Chem Factsheet

www.curriculum-press.co.uk Number 277

Water Fluoridation

Introduction

During the first half of the twentieth-century, dentists across Europe and the United States noted several localities with high incidences of enamel staining. Observations also suggested that rates of tooth decay were much lower in populations where staining was prevalent.

An American dentist, Dr. Frederick McKay, was the first to suggest a probable link to the local water supplies. In 1901, McKay began working at a dental practice in Colorado Springs, Colorado. He noted that large numbers of his patients had permanent brown stains on their teeth. In some cases, staining was so severe, teeth were mottled the colour of chocolate. McKay's research focused on the prevalence of staining with children born locally, but he also drew on work completed elsewhere.

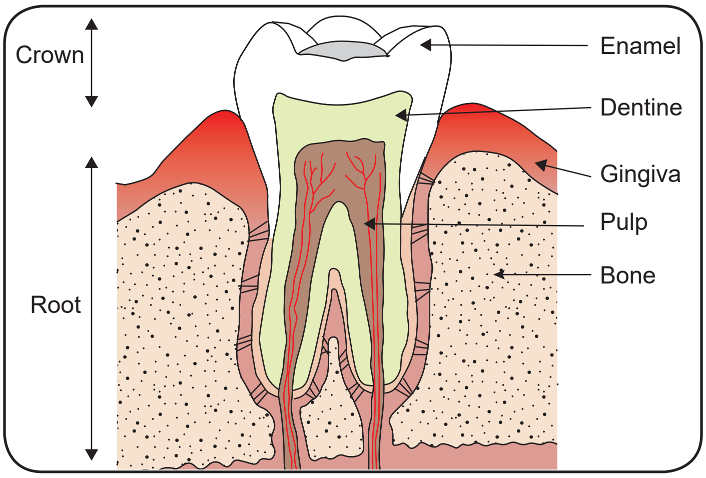
By the 1920s, theories on water-causation linked to dental mottling and improved dental health were gaining prominence. McKay had encouraged the inhabitants living in Oakley, a small town in Idaho, to stop drinking from the town's local water supply and drink water from a nearby mountain spring instead. This change in habit led to the elimination of dental mottling in younger children living in the town.

In 1931, chemists, working at the Aluminium Company of America, conducted tests on water samples from areas with high occurrences of mottling. Working with McKay, who collected the water samples, these tests would show high levels of fluoride ions.

Thirty years after commencing his research on Colorado Brown Stain, McKay had evidence linking dental mottling and improved dental health to high fluoride concentrations in water. Further research focused on the relative concentrations of fluoride in water affecting dental health and incidences of dental mottling.

In 1945, a city-wide programme of adding fluoride to the public water supply commenced. Scientific consensus at the time argued that concentrations of 1.0 mg dm^{-3} brought significant improvements to dental health without causing dental mottling.

Figure 1



For 15 years, inhabitants of Grand Rapids, Michigan, which included 30,000 school children, were monitored for occurrences of tooth decay. Cavity rates amongst children born after the introduction of fluoridation dropped by more than 60%.

From the 1950s, programmes of water fluoridation have been promoted to address the formation of cavities and tooth decay. In the United Kingdom, there was a rollout of water fluoridation between 1964 and 1988, primarily in Health Authorities in the Midlands and the North of England.

Teeth

Human teeth mechanically break down food by cutting and crushing what is eaten to allow for swallowing and digesting. Human-beings have four types of teeth; incisors, canines, premolars, and molars.

Healthy teeth are important in maintaining good health. Teeth are comprised of different types of tissue, see **Figure 1**, with varying density and hardness. The visible section is referred to as the crown, which is covered by enamel. The mineral, hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, is found in human bones and teeth. The enamel covering healthy teeth comprises 96% hydroxyapatite, making it the hardest material in the body. The body produces hydroxyapatite, one of the few inorganic substances it can synthesise. Dentine, which is also calcified tissue, comprising 45% hydroxyapatite by weight, is necessary to support the enamel.

Hydroxyapatite

Hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, occurs naturally and crystallises in the hexagonal crystal system, see **Figure 2**. The hydroxide ion, OH^- ion, can be replaced by other ions, including the fluoride ion, F^-.

Fluoride ions introduced to the mouth accumulate in saliva and interact with surface enamel. This reduces the rate of demineralisation and increases the rate of remineralisation (see below). This is achieved by individuals regularly using toothpastes containing fluoride and/or drinking water that has undergone water fluoridation. Where fluoride ions have replaced hydroxide ions, i.e. $Ca_5(PO_4)_3F$, the mineral formed is fluorapatite.

Tooth Demineralisation/Remineralisation

Tooth demineralisation is a chemical process involving the removal of key minerals from enamel and dentine. This process begins at the surface of the tooth and may develop into dental cavities. Cavities are caused by acid-producing bacteria found in dental plaque. The bacteria converts sugars into lactic acid in a process called glycolysis. Hydrogen ions, H^+, released by acids may diffuse into the tooth surface and dissolve the hydroxyapatite from the enamel (**Figure 3**).

Figure 2

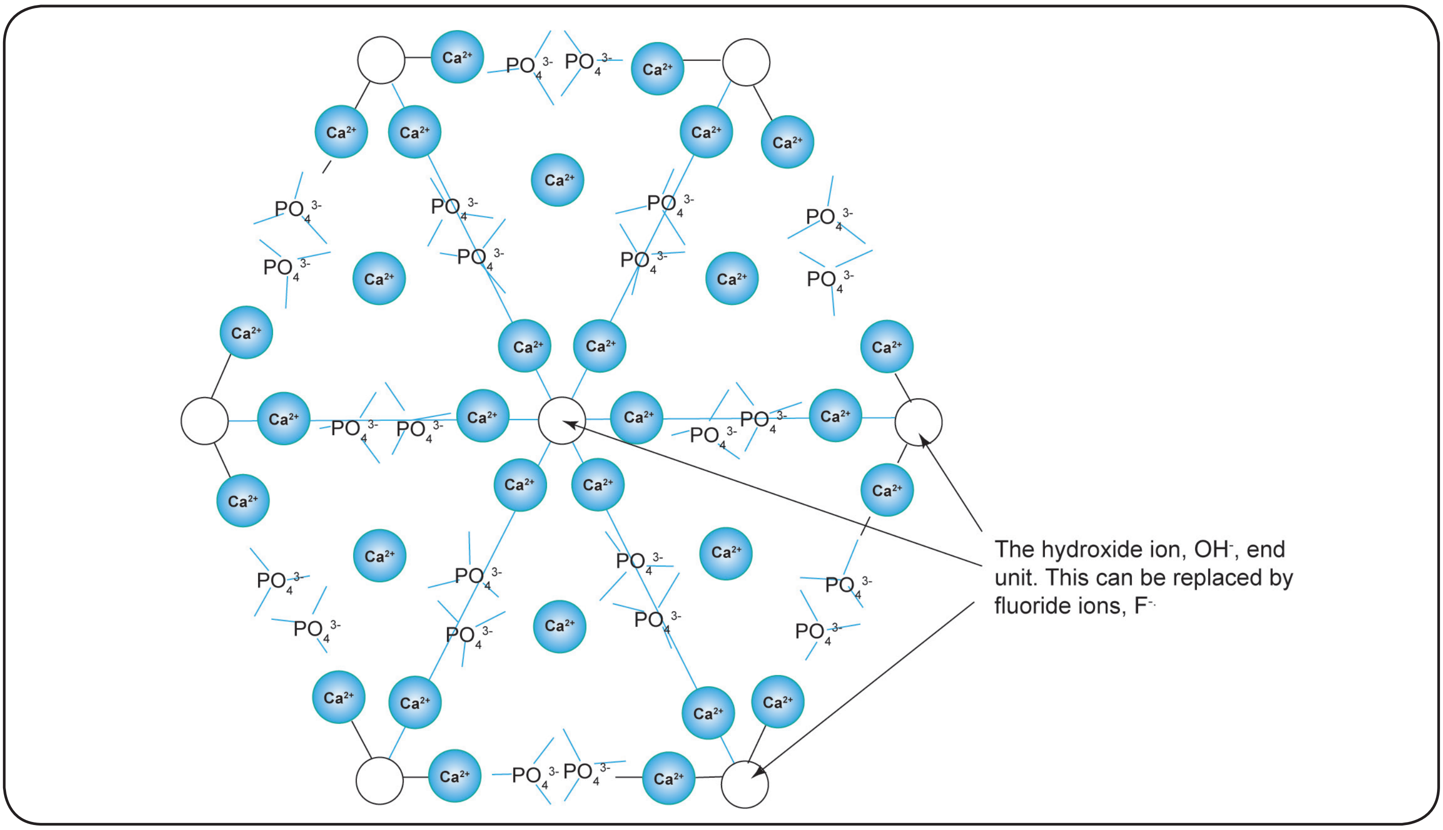


Figure 3

Hydrolysis of sucrose: Hydrolysis($+H_2O$)

Sucrose $C_{12}H_{22}O_{11}$ → Glucose $C_6H_{12}O_6$ + Fructose $C_6H_{12}O_6$

Bacterial glycolysis: Bacterial glycolysis (several steps)

Fructose $C_6H_{12}O_6$ → Lactic acid $C_3H_6O_3$

Actions of acids on hydroxyapatite: Hydrolysis($+H_2O$)

Hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ $\xrightarrow{2H^+}$ Calcium phosphate $3Ca_3(PO_4)_2$ + $Ca^{2+} + H_2O + ½O_2$

The acidic plaque in contact with the tooth surface is neutralised by saliva, but the capacity for remineralisation is compromised if sugar is consumed regularly. Tooth remineralisation occurs naturally and involves the deposition of calcium and phosphorus ions in voids or lesions created on the tooth surface by tooth demineralisation. The process repairs and strengthens the structure of the tooth. Demineralisation and remineralisation are dynamic processes.

When the rate of demineralisation exceeds that of remineralisation, for example, when sugary drinks and foodstuffs are consumed frequently, there is a net loss of hydroxyapatite from the enamel surface. This results in the formation of a cavity that allows bacteria to infect the inner structure of the tooth, leading to further decay. Under neutral conditions, i.e., pH 7, saliva contains saturated concentrations of calcium and phosphate ions. This maintains conditions for remineralisation and limits the level of demineralisation and reduces processes leading to the development of cavities. The presence of acid-producing bacteria lowers the pH, promoting conditions favouring demineralisation. The critical pH is defined when dynamic equilibrium is reached, i.e., there is no net demineralisation (mineral dissolution) and remineralisation (mineral precipitation). At pH values lower than the critical pH, mineral dissolution occurs as a greater concentration of calcium and phosphate ions is required to ensure saturated concentrations. At pH 5.5 and below, demineralisation occurs in hydroxyapatite.

Fluoride ions catalyse the rebuilding of damaged enamel. At increased pH levels, calcium and phosphate ion concentrations become supersaturated, forcing material onto the tooth. Fluoride ions adsorbed on the tooth surface attract calcium ions, speeding up remineralisation. Fluoride ions are also incorporated into the new surface, making it more acid resistant. The fluoride replacement of the hydroxide group, produces fluorapatite, see **Figure 2**. In fluorapatite, demineralisation now occurs at pH 4.5 and below, increasing resilience to demineralisation and processes encouraging cavity development.

Fluoride is retained for a period following application. It remains on dental hard tissue, the oral mucosa (the membrane lining the inside of the mouth) and within dental plaque. This is clinically beneficial, as fluoride is released during subsequent attacks by acid-producing bacteria.

Water Fluoridation

Water fluoridation involves the controlled addition of fluoride to public water supplies. The primary goal is to prevent cavities and reduce tooth decay. The World Health Organisation (WHO) suggests 1.5 mg dm^{-3} as the upper recommended limit, recognising that higher levels risk an increase in incidences of dental mottling.

Fluoride ions naturally occur in water in concentrations less than 0.5 mg dm^{-3}. In the United Kingdom, there are few local sources with concentrations up to 1.5 mg dm^{-3}, with concentrations tending to increase in naturally alkaline waters. Where water supplies exceed this upper limit, defluoridation processes are applied. There are several areas in the United Kingdom with relatively high natural fluoride concentrations. These include localities in; Durham, Essex, Norfolk, Shropshire, Suffolk, Wiltshire and in North East London.

The United Kingdom only permits using hexafluorosilicic acid, H_2SiF_6, and sodium hexafluorosilicate, Na_2SiF_6, for artificial fluoridation. Fluoridation does not affect the appearance, odour or taste of drinking water. These materials are selected due to their solubility, safety and availability. Hexafluorosilicic acid is a liquid by-product produced during the manufacture of phosphate fertilisers. Sodium hexafluorosilicate, the sodium salt of hexafluorosilicic acid, is a powder and easier to transport than hexafluorosilicic acid.

Implementation Of Water Fluoridation

It is estimated that 400 million people are supplied with fluorinated water, the majority living in the United States and Brazil. Countries with at least 60% of their population consuming fluoridated water include; the United States, Brazil, New Zealand and the Republic of Ireland. In the United Kingdom around 6 million people receive fluorinated water, approximately 10% of the population, the majority living in Birmingham and Staffordshire.

Several countries, including; Germany, Finland, Israel and Japan, have discontinued water fluoridation based on improved children's dental health programmes and an increase in the use of fluoridated toothpastes. Most European countries not implementing water fluoridation have recorded declines in occurrences of tooth decay, including in Germany and Finland, where rates continued to decline after discontinuing water fluoridation.

Fluoride ions may also be ingested through an individual’s diet. The following foodstuffs contain fluoride ion concentrations greater than 1.5 mg dm^{-3}; drinking strong tea, raisins, oily fish, e.g. mackerel, sardines, and fresh vegetables.

Action Of Fluoride On Oral Plaque Bacteria

The action of fluoride may inhibit essential bacterial activity. Fluoride ions are unable to cross the bacterial cell wall. In acidic conditions, it is possible for fluoride ions to combine with hydrogen ions and form molecules of hydrogen fluoride. These molecules can diffuse into the cell, where they dissociate, releasing hydrogen ions and fluoride ions. Inside the bacterium cell, fluoride ions can interfere with enzyme activity and help decrease the proliferation of *Streptococcus mutans*, the predominant bacteria related to demineralisation and potential tooth decay.

Dental Fluorosis

Excess remineralisation is referred to as hypo-mineralisation. Conditions promoting hypo-mineralisation includes drinking water with a high fluoride concentration. This may lead to staining and the build-up of calcareous material giving a ‘mottled’ appearance to teeth. This condition is called dental fluorosis or mottled enamel and is the condition observed by McKay and other dentists at the beginning of the previous century. The severity of dental fluorosis depends on the amount and duration of fluoride ingested. The condition is most prominent in children, specifically children under eight years. The effect on health is primarily cosmetic.

Levels of fluoride in drinking water are closely monitored and safety limits are well adhered to. It is likely occurrences of dental fluorosis happen when individuals drink water containing fluoride in combination with other sources of fluoride, for example; fluoridated toothpaste, foods containing fluorides and/or fluoride supplements. This is supported by incidences of dental fluorosis in areas that do not have public water fluoridation.

There have been rare incidents of accidental over-fluoridation of drinking water supplies, leading to fluoride concentrations up to 220 mg dm^{-3}. The symptoms of acute fluoride poisoning include nausea, vomiting and diarrhoea.

Concerns On Water Fluoridation

In 2009, the British Medical Association (BMA) reaffirmed their commitment to the fluoridation of public water supplies. They also argue that local authorities should be more proactive in helping to improve dental health across social groups.

The World Health Organisation (WHO), recognises that water fluoridation reduces the occurrence of cavities. They also state that there is no credible evidence linking water fluoridation with any adverse health concerns. In contrast, the European Union determined that fluoridation shows no benefit to dental health when compared to topical applications, i.e. fluoride varnish, gel, mouth rinse or toothpaste.

In Britain, local consultations are required before any programme of fluoridation is initiated. Despite the advice provided by the BMA, public concerns have blocked the further rollout of water fluoridation programmes since the late-1980s. Arguments for not implementing water fluoridation include the lack of control on the amounts of fluorinated water consumed individually, potentially leading to excessive consumption.

Key resistance to water fluoridation is driven by consumers’ ethical concerns. They argue; (1) water companies cannot force fluoridated water onto customers who do not want to consume it, and (2) water fluoridation is adding medicine to the public water supply, i.e., individuals are medicated without giving their consent. It is noted that the UK Medicines and Healthcare Products Regulatory Agency (MHRA) do not class fluoride as a medicine.

Questions

1. The estimated fatal dose of fluoride is 6 g, for an average adult. Calculate the volume of fluorinated water needing to be consumed to reach this limit:

   (a) Assuming World Health Organisation safety levels of 1.5 mg dm^{-3}.

   (b) Assuming levels measured following the accidental over-fluoridation in Alaska in 1992, where the concentration of fluoride was measured as high as 220 mg dm^{-3}.

2. Fluoride is added to water supplies through; (a) sodium fluoride, NaF (not in the United Kingdom); (b) fluorosilicic acid, H_2SiF_6; or (c) sodium fluorosilicate, Na_2SiF_6. Determine the % by mass of fluoride in each of these materials.

3. Outline the terms; (a) demineralisation, (b) remineralisation, (c) dynamic equilibrium and, (d) fluorosis, in terms of oral health.

Answers

1. (a) 4000 dm^3 (4000 litres)

   (b) 27.3 dm^3 (27 litres). There was 1 fatality recorded in this incident.

2. (a) 45.2 %

   (b) 79.1 %

   (c) 60.7 %

3. (a) The loss of mineral salts from healthy teeth that occur at low pH.

   (b) Where calcium and phosphate ions are deposited into crystal voids, rebuilding demineralised enamel.

   (c) The active processes of demineralisation and remineralisation are balanced (equal). There is no net loss/gain of minerals from the tooth surface.

   (d) Mottled enamel caused by hypo-mineralization due to the ingestion of excessive fluoride.

Acknowledgements: *This **Chemistry Factsheet** was researched and written by **Gareth Riley** and published in **January 2018** by **Curriculum Press**.*
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ISSN 1351-5136