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# Toothpaste

by Brad Yohe

Imagine snacking on a dish of ice cream and washing it down with your favorite soft drink. Delicious! The bacteria in your mouth like it, too. These bacteria are perfectly normal—you may have as many as 300 kinds—but they can cause tooth decay.

The bacteria consumer sugar from the food you eat and produce acids. When well fed, they multiply rapidly. Some attach themselves to your teeth and build up a layer of bacteria and food particles, called plaque. The plaque coats the teeth and traps the acids next to the surfaces. The acids slowly dissolve the hard enamel surface of the teeth.

The tooth enamel is about 2 mm thick and is composed of a strong, insoluble mineral called *hydroxyapatite*, $Ca_5(PO_4)_3OH$. Hydroxyapatite contains positive ($Ca^{2+}$) and negative ($PO_4\ ^{3-}$ and $OH^-$) ions. The attractions between these ions lock them together in a three-dimensional pattern. When hydroxyapatite dissolves (a process called demineralization), the ions separate and go into solution in the saliva.

$$Ca_5(PO_4)_3OH \Rightarrow 5\ Ca^{2+} + 3\ PO_4\ ^{3-} + OH^-$$

A certain amount of demineralization is normal. However, it is also normal for the reverse process, *re*-mineralization, to occur. The dissolved ions can join to form new hydroxyapatite. Remineralization is the body's natural defense against bacterial acids.

$$5\ Ca^{2+} + 3\ PO_4\ ^{3-} + OH^- \Rightarrow Ca_5(PO_4)_3OH$$

The forward and reverse reactions may occur at different rates. In children's growing teeth, mineralization usually occurs faster than demineralization. In adults, the processes may take place at about the

same rate—equilibrium. An equilibrium condition exists when two opposing reactions occur at the same time and at the same rate. However, in children or adults, if the acid becomes sufficiently concentrated at a specific point on a tooth, demineralization can outstrip remineralization, leading eventually to a cavity.

The concentration of hydrogen ions (pH) largely controls the weakening of the tooth. As plaque builds up, the bacterial acids supply hydrogen ions, $H^+$, which combine with the hydroxide ions, $OH^-$, to form water.

$$H^+ + OH^- \Rightarrow H_2O$$

The hydroxide ions are essential to remineralization; their neutralization by $H^+$ causes this process to slow down. If *de*mineralization continues at the normal rate while *re*mineralization is slower, the tooth gradually loses material. The normal pH of the mouth is about 6.8; demineralization becomes dominant whenever the pH drops below 5.5. The pH becomes this low about 10 minutes after drinking a sugary beverage. It returns to normal when the sugar is washed away or consumed, about an hour later.

What can be done to prevent tooth decay? An Assyrian legend of the 7th century B.C. professed that a toothache was caused by a worm that drank the blood out of the teeth and fed on the roots in the jaw. Modern research does not support this explanation. Rather it supports the slogan, "A clean tooth never decays." It is necessary to remove the built-up plaque from the teeth. How can we do this? Neanderthal man used toothpicks made from twigs. The Romans not only refined toothpicks by making them out of silver and gold, but they also developed special mixtures that were applied to the teeth. These mixtures were rudimentary toothpaste. Their concoctions included honey, blood, charcoal, oils, crab eyes, rabbit heads, and ground chalk (chalk is used in some modern toothpastes).

Toothpastes have come a long way from the crude mixtures of the Romans. Regardless of the brand, today's toothpaste is composed of several basic ingredients:

**Abrasive**—most commonly *silica*, $SiO_2$, *calcium carbonate*, $CaCO_3$, or *calcium monohydrogen phosphate*, $CaHPO_4$. These compounds have microscopically small particles with irregular edges that help rub away stains and cut through plaque. Because abrasion requires *solid* particles, the compound must be relatively insoluble in water.

**Foaming agent**—typically *sodium lauryl sulfate*, a detergent. It reduces surface tension, allowing the toothpaste to penetrate into

crevices; it also suspends food particles, helping remove them from the tooth.

**Solvent**—Water dissolves many ingredients and keeps toothpaste fluid.

**Humectant**—*glycerin* or *polyethylene glycol*. Reduces water loss when toothpaste is exposed to air.

**Binder**—*Carboxymethyl cellulose* or *calcium carrageenin* thickens the toothpaste and prevents the ingredients from separating.

**Flavoring**—*Oil of peppermint* or *wintergreen* gives a "fresh" taste.

**Sweetening agent**—*saccharin,* an artificial sweetener, or *sorbitol*, a fruit sugar that most bacteria can't digest. Sucrose (table sugar) is never used because bacteria thrive on it.

**Fluoride compounds**—These help teeth stay healthy.

Manufacturers have extensively advertised fluoride toothpaste, and scientific tests have shown that fluoride *does* reduce tooth decay. Crest toothpaste contains *sodium fluoride*, NaF, which provides fluoride ion, $F^-$. The fluoride ion takes the place of the $OH^-$ during the remineralization process:

$$5\ Ca^{2+} + 3\ PO_4^{\ 3-} + F^- \Rightarrow Ca_5(PO_4)_3F$$

The modified enamel, called fluorhy-droxyapatite, is more resistant to acid. The $F^-$ does not substitute for all of the $OH^-$; even a small uptake of fluoride makes the enamel less susceptible to decay.

Other manufacturers use different fluoride compounds. *Stannous fluoride*, $SnF_2$, is added to Gleem. *Sodium monofluorophosphate*, $Na_2PO_3F$, (called MFP in advertisements) is used in Colgate, Aim, Aquafresh, and Macleans. These compounds contribute fluoride by chemical pathways that are more complex than the one described above, but the final result is the same—acid-resistant fluorhydroxyapatite.

A few people have unusually sensitive teeth; they feel a slight pain when they eat something hot, cold, or sour. Potassium nitrate, sodium citrate, or strontium chloride may be added to counteract this "hypersensitivity." The precise mechanism by which these chemicals work is not known.

Which toothpaste should you use? It is impossible for one toothpaste to meet everyone's needs. Because tobacco smoke causes special discoloration, smokers may select a toothpaste made specifically to combat these stains (such as Topol). Some people have teeth with exposed dentin—which is much softer than enamel—and may need a toothpaste with little or no abrasive.

We can be thankful that toothpaste no longer contains blood or crab eyes. It is a mixture of compatible chemicals that can make your teeth whiter, your breath fresher, and reduce tooth decay.

## CAPTIONS

Tooth *enamel* is made of hydroxyapatite. It is supported by the softer, porous, *dentin*. Nerves and blood vessels are in the *pulp*.

Dental *plaque* is a gelatinous mass of closely packed bacteria, as shown in this photograph taken by an electron microscope. A common variety is *streptococcus mutans*, which assembles sugar molecules into insoluble polysaccharide strands that give strength to the plaque. The bacteria excrete lactic acid (and small amounts of acetic, formic, and succinic acids), which dissolves the enamel.

Hydroxyapatite, the substance in tooth enamel, contains calcium (orange), phosphate (brown), and hydroxide (gray) ions. Acids weaken the structure by reacting with the hydroxide ions.

## BIOGRAPHY

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