“A CRITICAL REVIEW OF THE EROSIVE POTENTIAL OF FOODSTUFFS AND THEIR EFFECT ON THE ADULT DENTITION”

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ABSTRACT

Background: The link between diet and erosion is now subject to extensive research as it becomes of growing concern to both the dental community and the public. Dental erosion is multifactorial in nature, highly influenced by individual habits and lifestyles alongside the chemical factors of each food or drink. The prevalence of erosion is growing and with this comes complications of tooth sensitivity, aesthetics and loss of occlusal vertical dimension.

Objective: The aim of this paper was to critically review the erosive potential of foodstuffs and their effect on the permanent dentition with regards to prevalence in adults, determinants of erosive potential, the erosive potential of foodstuffs and any efforts that have been made to modify food or drink to reduce erosive potential.

Conclusion: The erosive potential of many foods and drinks is clearly evident from the research. As erosion continues to become of greater importance in coming years it is vital to educate both dental professionals and the public to this area of dentistry, while continuing efforts to reduce the erosive potential of foods and drinks.

INTRODUCTION

The overall objective of this paper is to review the current research regarding the association between diet and its erosive effects on the adult dentition. Dental erosion or *erosio dentium* is the progressive loss of dental hard tissue by a chemical process without the involvement of micro-organisms (Lussi, 2006). It is a complex process, determined by various individual habits alongside a range of biological and chemical factors.

Over two decades ago Ten Cate and Imfeld (1995) stated in the *European Journal of Oral Science* that dental erosion was an area of dentistry that must be prioritised by the research community in coming years. This is now the case with the body of literature increasing substantially in the last decade. There are now over 50 studies exploring this topic each year compared to just 10 in the 1980s.

Despite this rapid expansion of evidence in the scientific community, the public has surprisingly little knowledge of the topic and awareness of its clinical signs by dental professionals is commonly lacking (Dugmore & Rock, 2003), often being confused with other forms of tooth wear. This can be attributed to an ongoing debate regarding the terminology and aetiology of tooth wear, which is currently divided into attrition, abrasion, abfraction and erosion. Not only epidemiological data but *in vivo* and *in vitro* studies have shown that of these four processes involved in tooth wear, while often acting synergistically, erosion is commonly the most significant (Nunn, 2000; Zero & Lussi 2000).

Specific aspects of dental erosion that will be covered in this paper include:

- The determinants of erosive potential
- The prevalence of erosion in the adult population
- The erosive potential of different types of food and drink
- Efforts to prevent or inhibit erosion by modification of food and drink

THE DETERMINANTS OF EROSIVE POTENTIAL

Debate continues over the exact determinant of erosive potential. Early research linking diet to erosion indicated that pH was the foremost indicator (Eccles & Jenkins, 1974). Yet the interaction between erosion and pH, a measure of hydrogen ion concentration, is not quite so simple. While the pH value is a useful indicator during the initial minutes of exposure, it has been accepted that neutralisable acidity, which measures the amount of free hydrogen ions available, is a superior factor (Lussi *et al.* 1995; Barbour and Rees, 2004) and is more applicable to longer exposures (Jensdottir *et al*. 2006).

However, these two parameters alone do not entirely explain erosive potential, instead, a range of chemical factors specific to each food or drink can now be measured that attribute to erosion. It is important to note that at an individual level behavioural and biological factors must also be taken into account to appreciate how the tooth surface is affected by diet, factors are summarised in Table 1.

TABLE 1.

FACTORS THAT CONTRIBUTE TO THE EROSIVE EFFECT OF FOODSTUFFS ON THE DENTITION

Chemical	**Behavioural**	**Biological**
Adhesion of the product to the dental surface	Unhealthy life style: frequent consumption of alcohol	Composition of dental substrate
Calcium, Phosphate, Flouride concentration	Frequency of consumption of acidic foods and drinks	Physiological soft tissue movements
Chelating properties of the product	Alcoholic disease	Acquired salivary pellicle
Type of acid (pKa values)	Oral hygiene practices	Dental anatomy and occlusion
pH and neutralisable acidity	Eating/Drinking habits	Saliva: flow rate, composition, buffering capacity and stimulation capacity
	Night time consumption of acidic foods and drinks	Anatomy of oral soft tissues in relationship to the teeth

Adapted from Lussi (2006)

Chemical

Fluoride, calcium and phosphate concentrations are all important parameters that may reduce erosive potential, however, discussion continues over which of these elements has the greatest influence. In 1995 Lussi *et al*. suggested that phosphorus concentration was the best indicator of preventing enamel demineralisation, although more recently, Hara and Zero (2008) presented evidence that the calcium concentration was a superior indicator, reinforcing findings of an *in vivo* study (Hooper *et al*. 2004). Despite the expectations of fluoride to reduce erosive potential, it has been repeatedly shown that it does not significantly reduce erosive potential (Larsen 2001; Larsen & Richards, 2002). However due to the discrepancy between the particular drinks evaluated in each study, along with differing immersion times, it is hard to say with confidence which element is the best at determining the prevention of enamel erosion. More recent research has found that calcium and phosphorus when used together may be the most effective combination (Attin *et al.* 2005).

Several other noteworthy factors are the chelating properties of the particular acids, in particular citric acid (West *et al.* 2000), which enhances the erosive process. Another factor is the ability of a drink to adhere to the tooth surface, which depends on its thermodynamic properties (Ireland *et al.* 1995). The more adherent the drink, the greater the erosive effect due to the increased contact time. On the other hand, the displacement of a drink is equally important. It has been shown that soft drinks are less readily displaced by saliva than saliva is displaced by soft drinks (Busscher *et al.* 2000). Further research is needed in this area to improve our understanding of the complex environment that occurs at the tooth surface.

Biological

From a biological point of view, saliva and the salivary pellicle are considered the most important factors. The salivary pellicle has been shown in both *in vitro* and *in vivo* studies to either totally or partially protect the tooth surface from acidic attacks (Amaechi *et al*. 1999; Hannig and Balz, 1999; Nekrashevych and Stösser, 2003). The importance of saliva was demonstrated by a comparison between an *in vitro* study without saliva and an *in vivo* study with saliva, erosion was decreased by 10 times *in vivo* (West *et al*. 1998). Studies investigating erosion in patients with reduced salivary flow clearly present evidence of the protective effects of saliva (Jarvinen *et al.* 1991; Rytomaa *et al.* 1998). The time that it takes for saliva to neutralise an acidic attack may vary between 2 and 7 minutes and this variance is attributed to individual differences (Bartlett *et al*. 2003; Millward *et al*. 1997). These two parameters can only be accurately included by *in vivo* studies, which are extremely rare due to the ethical implications of subjecting people to a potentially erosive process. Consequently evidence usually relies on *in vitro* studies or efforts to recreate the oral environment, which limits the reliability of results.

Behavioural

Fundamental behavioural factors include an excessive frequency of consumption (Dugmore & Rock, 2004; Johansson *et al.* 2002) alongside unusual ingestion habits (Edwards *et al.* 1998; Johansson *et al.* 2004; Millward *et al.* 1994). Behavioural factors are rarely considered in the literature; possibly as they are difficult to accurately quantify or measure, but their influence gives rise to a great variation between individuals.

In summary, it is essential to remember that the behavioural and biological factors unique to individuals mean the effects of erosion *in vivo* cannot only be decided by pH, neutralisable acidity, fluoride, calcium or phosphate concentrations. Instead all of the above factors must be considered in order to understand and determine the effects a food or drink will have on the adult dentition.

PREVALENCE OF TOOTH EROSION IN ADULTS

As human behaviour is always altering, so too does human diet, including the volume and frequency of consumption of acidic food and beverages (British Soft Drinks Association, 1991; Calvadini *et al.* 2000; Lussi and Schaffner, 2000). The frequency of intake has increased significantly in the last several decades (French *et al.* 2003) and the prevalence of erosive lesions is growing, particularly in adolescents (Deery *et al.* 2000; Dugmore and Rock, 2003; Jaeggi and Lussi, 2006).

From the moment teeth erupt into the oral cavity they are susceptible to the erosive process. If this process continues for long enough, evidence can be seen clinically. Anteriorly, incisal edges become translucent, smooth surfaces become dull, convex areas flatten and concavities may appear on facial and palatal surfaces just above the gingival margin (Fig.1 and Fig.2). Posteriorly, molar and premolar cusps become rounded, the occlusal surfaces become smooth and in severe cases, perimolysis or cupping of molars occurs (Magalhaes *et al.* 2009) and a reduction in occlusal vertical dimension can be present (Fig.3). The prevalence of these signs are understandably hard to measure due to different assessment standards (scoring systems, standards, examiners) and inclusion criteria- (age, gender, number of individuals, socio-economic status, geographic location) and even more difficult to compare. Therefore a figure of the exact prevalence of tooth wear is unclear, without an accurate tooth wear index to be universally adopted. (For localisation of these clinical signs, see Appendix A).

Lussi *et al.* (1991) published one of the first examinations of adult tooth erosion, selecting 91 Swiss adults in two different age groups, one younger and one older (26-30 and 46-50 years old). For facial surfaces 7.7% of the younger age group and 13.2% of the older age group showed at least one tooth affected with erosion with involvement of dentine. Occlusally, at least one severe erosive lesion was observed in 29.9% of the younger and 42.6% of the older sample, together these indicate an increase of erosion with age. However the reliability of this study is undermined by its small sample size and, as with many prevalence studies, only offers results from an individual population and has to be considered as a cross sectional study.

There is a distinct lack of systematic reviews regarding prevalence of dental erosion in adult populations. The most recent systematic review using literature from both Pubmed and Cochrane libraries found that 3% of young adults show signs of severe tooth wear and that this gradually increases to 17% by the age of 70 years old (Van't Spijker *et al.* 2009). El Aidi *et al.* (2008) also showed this trend of dental erosive wear increasing with age in a longitudinal study of adolescents. Both reviews reinforced findings that more men than women present with dental erosion.

One recent study (including one of the largest sample sizes of 1010 adult students) showed that all subjects had mild evidence of enamel loss and 20.1% displayed moderate enamel loss. This pattern of loss was most frequently located on anterior teeth and occlusal surfaces of first molars. Erosion so severe it had led to dentine exposure affected 5.3% of subjects and was most commonly observed on the incisal surfaces (Bartlett *et al*. 2011). This study did however use “students” and is arguably therefore not a true representation of adults and prevalence could vary greatly from other social groups.

Smith and Robb (1996) found that tooth wear affected 97% of 1007 adult dental patients, with dentine exposure becoming more common with increasing age and 5-7% of adults presenting with severe tooth wear. This study did not distinguish between the tooth wear processes and therefore the impact of erosion specifically cannot be determined.

One of the most useful reports with regards to erosion within the United Kingdom comes from The National Diet and Nutrition Survey (NDNS) that stated 62% of 15–18 year olds presented with at least mild erosion of the permanent dentition.

It is accepted that the erosive process causes a considerable reduction in micro hardness (Lussi *et al*. 1995) resulting in the tooth surface becoming more susceptible to mechanical impacts (Attin *et al.* 1997) allowing erosion to act together with other forms of tooth wear such as attrition and abrasion. Distinguishing each process or the combination of each is difficult and in each prevalence study these processes may act as confounding factors and threaten internal validity.

As previously mentioned, comparing studies is challenging due to different measurement indices and differing inclusion criteria. Many studies have insufficient sample sizes and the multifactorial nature of tooth wear means grading erosion is even more challenging. There is an obvious lack of systematic studies in adult populations; it is however possible to say the prevalence of dental erosion is increasing, especially in younger generations, possibly attributed to changes in eating habits and diet.

In the future, it is imperative to carry out broader systematic studies to include all ages, social classes, cultures, and populations worldwide. It is of equal importance to develop a universally accepted reproducible index. New quantitative measuring systems using laser scanners are already beginning to be used and may be part of the answer (Al-Omiri *et al.* 2010; Field *et al*. 2010).

Fig 1. Severe facial erosive tooth wear. Age of patient: 25 years. Known aetiological factors: lemon slices under the lip and fruit juices. (Lussi, 2006).

Fig 2. Severe palatal erosive tooth wear with extensive dentinal exposure. Age of patient: 38 years. Known aetiological factors: soft drinks (Lussi, 2006).

Fig 3. Occlusal erosive tooth wear. Age of patient: 29 years. Known aetiological factors: soft drinks and sports drinks. (Lussi, 2006).

ALCOPOPS

Alcopops arrived on the market in 1995, targeted at young adults. They are a sweet alcoholic fruit based drink with a high citric acid content. These drinks have consistently been found to have a highly erosive effect on dental hard tissues in not only a case report (O'Sullivan and Curzon 1998) but also several in vitro studies (Rees et al. 1998; Rees and Davis 2000, Ablal *et al*. 2009).

Rees *et al.* (1998) and Rees and Davis (2000) investigated a wide range of alcopops which all demonstrated considerable surface demineralisation similar to that of orange juice. However both investigations reported slightly lower pH values ranging from 2.57-2.86 compared to the values of Ablal *et al*. (2009) that ranged from 2.95-3.63. This may be explained by the possibility of a change in ingredients during the period of time between studies but as the ingredients were not specifically stated, this is not conclusive. Similar neutralisable acidity values were found between studies ranging from 15.4-23.26mls between brands.

Conflicting results with regards to surface loss were reported by each study. Despite similar pH values for different alcopop flavours tested by Rees *et al*. (1998) and Rees and Davis (2000), the surface loss measured was low at 1.80-3.28µm compared to more significant surface loss after one-hour immersion reported by Ablal *et al*. (2009) at 24.2-44.4µm. This difference may be explained by a variety of factors. The study held by Ablal *et al*. (2009) used bovine teeth which have been shown to have structural differences to human teeth, rendering them more porous and therefore less resistant to acidic attack (Arends *et al*. 1989). Furthermore, the removal of the smear layer in this study through polishing and grinding leaves the enamel more susceptible to acids as the more porous subsurface is exposed (Ganss *et al.* 2000). Finally, it has been shown that a salivary pellicle should be allowed to mature for a minimum of 24 hours in order to protect the tooth surface form acidic attacks (Nieuw Amerongen *et al*. 1987) and the 2 hours that were allowed would not be sufficient and hence such high values were obtained by Ablal *et al.* (2009). Despite this exaggeration of erosive potential, it is still clear when reviewing all of the evidence that alcopops are highly erosive.

CIDER AND BEER

While the majority of research is directed towards other alcoholic drinks, one *in vitro* study has examined the erosive effects of cider, a popular alcoholic drink made from fermented apple juice. Rees and Griffiths (2002) compared several different brands of cider concluding that all ciders had a high erosive potential. The pH values ranged from 2.96 to 4.04 and neutralisable acidity values ranged from 14.54 to 21.47mls. The surface enamel lost during a four-hour immersion in each cider was valued from 8.60-23.95μm in comparison to 12.85μm from an orange juice control. It is worth noting that the surface loss did not reach higher levels than the orange juice control until one hour after immersion. The conclusion states that cider does have a substantial erosive potential *in vitro* which was comparable to orange juice (Rees and Griffiths, 2002). The high values of surface enamel loss may be explained by the addition of ascorbic acid to cider apples during the manufacturing process, used to prevent discolouration but therefore increasing total acid content (Rees and Griffiths, 2002).

There is also very limited research directed towards malt drinks but both lager and beer have been shown by both an *in vitro* and *in vivo* study to be similarly erosive to cider. Although again dependant on the brand of drink (Caglar *et al.* 2008; Nogueira *et al*. 2000). Further inclusion of these drinks in future studies against a range of other drinks would be useful to determine just how erosive they are.

WINE

It was in 1907 that the potential erosive effects of wine were first postulated (Miller, 1907). Since then, ongoing research in both *in vitro* and *in vivo* studies has revealed Miller was correct.

The majority of research linking wine to dental erosion is reported *in vivo* in either wine tasters or wine merchants (Chaudhry *et al.* 1997; Chikte *et al.* 2005; Ferguson *et al*. 1996; Gray *et al.* 1998; Meurman & Vesterinen, 2000; Mok *et al.* 2001; Mulic *et al.* 2011; Wiktorsson *et al.* 1997). In these cases, dental erosion is unavoidable due to most wine tasters sampling between five and fifty wines each day combined with each wine being held in the mouth for between fifteen to sixty seconds (Ferguson *et al.* 1996). Inevitably this frequency and duration of exposure subjects the dentition to an increased acidic attack than if the wine was swiftly swallowed (Millward *et al.* 1997). *In vitro* studies have shown that the exposure of extracted teeth to both white and red wine can decrease the microhardenss of enamel in less than two minutes (Chikte *et al.* 2003; Lupi-Pegurier *et al.* 2003). These findings were reinforced by scanning electron microscopy (Lupi-Pegurier *et al.* 2003).

The pH of wine has been shown to range from 3.0 to 4.0 (Gray *et al.* 1998; Mok *et al.* 2001; Wiktorsson *et al.* 1997), with white wine indicated as marginally more acidic than red wine (Meurman and Vesterinen, 2000; Wiktorsson *et al.1997*) despite a lower neutralisable acidity (Brand *et al.* 2009a). The acidity in white wine can be attributed to its levels of fruit acids, primarily malic and tartaric acids followed by citric and succinic acids (Ferguson *et al.* 1996). In another *in vitro* assessment, white wines were shown to be equally, if not more erosive than orange juice, while a small selection of wines, in particular the "Cava", displaying a significantly more erosive effect (Rees *et al.* 2002).

In both an *in vivo* experiment and a case report the occlusal surfaces of the lower first molars were the most commonly affected (Mandel, 2005; Mulic *et al.* 2011). But due to the swishing and retaining of the wine around the mouth, all surfaces may be affected, particularly the mandibular teeth due to gravity (Mandel, 2005).

However, the results of *in vitro* experiments must be viewed with caution as *in vivo* the erosive potential of wine is altered by the buffering and remineralising effects of saliva. Proven by one study observing no significant changes in salivary pH after ''passively'' drinking wine (Brand *et al.* 2009b).

FLAVOURED WATERS

Flavoured waters are one of the more recent soft drinks available to the public, yet their dramatic rise in popularity means that 25% of adults in the UK are now consuming this brand of drink (British Soft Drinks Association, 1991).

Edwards *et al.* (1999) was one of the first to research these drinks, drawing comparisons against still and carbonated waters. The pH of still mineral waters was found to be close to neutrality, while the pH of carbonated water was slightly more acidic at around 5.2. Both drinks were shown to have negligible erosive effects, and while carbonated water produced slightly higher values, both can be deemed to have minimal clinical significance (Edwards *et* *al.* 1999). The same study did not investigate the erosive effect of flavoured waters but did note a pH value of around 3.3.

A recent *in vitro* study found the pH values of popular flavoured waters ranged from 2.64-3.24 compared to a slightly higher value of the orange juice control at 3.68. The neutralisable acidity values varied from 4.16mls – 16.3mls compared to 19.68mls for the orange juice control. The low pH values may be attributed to the supplementation of fruit extracts to these beverages to act as flavouring agents. In addition, to extend expiry dates certain drinks may have citrate based compounds added to them, which also increase the overall acid content (Rees *et al.* 2007).

The amount of enamel surface loss from the flavoured waters ranged from 1.18 to 6.86µm while the surface loss of the orange juice control was valued at 3.34µm. This means that 5 out of 7 flavoured waters produced higher levels of enamel erosion (Rees *et al.* 2007). The two drinks that produced noticeably lower levels of enamel erosion were the orange and elderflower based drinks while the highest values were derived from the lemon, grapefruit and cranberry based drinks, obviously capable of producing enamel erosion. The wide range in values, and low values for these two drinks, may be due to the difference in concentrations of fruit acids found in each fruit used as shown in Table 2.

TABLE 2. TOTAL ACID CONTENT OF VARIOUS FRUIT JUICES
(mg per 100 gms of fruit)

Fruit Juice	**Total Acid content**
Elderflower	66
Orange	980
Grapefruit	1460
Cranberry	1560
Lemon	6370

Adapted from Geigy (1956).

However, as with all *in vitro* studies, the environment within the oral cavity cannot be duplicated and so the results must be viewed with slight caution. Within the oral cavity, there is a salivary pellicle present to protect the tooth surface from acidic attack and the buffering and remineralising effects of saliva are also occurring.

It is also worth noting that this study used beverages at a temperature of 37°C to both emulate the warmth of the oral cavity and to allow comparison with the authors' previous studies. However, these drinks are commonly consumed at much colder temperatures as they are usually refrigerated, at these lower temperatures the drinks would have a lower number of dissociated H+ ions and may consequently have a lower erosive potential (Eisenburger and Addy, 2003).

DILUTABLE FRUIT DRINKS

Dilutable fruit drinks are often perceived by the public to have no detrimental effect on dental health. This may be due to the idea of diluting the drink and therefore minimising any harm to the dentition. One study agreed that due to dilution the erosive potential is sufficiently reduced but offered no evidence to support this claim (Milosevic *et al*. 1997).

Another study investigated the effect dilution of these drinks truly had on their erosive potential. Based on the results of proportionally reduced neutralisable acidity values they concluded that the erosive potential of diluted drinks is notably reduced despite little change in pH values on dilution. However no surface loss or enamel hardness tests were carried out, yet the study did conclude that these drinks would still cause enough erosion at the dilution levels of a normal consumer (Cairns *et al.* 2002).

Carrying on from this research, Hunter *et al.* (2008) included further tests in their search to determine erosive potential. Manufacturers commonly recommend dilutions of 1:4 (1 part concentrate: 4 parts water). However the *in vitro* study by Hunter *et* al. (2008) found the pH values of dilutable fruit drinks ranged from 3.2-3.6 even at a very high dilution of 1:15. The neutralisable acidity values varied from 2.07mls – 2.46mls at a dilution of 1:15, in accordance with the previous study, although at dilutions of 1:3 this value reached 10.06mls.

This study also investigated the amount of enamel surface loss, which ranged from 1.83 – 6.58µm at 1:15 dilution while at 1:3 the highest value was 8.13µm (Hunter *et al.* 2008). These results indicate that despite a proportional decrease in neutralisable acidity with dilution in some drinks, all drinks offer sufficient enamel surface loss to be of clinical significance, even at quadruple the manufactures recommendations. When diluted at the level suggested to the public, these drinks certainly have a significant erosive potential.

HERBAL AND FRUIT TEAS

Herbal and fruit teas are commonly seen as a healthy alternative to other beverages. They have been shown to have many beneficial properties such as high levels of antioxidants (Karakaya, 2001), high fluoride content (Chan and Koh, 1996) and shown to prevent the growth of cariogenic bacteria (Otake *et al*. 1991; Wu-Yuan *et al*. 1988). These teas are produced with dried fruit products. The high citric acid contents documented in these ingredients, and previous research would already suggest some level of erosive potential (Hughes *et al*. 2000).

Brunton and Hussain (2001) compared a traditional tea with a pH of 4.8 against a popular herbal tea of pH 3.2. The experiment showed the herbal tea to be five times more erosive to enamel than the traditional tea. Yet this study is limited in its method, immersing teeth for 14 days is not an accurate representation of drinking habits over many years but conclusions on the higher erosive effects of herbal tea can still be drawn.

Phelan and Rees (2003) undertook a more in depth study focussing on a range of herbal and fruit teas. Their results showed all teas, apart from camomile tea, were equally if not more erosive than orange juice. The erosive herbal teas having a pH range of 3.15 to 3.78 and neutralisable acidity values from 13.52-60.3mls. Enamel loss was measured after a one-hour immersion ranging from 2.24-9.6μm. In comparison, the orange juice control had a pH of 3.73, neutralisable acidity of 21.4mls and enamel loss of 3.3μm. Due to almost all herbal teas tested being equal to if not more erosive than orange juice the significance of erosive potential is evident.

SOFT DRINKS AND SPORTS DRINKS

The popularity of soft drinks has risen exponentially worldwide, consumption has increased by seven times in the UK compared to what it was in the 1950s (Rees, 2004) and by four times in the USA since 1990 (Calvadini *et al*. 2000). Soft drinks have been shown to have pH levels below 4.0 (Lussi *et al.* 2004) comparable to sports drinks and energy drinks, in all cases this is attributed to high levels of phosphoric and citric acids (Coombes, 2005; Hooper *et al.* 2005). When an epidemiological assessed erosive wear in 419 children aged 14 years old, it was found that over 80% of these drank soft drinks on a regular basis and 51% presented with moderate erosion (Al-Dlaigan *et al*. 2001a).

The high erosive potential of these drinks has been clearly shown in several *in vitro* experiments (Ehlen *et al.* 2008; Meurman *et al.* 1990; Milosevic, 1997; Owens and Kitchens, 2007; Rees *et al.* 2005; Von Fraunhofer and Rogers, 2004), supported by observational studies from a range of different countries linking consumption of these drinks to evidence of dental erosion (Al-Dlaigan *et al.* 2001a; Al-Majed *et al.* 2002; Dugmore and Rock, 2004; Järvinen *et al.* 1991; Jensdottir *et al.* 2004; Johansson *et al.* 2002; Millward *et al.* 1994). It was specifically stated in a case control study by Jarvinen *et al*. (1991) that consumption of soft drinks at least once per day causes erosion. Lussi and Jaeggi (2006) argued sugar free soft drinks show no significant difference in erosive effects when compared to sugar-containing soft drinks. Yet, two *in vitro* studies opposed this, proposing sugar free cola beverages had lower erosive potential than sugar containing cola drinks (Owens *et al.* 2007; Rytömaa *et al.* 1988). Furthermore, some studies failed to find a significant relationship to erosion at all in any of these drinks (Bartlett *et al.* 1998; Nunn *et al.* 2003; Waterhouse *et al.* 2008).

Despite sports drink offering no performance advantage to an athlete over water (Coombes & Hamilton, 2000) they remain a popular choice of drink. Both *in situ* and *in vitro* studies have shown sports drinks to be erosive (Hooper *et al*. 2004; Hooper *et al*. 2005; Venables *et al*. 2005) with the *in vitro* study finding neutralisable acidity values to range from 9.74-13.44mls and enamel loss between 1.18-5.36µm (Rees *et al.* 2005), similar enamel loss results were reported by Venables *et al.* (2005) at 4.6µm .

A recent review of acidic beverages stated that sports drinks did not hold as much evidence in regards to dental erosion as other non-alcoholic beverages (Coombes, 2005). A study including British athletes failed to find a relationship between sports drinks and erosion (Milosevic *et al.* 1997), as did another study including American athletes, that stated despite 92% regularly consumed sports drinks, the prevalence of erosion was 37%, finding no association (Mathew *et al*. 2002). To support this claim, the erosion prevalence is similar to a study held by Lussi *et al*. (1991) using the same index and randomly selected subjects.

A cross-sectional observational study and a case control study also did not find a relationship between consumption of sports drinks and dental erosion (O'Sullivan & Curzon, 2000; Sirimaharaj *et al.,* 2002). However one case control study did, finding a considerable increased risk of erosion during weekly consumption of sports drinks (Järvinen *et al.,* 1991).

Coombes (2005) believed the reason many studies did not find an association between erosion and sports or soft drinks was due to too much focus on one particular drink. A conclusive study focussing on all brands of soft and sports drinks with comparisons drawn to controls such as water and orange juice may settle this argument.

FRUITS AND VEGETABLES

A high frequency of acidic fruit and vegetable intake has repeatedly been associated with dental erosion (Järvinen *et al*. 1991; Linkosalo and Markkanen, *1985*; Lussi *et al*. 1991).

Ganss *et al*. (1999) conducted a study investigating whether living on a raw food diet had an impact on dental erosion. Overall, 130 subjects showed a higher incidence of dental erosion compared to the control group. Erosive defects were found in 97.7% of subjects (86.8% of the controls) with 60.5% of these deemed as severe defects (31.6% of controls). The study also concluded the major contributors to erosion were thought to be vinegar, citrus fruit and acidic berries. However diagnosis was only obtained via study models, which may not be as accurate as a clinical examination, therefore the accuracy of these results must be questioned. Yet, similar results were obtained from a prevalence study including 26 Finnish vegetarians (Linkosalo and Markkanen, 1985).

Chadwick (2006) held an *in vitro* study to determine whether different methods of cooking vegetables can vary their erosive potential. The study showed that oven-roasted ratatouille had a far higher erosive potential with a neutralisable acidity value of 8.60mls compared to the traditional stewed version with a neutralisable acidity value of 3.93mls. Testing the vegetables individually, the results showed roasting tomatoes or onions did not effect their erosive potential but increased the erosive potential of aubergines, green peppers and courgettes while red peppers were more acidic when stewed.

Diets consisting of raw vegetables and fruit do include a greater amount of acid than other foods, and an arguable increase in coarseness. This combination could presumably lead to tooth wear due to the synergistic effects of erosion and abrasion.

In contrast to the evidence above, prevalence data from both national and regional cross-sectional studies held in the UK concluded that there are no significant dietary associations with dental erosion, including between vegetarian and non-vegetarian diets (Nunn *et al.* 2003; Al-Dlaigan *et al.* 2001b).

EFFORTS TO PREVENT OR INHIBIT EROSION BY MODIFICATION OF FOOD AND DRINK

Over the last two decades there have been many attempts to reduce the erosive potential of foodstuffs with promising results. The best addition appears not to be fluoride (Larsen and Richards, 2002) but either calcium or a combination of calcium and phosphate, which has successfully been added to soft drinks (Attin *et al.* 2005; Larsen and Nyvad, 1999) although often causing the drink to have a bitter taste. Similar success was found in sports drinks with one study showing a marked reduction in erosive potential with the addition of calcium *in vivo* (Hooper *et al.* 2004) and another using casein phosphopeptide-stabilized amorphous calcium phosphate *in vitro*, which also concluded there was no detrimental effect to the product taste (Ramalingam *et al*. 2005). Addition of these elements has even been successful in reducing the erosive potential of acidic sweets (Jensdottir *et al.* 2007).

In the United Kingdom 'Ribena' was the first drink available to the public which had attempted to reduce its erosive effects with the addition of calcium (Hughes *et al.* 1999) and in the Netherlands another fruit based drink 'Joy' was released (Huysmans *et al.* 2006). Both drinks were taken off the market due to a dislike to their taste and increased price, however an improvement to 'Ribena' was made with the addition of xanthan gum, which attained the same low erosive potential and an improved taste (West *et al.* 2004).

While this is definitely an area of research with a rapidly growing interest, conclusive studies that evaluate alternative drinks or foods for the same price and flavour are yet to be noted. However with growing concerns into everyday aspects of health, this may be a market that we soon see swiftly expanding as research continues.

CONCLUSION

A conclusion from this paper is that erosion is clearly increasing in prevalence and will become of growing concern to both dental practioners and the public in coming years. While dependant on many factors and their interplay, the erosive potential of many foodstuffs is evident throughout the research.

Systematic investigations using a standardised and reproducible index to measure the prevalence of erosion in all ages, social classes, cultures, and populations worldwide is key to understanding this condition further. Additionally, chairside diagnotistic tools to identify and monitor progression of these lesions would be a useful instrument for the modern dentist.

As erosive tooth wear becomes a 21st century challenge it is paramount to educate the public to the risk factors and preventative methods with regards to erosion. Comprehensive information detailing acidic foods and drinks alongside tooth friendly eating and drinking habits may help to prevent this increasing incidence.

A large scale standardised study to include all foodstuffs with the same parameters, measurements of all chemical factors and surface loss values would help to settle some of the debate that continues regarding particular foods and drinks. Continued efforts to recreate the oral environment are paramount for reliable results, yet we must accept that individual habits may override the results of any study.

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APPENDICES

Appendix A

LOCALISATION OF EROSION IN ADULTS: A SURVEY OF DIFFERENT EPIDEMIOLOGICAL STUDIES LISTED IN THE ORDER OF THE AGE OF THE EXAMINED SAMPLES

Author(s)	**Year**	**Age (years)**	**Localisation**
Sognnaes et al.	1972	-	Mandibular teeth (21%) with a higher frequency than maxillary teeth (13%); with mandibular incisors showing the most lesions (28%)
Xhonga and Valdmanis	1983	14-88	Minor erosions: premolars and anterior teeth Severe erosions: molars and premolars
Mathew et al.	2002	18-28	Occlusal surface of mandibular first permanent molars most often affected
Ganss et al.	1999	18-63	Facial erosions: maxillary anterior area; mandibular canines and premolars Occlusal erosions: mandibular first molars Palatal erosions: maxillary and mandibular anterior area
Jaeggi et al.	1999	19-25	Facial erosions: maxillary and mandibular canines and premolars Occlusal erosions: maxillary and mandibular first molars and premolars Palatal erosions: maxillary incisors and canines
Lussi et al.	1991	26-50	Facial erosions: maxillary and mandibular canines and premolars Occlusal erosions: maxillary and mandibular premolars and molars Palatal erosions: maxillary incisors and canines
Lussi et al.	2000	32-56	Facial erosions: premolars and molars Occlusal erosions:canines, premolars and molars Palatal erosions: maxillary central incisors

Appendix A -Shows the localisation sites of certain clinical signs on the adult dentitions. Adapted from Lussi (2006).