Review
Factors affecting intra-oral pH – a review

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SUMMARY One of the greatest challenges to modern dentistry is the progressive destruction of tooth material due to chemical erosion. Dental erosion is the loss of dental hard tissue, without the action of bacteria, in which demineralisation of enamel and dentine results due to a decrease in intra-oral pH. The aim of this review was to appraise the scientific literature on the factors that can affect intra-oral pH. The review will examine (i) the protective role of human saliva, in terms of its mineral composition, flow rates and buffering systems and (ii) sources of in-mouth acids such as extrinsic acids, which are derived from the diet and environment, as well as intrinsic acids, which are related to disorders of the gastro-oesophageal tract. This review may assist clinicians to identify the risk factors for tooth wear and to recommend adequate preventive measures to patients.

KEYWORDS: intra-oral pH, saliva, dental erosion, dietary acid, gastro-oesophageal reflux, dental wear

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Introduction
Dental erosion is the loss of dental hard tissue through a chemical process, without the action of bacteria, in which demineralisation of enamel and dentine results due to a decrease in pH in the oral cavity (1). A recent systematic review (2) reported that the average prevalence of dental erosion in various populations was estimated to be 30–40%, with the figures ranging between 7–12% and 74–100%. The wide variability in the prevalence of dental erosion is attributed to numerous factors, such as geographical factors, age of the samples, location of teeth examined and the different indices used to diagnose the condition. There is also evidence that the prevalence figures are increasing steadily over time (3).

The average intra-oral pH is around pH 7.4 (4), and it slightly decreases during sleep time (5, 6). The critical pH is defined as the highest pH at which there is equal ion exchange between a solid immersed in its saturated solution. The critical pH of dental caries is well established to be in the range of 5.5–5.7 (7), in which pH levels below this threshold will initiate the dissolution of enamel. However, there is no definite critical pH for dental erosion (8).

Salivary pH can be largely influenced by dietary intake, but also by intrinsic factors, such as regurgitation (9), and by the flow rate and buffering capacity of saliva (10, 11).

This review will examine the factors that can affect intra-oral pH. First, we will discuss the protective role of saliva in dental erosion, followed by the extrinsic and intrinsic sources of acid, which can be detrimental to the dentition. This information may help clinicians to identify the potential risk factors for dental erosion in patients.

Normal values of intra-oral pH
A major determinant of intra-oral pH is dependent on the salivary pH, and it varies throughout the day (12, 13). The average pH of unstimulated saliva is approximately 6.8, and this increases up to 7.8 upon stimulation (14). A higher salivary pH will effectively buffer acids, facilitate remineralisation of enamel and suppress the tendency of aciduric bacteria (15).
The protective properties of saliva

Saliva is secreted from the three major salivary glands (sublingual, submandibular and parotid) and from other minor salivary glands around the palate and oral mucosa (10). The first protective mechanism of saliva is that it forms a semipermanent layer around the tooth surface, more commonly known as the acquired pellicle. This layer acts as a barrier that protects the tooth surface from coming into contact with the acid (16). Secondly, it gradually clears and eliminates the acid introduced into the mouth through swallowing (mechanical cleansing) and by increasing its flow rate (16). It also contains protective proteins and buffering systems to neutralise acid attacks (11), thus maintaining the intra-oral pH at a physiologically healthy range of 6.8–7.8 (14).

Salivary mineral content

The constituents of saliva include fluoride, calcium and phosphate, which are responsible for the remineralisation of tooth surfaces (17). Calcium and phosphate in saliva slow down the dissolution rate of the minerals in enamel and dentine (18). Fluoride has been long recognised for its ability to enhance remineralisation under cariogenic attack; however, a high concentration is required to be effective (19).

The mineral in dentine and enamel is calcium-deficient carbonated hydroxyapatite (20). The crystalline hydroxyapatite structures include calcium, phosphate and hydroxide ions and other ‘impurities’ (the ions sodium, potassium, magnesium, chlorine), and when immersed in a solution such as saliva, there is ion exchange between the solution and the crystal structures (20). Carbonate can replace the phosphate ions, and the hydroxide can be substituted with fluoride; however, the carbonate weakens the crystal structure, predisposing the surface to erosion.

The critical pH is defined as the pH at which a solution is just saturated with respect to a solid structure (7). It is the highest pH at which there is equal ion exchange between the solution and the solid. It also depends on the solubility of the solid structure and the concentrations or activities of certain mineral constituents of the solution. In the case of dental caries, the concentration of calcium and phosphate in plaque fluids varies between different people and contributes towards the interindividual variation in their critical pH value, which is on average between 5.5 and 5.7 (7). In erosion, there is no defined critical pH as it is the dissolution of dental hard tissues without plaque. Therefore, it was suggested that the critical pH value for dental erosion depends on the concentration of calcium, phosphate and fluoride of the solution (8).

Salivary flow rate

Salivary flow rate has been suggested to be the best clinical indicator of the protective properties of saliva (16). With an increase of salivary flow, there will be an increase in mineral contents and the bicarbonate buffering system (12), which is responsible in neutralising acids (11).

Details of this buffering system will be discussed in the next section. With an increase of salivary flow, the rate of swallowing also increases, thus clearing and diluting the acid in the mouth more effectively. An example depicting the opposite scenario is the mouth-breathing habit, where dehydration of the oral cavity occurs, leading to the reduction of clearance rate and bicarbonate buffering system.

The clearance rate varies among different sites in the mouth. The pH recovery time following acidic stimuli is quicker in the palatal surface of the upper central incisor compared to the palatal surface of the upper molar (21). This can be explained by the tongue moving the acidic substances around the upper molar sites before swallowing, therefore contributing to slower clearance of the acidic stimuli in that area. Salivary clearance has also been reported to be fastest in the lingual surfaces to the mandibular incisors (submandibular and sublingual glands) and slowest on the buccal surfaces of the teeth (parotid gland) (22). This may also explain the site-specific differences of plaque pH, with lower pH values in the labial surfaces of the maxillary teeth than the lingual surfaces of the mandibular teeth in the anterior part of the mouth, whilst the posterior part of the mouth showed a reverse pattern (23).

Certain activities and medical conditions can cause a reduced salivary flow rate, which in turn may result in a low intra-oral pH due to a reduced buffering capacity of the saliva. Physical activities such as exercise or playing sports can induce sweating, and the body responds to the loss of bodily fluids and dehydration by reducing salivary flow (24).
Individuals who have had radiation to their head and neck region for cancer treatment have Sjögren syndrome or are on antimuscarinic agent medications have all been reported to have a decrease in salivary production and flow rate (11, 25, 26). Interestingly, individuals with psychosomatic disorders related to self-induced regurgitation (bulimia and/or anorexia) were reported to have increased saliva flow and production (hypersalivation) prior to vomiting. This was suggested to be a self-protective mechanism to minimise erosion, in anticipation to the introduction of the low pH gastric contents (27, 28). However, this does not occur in individuals suffering from gastro-oesophageal reflux disease (GORD) due to the involuntary nature of regurgitation. Furthermore, there is inadequate time for saliva to respond to the acid attack (29).

Buffering capacity

Saliva has buffering systems (30), which act to resist changes in pH. The saliva buffering components involved are dihydrogen phosphate/hydrogen phosphate and carbonic acid/bicarbonate (11, 31, 32). Bicarbonate is the main buffering component in the saliva that is responsible for neutralising acids. Its concentration in stimulated saliva is approximately 28 mM and varies largely among individuals. Its concentration in stimulated saliva was also reported to be approximately 12 times higher compared with unstimulated saliva (~2–5 mM) (33, 34). The main role of stimulated saliva is to protect the dental hard tissues against extrinsic acid stimuli with its high buffering capacity (11). The equilibrium for the bicarbonate system is as below:

\[ \text{HCO}_3^- + \text{H}^+ \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{CO}_2 + \text{H}_2\text{O} \]

Bicarbonate (HCO$_3^-$) that is present in saliva reacts with hydrogen ions (H$^+$ from acids). Through the reaction, it removes the protons to produce carbonic acid (H$_2$CO$_3$). H$_2$CO$_3$ is then converted to carbon dioxide gas (CO$_2$) and water (H$_2$O) by the enzyme carbonic anhydrase that is present in the saliva (35). CO$_2$ gas will then diffuse into the environment, due to the differential partial pressure of CO$_2$ in the saliva and the environment (36).

The dihydrogen phosphate buffer system works in the opposite direction, with a higher concentration (5 mM) in unstimulated saliva compared with when stimulated (3 mM) (13), but it plays a minor role in the total buffering capacity of saliva.

Saliva also contains proteins that act as buffers. The ability of a protein to buffer depends on the structure of its building blocks, amino acids. When the protein is in a solution, the amine (NH$_3$) and carboxyl groups (COOH) can either lose or gain hydrogen ions, depending on the pH of the solution (37).

Despite the many protective properties present in saliva, its role is limited in the presence of frequent and large amounts of strong acids (22). Frequent and large amounts of strong acids can easily displace the acquired salivary pellicle, which is usually about 1 µm thick. The residual volume of saliva in the mouth is about 0.8 mL and thus is insufficient to dilute a large mouthful of an acidic beverage. Furthermore, only unstimulated saliva is present initially when the acidic beverage is taken, which is a poorer buffer compared with stimulated saliva.

Sources of in-mouth acid

Intra-oral pH is lowered by the introduction of acids into the oral cavity. The acids can be derived from extrinsic (external) and intrinsic (internal) sources. An overview of these sources with their pH value is summarised in Table 1.

Although the pH value of an acid provides a good indication for dental erosion, the buffering capacity or titratable acidity of the acid is more important. Buffering capacity is expressed as the amount of acid/base required to raise/lower the pH to 7.0 (61). If the particular food substance is said to have a high buffering capacity, it is capable of maintaining the low pH in the oral environment for a longer amount of time. Beverages with high buffering capacities affect erosion significantly, as the longer the time that the tooth in a low pH environment, the more outflow of mineral ions from the tooth, hence increased demineralisation (62). The addition of calcium and phosphate salts in low pH beverages has been shown to reduce the erosion potential (61).

Fruit juices, especially of citrus origins, have a high buffering capacity and are capable of maintaining low pH in the oral environment for a longer amount of time (61). Citric acid, also known as a chelating agent, can form two or more coordinate bonds; in addition to providing hydrogen ions, it can further...
bond to calcium ions, predisposing the crystal structure to more erosion (63). A diet consisting of high consumption of acidic foods and drinks can lower intra-oral pH, thus contributing to erosion (64). In particular, excessive intakes of fruit juices and carbonated/soft drinks have been consistently associated with dental erosion (65). Individuals between 15 and 30 years of age were more likely to drink fruit juices and soft drinks than other age groups (66). A nutrition survey found that New Zealanders of lower socio-economic status were also more likely to drink soft drinks and energy drinks, with a frequency of three or more times a week. In the year 2013, carbonated drinks were reported to account for 1.8% of food expenditure (approximately $166 per year) in each New Zealand household (67).

The method of drinking acidic beverages also affects the risk of erosion (68). The study measured intra-oral pH in six different drinking methods (holding, short sipping, long sipping, gulping, nipping from a baby bottle and sucking from a straw) of Coca-Cola Light (pH 2.6). In all drinking methods, a drop in intra-oral pH was detected. However, there was a difference in intra-oral pH variation following the introduction of the beverage. ‘Long sipping’ was defined as sipping from a glass for 15 min, and it caused a prolonged depression in intra-oral pH compared with ‘short sipping’ (sipping from a glass for 2 min) and ‘gulping’ (swallowing quickly). ‘Holding’ was defined as keeping 10 mL of the beverage in the mouth for 2 min before swallowing, and it caused the most pronounced reduction in intra-oral pH. However, once the beverage was swallowed, the pH recovered to baseline value within 5 min. Although the intra-oral pH only dropped moderately with the ‘long-sipping method’, it took the longest to recover to baseline value (20 min) among all of the sipping methods.

Rinsing was also reported to cause a lower and more prolonged pH change (21, 68, 69). Therefore, ‘long sipping’ and rinsing of acidic beverages should be avoided to prevent prolonged periods of low intra-oral pH and reduce the potential for dental erosion.

Alcohol consumption can also contribute to dental erosion. Wine has a low pH ranging from approximately 3–4 (45, 70, 71), with the main organic acid constituents being tartaric, maleic, lactic and citric acids (70, 71). Wine tasters who are exposed to the low pH substance for up to sixty times daily, for a number of years, have been reported to exhibit significant dental erosion (46, 72). Wine judges are at an even higher risk of dental erosion, as they may taste up to 200 wines daily for four days straight, several times a year (71). As with fruit juices and soft drinks, the method by which the beverage was consumed impacts on tooth erosion. Wine tasting requires that the liquid be swirled around the mouth and held in the mouth for about 15–60 s before swallowing (46, 70). The high frequency of exposure to the acidic substance and drinking method cause prolonged contact of the low pH beverage with the tooth surface and inevitably increase the risk of dental erosion (64, 71, 73). Champagnes and white wines are more erosive than red wines, as the red wines have more potential inhibitors of erosion, which are produced during its maturation period. However, the nature of these inhibitors is currently unknown (71).

Oral medication and supplements such as aspirin, especially in a chewable tablet form or powder, increase the risk of dental erosion (52, 53). Individuals with rheumatoid arthritis requiring daily aspirin medication have been reported to exhibit erosion in

Table 1. The pH range of various extrinsic and intrinsic sources that can affect intra-oral pH

<table>
<thead>
<tr>
<th>References</th>
<th>Source</th>
<th>pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td>(6, 38, 39)</td>
<td>Mineral water</td>
<td>4.5–9.5</td>
</tr>
<tr>
<td>(40, 41)</td>
<td>Cola</td>
<td>2.5–3.2</td>
</tr>
<tr>
<td>(42)</td>
<td>Lemon juice</td>
<td>2.0–2.3</td>
</tr>
<tr>
<td>(6, 43, 44)</td>
<td>Orange juice</td>
<td>2.7–4.4</td>
</tr>
<tr>
<td>(40)</td>
<td>Sports drinks</td>
<td>2.8–4.9</td>
</tr>
<tr>
<td>(45)</td>
<td>Wine</td>
<td>2.8–4.0</td>
</tr>
<tr>
<td>(46)</td>
<td>Spirits</td>
<td>3.9–6.9</td>
</tr>
<tr>
<td>(47)</td>
<td>Beer</td>
<td>4.9–6.0</td>
</tr>
<tr>
<td>(48)</td>
<td>Iced tea</td>
<td>2.6–4.0</td>
</tr>
<tr>
<td>(49)</td>
<td>Coffee</td>
<td>4.9–6.0</td>
</tr>
<tr>
<td>(43, 50, 51)</td>
<td>Milk</td>
<td>6.4–6.8</td>
</tr>
<tr>
<td>(52, 53)</td>
<td>Aspirin</td>
<td>2.0–7.0†</td>
</tr>
<tr>
<td>(54, 55)</td>
<td>Vitamin C</td>
<td>2.0–4.0</td>
</tr>
<tr>
<td>(39, 56, 57)</td>
<td>Mouthwashes</td>
<td>3.0–7.4</td>
</tr>
<tr>
<td>(44, 58)</td>
<td>Swimming pool water</td>
<td>2.9–8.0</td>
</tr>
<tr>
<td>(59)</td>
<td>Antacid</td>
<td>9.5–10.5</td>
</tr>
<tr>
<td>(60)</td>
<td>Gastric fluid</td>
<td>1.0–2.0</td>
</tr>
</tbody>
</table>

Please note that a low pH value does not necessarily represent a high erosive potential. The titratable acidity/buffering capacity of the substances, which are highly variable among different manufacturers, would be more accurate representations of their erosive potentials.

†Neutralised pH 7 coated tablets are currently available.
the posterior teeth (54). An in vitro study found that the enamel and dentine surfaces underwent morphological changes within just a few minutes following exposure to aspirin (74). Vitamin C (ascorbic acid) supplements in different forms such as chewing tablets, syrup and effervescent tablets are becoming vastly popular (75). These tablets have low pH levels and could cause the intra-oral pH to drop to less than pH 2 (54). Hydrochloride containing tablets, which are prescribed to treat stomach disorders, can also cause dental erosion (76).

Some medications containing magnesium hydroxide, aluminium hydroxide, sodium alginate, calcium carbonate or hydrated magnesium aluminate increase intra-oral pH. These medications are also known as antacids and are regularly prescribed for the treatment of chronic vomiting or reflux (77). Alkaline water is also currently available in the market and may help to increase oral pH.

Oral care products such as low pH mouth rinses containing ethylenediaminetetraacetic acid (EDTA), acidified sodium chlorite, essential oil and hexetidine have been reported to exhibit erosion potential (39, 78). However, their potential erosive threat is generally low and was reported to be only significant after 14 h of continuous use (56). It is also advised that the low pH mouthwashes should not be used immediately before tooth-brushing (56).

Extrinsic acids can also be derived from the environment and be occupation related. Workers in manufacturing factories involved in galvanising, electroplating, metal and glass etching and printing are at high risk of being exposed to acid fumes such as sulphuric, nitric and hydrochloric acids (79). Swimming in unmodulated chlorinated pools can also expose the swimmers to high levels of hydrochloric acid (80). These individuals are more susceptible to dental erosion due to the prolonged and increased contact time with acid in their environment.

The main intrinsic source of acid is from the stomach. Gastric contents are very acidic and were reported to have a pH as low as 1 (60). Gastric contents can travel up into the oral cavity by vomiting, and regurgitation which is commonly associated with gastro-oesophageal reflux disease (GORD). Vomiting is defined as the forceful ejection of the gastric contents through the oral cavity due to strong, sustained abdominal muscle and diaphragm contractions (27). High prevalence of dental erosion was found in cases of self-induced vomiting, shown in young teens with psychological disturbances such as bulimia nervosa (1). These disorders are more prevalent in females with body image issues (79). Participants with bulimia were reported to have an average of 69% of their teeth exhibiting signs of erosion as opposed to an average of 7% of teeth of individuals in the control group (81). Furthermore, the participants with bulimia were found to have more severe dental erosion, in terms of the depth of penetration and quantity of tooth structure involved.

Certain drugs such as opiates, dopamine antagonists and cancer chemotherapeutic agents can cause vomiting or emetic effects (27). Aspirin, diuretics and alcohol can also irritate the stomach and induce vomiting (82).

Regurgitation is the involuntary movement of the gastric contents from the stomach to the oral cavity (83). Regurgitation is different from vomiting as it does not involve nausea, retching or abdominal contractions (79). The contents that are regurgitated include hydrochloric acid, undigested food particles, bile acids and trypsin (84).

Gastro-oesophageal acid reflux is the backward flow of gastric acid into the oesophagus (9). Following an episode of acid reflux, a bitter or sour taste at the back of the mouth, as well as a burning sensation in the chest (heartburn), can be present. Occasional acid reflux, such as that experienced in pregnant women (85) or after a spicy meal (86), can be considered as normal and easily managed with lifestyle and dietary changes (87).

Gastro-oesophageal reflux disease (GORD) is a chronic condition and is usually caused by the weakening of the lower oesophageal sphincter. It can be treated by medications such as H2 blockers and proton pump inhibitors. The medications work by either reducing the acidity of the gastric contents or decreasing the amount of acid production (9).

Regurgitation is a common feature in individuals with GORD. The high acidity of the gastric components reaching the oral cavity is likely to cause more dental erosion compared with carbonated drinks (86, 88). The most common location of erosion is on the palatal surfaces of the maxillary teeth; however, it can also extend to the occlusal and other surfaces of the dentition (4, 89, 90).
Conclusion

Saliva has an important role in maintaining the intra-oral pH at a physiologically healthy level. However, its protective properties are limited in the presence of excessive consumption of acidic food and beverage. There is also a large interindividual variation in the quantitative and qualitative properties of saliva. Individuals with different salivary mineral composition and buffering capacity exhibit different pH recovery times and responses following acidic stimuli. Therefore, different individuals may show different susceptibilities and severities of erosion even though they are exposed to similar environments.

Intra-oral pH can be lowered by an excessive consumption of acidic food and beverage, which in turn may cause dental erosion. Rinsing and the ‘long-sipping’ (sipping from a glass over 15 min) drinking methods should be avoided as they cause a prolonged depression of intra-oral pH. Oral pH can be often lowered in individuals with bulimia and GORD, especially on the palatal surfaces of the maxillary teeth.

Intra-oral pH is influenced by a multitude of intrinsic and extrinsic factors, in which they interact with each other in the process of dental erosion. Dental wear is due to a combination of erosion, attrition, abrasion and abfraction, where these mechanisms often act synergistically, sequentially or additively. The multifactorial aetiology makes it difficult to identify the main cause of the dental wear. Therefore, more studies of long-term monitoring of intra-oral pH are required to provide new insights into the variations of intra-oral pH over time, and its relationship with dental wear as well as dental caries.

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Disclosure

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References


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