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Perspective

Common toothpastes abrasives and methods of evaluating their abrasivity.

Abrasivos de pasta de dientes comunes y métodos para evaluar su abrasividad.

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Dental enamel is highly mineralized and the hardest biological tissue.[1,2] It is ectodermal in origin and is formed by ameloblasts during the process of amelogenesis. The enamel forms the outer covering of the tooth structure and is thicker over the cusps and incisal edges, and thinner at the cervical margins of the tooth. Enamel is a brittle hard tissue that has a high modulus of elasticity and is more resistant to abrasion.[3]

The characteristic surface mechanical properties of enamel are required to survive and perform in the harsh conditions oral cavity. Enamel once lost, cannot be repaired or regenerated; hence exposing the sensitive and softer dentine tissue to the oral environment[3,4] leading of the conditions such as hypersensitivity pain, and pulpitis. Additionally, the mechanical properties of dentine (such as hardness, elastic modulus) are remarkably lower than enamel making it prone to wear.[5]

Abrasion is defined as the removal of hard tissues mechanically with the introduction of foreign bodies repeatedly to the oral cavity, which comes in contact with the tooth surfaces.[6] Abrasion leads to the loss of tooth structure which occurs by factors other than contact of the teeth.

Dental abrasion wears the tooth structure, which could be caused by brushing incorrectly, and toothbrush abrasion might be a cause of non-carious cervical carious lesions[7,8] requiring restorations. In addition to the individual factors, the abrasivity of various particles added to dentifrices for tooth cleaning can play an important role in controlling the abrasion of dental tissues.

This current review was carried out to summarize the scattered information present in the literature about the common abrasives being used in toothpastes and methods of evaluation of toothpaste abrasivity, in order to enhance current understanding of dental practitioners about the researched topic. In compiling data for this perspective, the online databases Google Scholar and SCOPUS were searched using various keywords: *"abrasivity of toothpastes"*, *"toothpaste abrasion"*, *"abrasives in toothpaste"*, *"toothpaste abrasivity and dentistry"*, *"methods of evaluating tooth abrasion"*, *and "methods of evaluating toothpaste abrasivity"*. The search revealed over 100 articles which were reviewed and then 54 relevant English-language articles were selected and evaluated in detail.

ACID EROSION SUPERIMPOSING TOOTH ABRASIVITY

Erosion is the loss of hard tissues or dissolution of teeth by means of chemicals, which could be acids of non-bacterial origin.[9,10] Hydroxyl-apatite (HAP) is the main mineral component of the hard tissues of the oral cavity and

its dissolution over time can damage human enamel.[10] Davis *et al.*,[11] are amongst the first in introducing the concept that dissolution or acid softening could accelerate abrasion. Several *in-vitro* studies have shown support of this concept demonstrating that when combined, erosion and abrasion have a greater destructive effect then either on its own.[12,13]

Different researchers have performed in-situ studies and reported that the softened tooth surface condition, if not exposed to the mechanical abrasion, can be reversed by re-mineralization when exposed to saliva for a prolonged period.[14] It was summarized from these studies that abrasion resistance of the tooth surface can be increased by delaying brushing after an acid challenge for at least one hour.

A combination of any erosive agent and tooth brushing using toothpaste can cause an enormous amount of tooth surface loss.

When a tooth is in contact with an acid, not only there is a loss of hard tissues but the remaining structures are also softened. It has been reported that if surface softening extends beyond 3-5 microns, an easy removal of the soft and hard tissue will be seen when an abrasive challenge follows.[15]

COMMON ABRASIVES USED IN TOOTHPASTES

In recent years, abrasives have been added by toothpaste brands for aesthetic reasons. Primarily, the purpose of adding abrasive is the removal of plaque from the surface of the tooth[16] and removal of stains.[17,18] Various factors such as distribution and size of abrasive particles are important as they determine the abrasivity of toothpaste and its ability to remove stains.[10]

In the dentifrices, thickening agents are used to hold abrasive particles uniformly in a suspension and surface active agents are to remove the plaque.[19] Abrasives in toothpastes have been commonly divided into four major categories such as carbonates, silica, phosphates, and alumina (Table 1).

These toothpaste abrasives have different Mohs hardness values the enamel and dentine (Table 2).[20,21] These common abrasives are discussed below in detail.

Carbonate group

Abrasives in the carbonate group include sodium bicarbonate and calcium bicarbonate. These abrasives possess an alkaline pH in the oral cavity, thus acting as a natural buffer.

Baking soda (sodium bicarbonate)

Sodium bicarbonate ($NaHCO_3$; boiling point of 1,564°F (851°C), and specific gravity of 2.2g/cm^3) is a water-soluble chemical compound added as an abrasive in toothpastes. It is a white crystalline solid in the form of fine powder.[22]

The hardness of baking soda as compared to enamel and dentine is relatively low and other commercially abrasives are harder than baking soda. The low abrasiveness of baking soda makes it safer to maintain oral hygiene regularly. However, baking soda is not approved by the American Dental Association (ADA) as brushing with it alone will not provide fluoride for remineralization and to prevent cavities.

Fluoride when added to the dentifrices and restorative materials, prevents the activity of cariogenic bacteria.[23,24] Cleaning teeth using baking soda is cost-effective however, it is not recommended to be used alone due to lack of antibacterial and cariogenic functions. Another drawback is that the manufacturers of baking soda have not standardized the packaging so the consumers cannot use it as an alternative for the commercially available toothpastes.[25,26]

Calcium carbonate ($CaCO_3$)

Calcium carbonate ($CaCO_3$; melting point of 1,517°F (825°C) and specific gravity of 2.71 g/cm^3) is commonly added abrasive that helps to remove extrinsic stains deposited on the tooth surfaces.[27]

Apart from its abrasive effect, calcium carbonate can deposit and block the dentinal tubules and prevent dentine hypersensitivity.[28] However, excess calcium in the body can cause build-up on arterial walls of the heart, can also cause kidney stones, loss of appetite, constipation, nausea and vomiting.[29]

Silica

Silica or silicon dioxide is an abrasive or thickening agent incorporated in various toothpastes available in the market.[30] Silica (silicon and oxygen based minerals) mainly composed of silicon bonded to two molecules of oxygen (SiO_2). It has the molecular weight (Mw) of 60.08 g/mol, melting point of 3,110°F, density of 2.65g/cm^3.[30]

The desire for whiter teeth can be blamed for the fast development of tooth whitening dentifrices. Many tooth brightening items are accessible nowadays over the counter, which claim to brighten the teeth. Toothpastes with special abrasive particles interestingly relinquish extraneous stain through regular use.[31,32] Silica whitening toothpaste has been produced for a quick brightening, which works by conveying blue covarine to pellicle-covered tooth surfaces.

The blue covarine is saved and kept on pellicle-covered tooth surfaces causing a shift in shading, giving the impression of immediate tooth whiteness.[33,34]

Phosphates

Various forms of phosphates are added to the toothpaste formulations (at ~30-35%w/w) to function as abrasives. Due to the abrasive nature, phosphates play a vital role in cleaning of plaque and polishing tooth surfaces.

Dicalcium phosphate

Dicalcium phosphate ($CaHPO_4$) is an odourless abrasive white powder in appearance (Mw; 136.06g/mol and specific gravity; 2.93g/cm^3). Dicalcium phosphate acts as a cleaning agent for natural teeth as well as composite restorative material.[35]

The addition of an excessive dicalcium phosphate or calcium supplement may cause a number of conditions such as formation of kidney stones, muscle weakness, arrhythmias confusion, constipation or diarrhoea, headaches, fatigue, nausea and vomiting, frequent urination and even coma.

Sodium metaphosphate

Sodium metaphosphate has a chemical formula of NaO_3P, molar mass of 611.77g/mol, and density of 2.48g/cm^3. Sodium metaphosphate is water-insoluble and is used in water-free toothpastes.[36] Sodium metaphosphate has antimicrobial activity and prevents biofilm formation. Excess of sodium metaphosphate in the body can cause nausea, vomiting, bone pain, dizziness, muscle pain.[37]

Calcium pyrophosphate (zirconium silicate).

Calcium pyrophosphate is an abrasive material which is frequently incorporated in dentifrices. The chemical formula is Ca_2O7P_2, molar mass is 254.053g/mol, and density is 3.09g/cm^3. It is insoluble in water and soluble in acids like hydrochloric acid and nitric acids.[38]

Calcium pyrophosphate has anticalculus activity and it also prevents formation of plaque.[39]

Figure 1. A representative profilometry image showing surface peaks and valleys and evaluation of quantitative data.

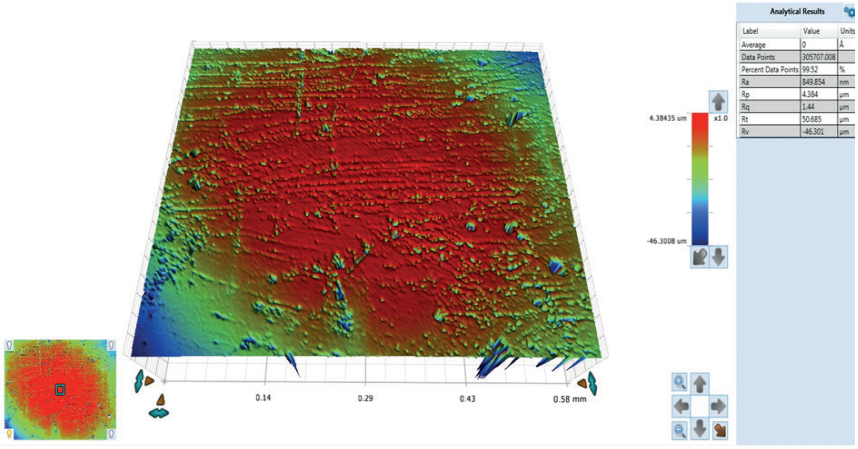

Figure 2. A representative Vickers micro-hardness testing image.

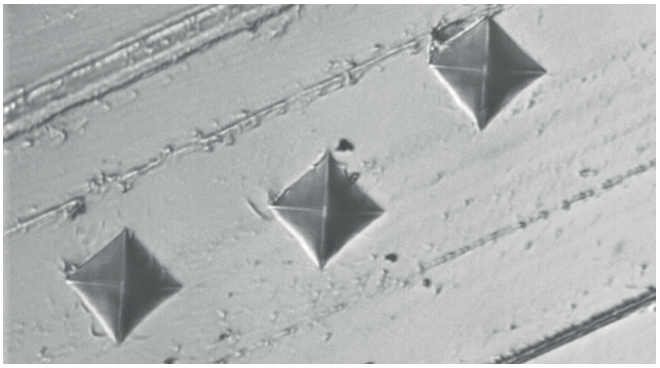

Figure 3. Schematic representation of indentation showing the surface of enamel before and after abrasion.

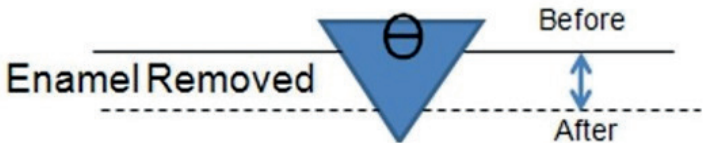

Table 1. List of commonly used abrasives in toothpaste formulations.[20]

Chemical group	Ingredients
Carbonates	Chalks Mined and Synthetic calcium carbonates Baking soda Sodium Bicarbonate
Silica	Hydrated silica Abrasives or thickening agent
Phosphates	Di-calcium phosphate (anhydrous and dehydrated) Calcium pyrophosphate
Other Types	Alumina (aluminium oxide)

Table 2. Mohs hardness of enamel, dentine and common abrasives used in dentifrices.[21,22]

Material	Mohs Hardness
Enamel	3.5
Dentine	2.0 - 2.5
Calcium carbonate	3.0
Baking Soda	2.5
Hydrated silica	2.5 - 5.0
Dicalcium phosphate dehydrate	2.5
Calcium pyrophosphate	5.0
Alumina	9.25

Alumina

The idea of alumina to be used in toothpastes grew in 1970's and 1980's. The reason for its growth was its compatibility with almost compounds which were incorporated in a toothpaste formulation.[40]

There are studies that reported alumina having good compatibility with sodium monofluorophosphate, and clinical trials have also shown that toothpaste formulation containing them are effective in reduction of dental caries for considerably long period.[41,42]

In vitro methods of evaluating abrasivity of toothpastes

When discussing the properties of toothpastes, abrasivity is an important factor as it is the ability of toothpaste to clean the teeth. However, a too high abrasivity can cause damage to the oral tissues as well.

Dental professionals widely accept that toothpastes need some degree of abrasivity in order to achieve satisfactory cleaning of the tooth structure. For better understanding of abrasivity of toothpastes, it is mandatory

to study the quantitative as well the qualitative aspects of determining abrasivity. Some of the common methods of assessing abrasivity of toothpastes are mentioned below.

ISO Radioactivity Method

This standard involves the use of a reciprocating cross brushing machine on irradiated human teeth. The teeth following irradiation, contain radioactive 32P which after brushing is released into the abrasive slurry and measured via Gieger–Muller Planchet counting. The specimen criteria for enamel and dentine is that it should be at least 14mm long and 2 mm wide, mounted in cold cure methyl methacrylate denture resin.

The specimens are then packed in 4% formaldehyde solution and later on, can be submitted for irradiation to a nuclear reactor. The amount of substance removed is calculated and is compared with that of the reference paste.[43] The calcium pyrophosphate is commonly used as a reference paste with the abrasivity value set to 100, while the abrasivity of the test pastes is expressed in relative value of abrasivity[44] referring to Relative Enamel Abrasivity (REA) and Relative Dentine Abrasivity (RDA) corresponding to enamel and dentine tissues. This ISO standard method requires a dedicated radiation laboratory.

RDA and REA

The RDA and REA are the standards which give us values for measuring dentine and enamel wear *in vitro* for determining the safety of abrasives. In 1974, the British Standards Institute (BSI) set a standard for toothpastes which were revised and documented in 1995. The abrasion of enamel (checked by REA) and abrasion of dentine (checked by RDA) will define the abrasivity potential of any standardized material using a normalized scale to serve as a reference.[38] The abrasivity values of experimental paste can be expressed relative to the reference paste. Ideally, the tested paste for the dentine should not be exceeding twice the abrasivity set by BSI, and the test paste for enamel should not be exceeding four times compared to the abrasivity of the BSI pastes.[45] The RDA and REA values provide an estimation of the amount of abrasion from the surface.[46]

Profilometry

Profilometry gives the qualitative measurements for the evaluation of abrasivity of a toothpaste. In Profilometry technique, the profiles of surface peaks and valleys are measured and quantitative data can be presented for abrasion (Figure 1).

In one form of profilometry *i.e.* surface contact profilometry, a diamond stylus is used with which the profile of the surface is scanned. The force on the tip and scan speed can be adjusted so that the tip can follow the abraded surface closely. Davis and Winter did a study on human enamel. A profilometer was used to evaluate abrasivity of different dentifrices and measured average depth of the profiles. The result was presented as a percentage of abrasion of the chalk.[44,46]

For measuring the loss of dentine, surface contact profilometry is a widely used method.[47,48] This technique gives measurements only in a two-dimensional field but is accurate and reproducible.[47,49] A surface non-contact profilometric method such as white light profilometry, can give an image which is three-dimensional (3D) topographical showing far more surface change information on the lost surface of the dentine as compared to the other methods.[45]

Indentation

Hardness of enamel and dentine is known to have considerable variations according to the location/surface.[50] Micro-indentation is the method for determining the hardness of enamel and dentine. Vickers and Knoop diamond indenters are the common types, used by a number of investigators. It has been reported that both Vickers and Knoop results in the same value approximately.[51,52] An example of Vickers indentation. (Figure 2)

For measuring the abrasivity or wear of the tooth surface by a toothpaste, the measurement of the length of the Knoop indents is performed prior to indentation. Following the indentation, the indents are cleaned using an ethanol impregnated cotton swab and re-measuring indents. The measurement is completed with a micro-hardness testing machine. As there will be a change in the indents length; an average of changes in the indent depth is calculated to estimate the amount of enamel abraded.[51,53,54] (Figure 3)

CONCLUSIONS

The present review perspective summarizes various aspects of commonly used toothpaste abrasives and the methods of evaluating their abrasivity. The abrasive effects of a toothpaste depend on various factors including the type of abrasive, its hardness, fraction, and particle size. The manufacturers should disclose REA and RDA values on the packaging of their toothpaste so that the consumers can choose the most suitable toothpaste for their needs.

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