drink consumption[41]	1	4	25%
					Rinsing after carbonated drink consumption[53]	1	1	100%

Figures legend

FIGURE 1 Flow chart of selection of articles

FIGURE 1 Flow chart of selection of articles