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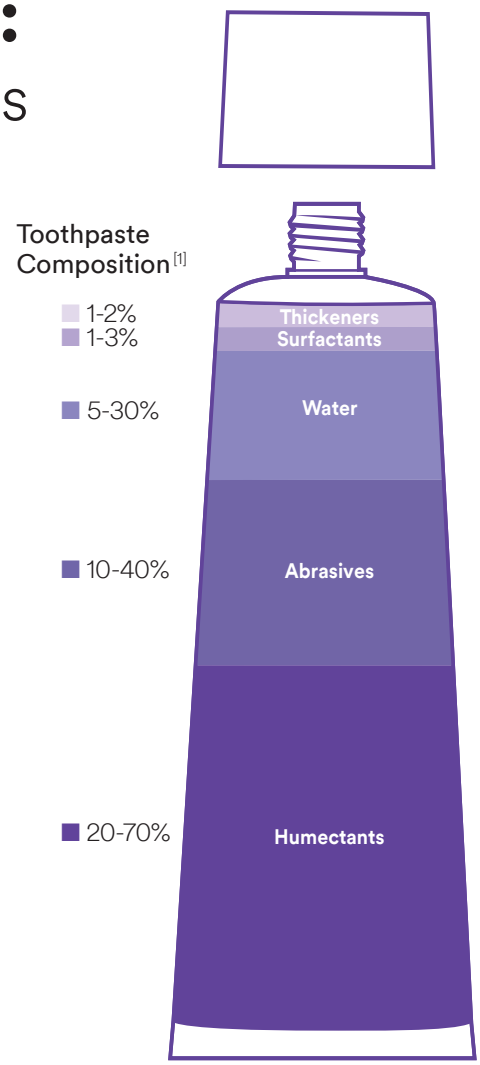
What's in your toothpaste?

Take a look at the secret ingredients behind healthy smiles.

Toothpaste composition:
Finding the formula for success

As a dental professional, you likely spend a lot of time reminding your patients to brush their teeth. Maybe you recommend a standard fluoride toothpaste to help prevent cavities, or a particular kind to reduce sensitivity, plaque or gingivitis. Your patients probably don't choose their toothpaste based on the formulation listed on the label. But materials matter, and toothpaste is more than the sum of its parts. Do you know the "recipe for success" to making the right choice for your patients?



Toothpastes typically consist of active ingredients (those that aid in the prevention and treatment of tooth decay or other diseases) and inactive ingredients (the non-medicated parts of the formulation), combined at different levels to produce a desirable medical and esthetic outcome. Composition varies by brand, manufacturer and purpose, but in general, component concentration breaks down to: 10-40% abrasives, 20-70% humectants, 5-30% water, 1-2% thickeners, 1-3% surfactants and small concentrations of flavoring, colorings and other agents.[1] These materials are listed on the box in volumetric order – so though you won't see an exact breakdown, knowing what each ingredient does can provide a bigger picture of its unique benefits.

Fluoride

Fluoride works by holding onto calcium and phosphate in the mouth, thereby increasing the remineralization of enamel and replacing the normal enamel crystalline composition hydroxyapatite with more decay-resistant fluorapatite. But why does knowing this mechanism matter?

Fluoride, for better or worse, has become ever more conspicuous in the social consciousness. Today's patients are more curious and cautious about what exactly the mineral means for their oral health. Being able to discuss this ingredient in detail with your patients can help reassure them of its efficacy and cut through some of the noise surrounding the topic.

Over-the-counter fluoride toothpastes sold in the United States contain between 850 and 1150 ppm fluoride (prescription options contain 5000 ppm) and account for 95% of toothpaste sales.[2] The U.S. Food and Drug Administration (FDA) recognizes three types of fluoride as the only toothpaste ingredients that help prevent caries: sodium fluoride (NaF), stannous fluoride (SnF_2) and sodium monofluorophosphate (Na_2FPO_3, also know as MFP).[3] The concentrations and pH levels of each type are carefully regulated and evaluated.

Sodium fluoride is the most common fluoride used in toothpaste and has the longest history – it was the first compound to be recognized for its safe decay-prevention properties and the first to be integrated into public water fluoridation.[3] Sodium monofluorophosphate is actually the product of combining sodium fluoride with sodium metaphosphate. It is colorless, odorless and soluble in water, though not used for water fluoridation. The main differences between these two

minerals are that MFP is compatible with a wider range of abrasives than NaF – including calcium, which renders NaF inactive – but requires an extra step to release fluoride. Unlike NaF, which releases fluoride freely immediately upon use, MFP requires enzymatic hydrolysis, a specific reaction between an enzyme and water, to break the monofluorophosphate bond and release fluoride.[4] Depending on the other agents in the formulation and the given pH of the patient's mouth, this extra step can greatly affect the toothpaste's efficacy.[5, 6]

Unlike the other two options, stannous fluoride does more for teeth than just simply protect from decay – it also has antibacterial and anti-hypersensitivity properties. It's important to keep in mind that all three options are generally considered equally effective against caries (the subject is still under debate in the scientific community, with no conclusive results of one mineral over another), and are chosen mainly based on other desired benefits, as well as what it will react with in the formulation.[6, 7]

The American Dental Association (ADA) recommends that most individuals brush twice a day with a fluoride toothpaste, with specific recommendations based on level of caries risk.[8] Those at a lower risk may not benefit from additional fluoride, but high-risk patients may need higher-concentration prescription toothpaste or professional topical treatments.

The ADA defines high-risk adult patients as those who have one or more risk factors including:

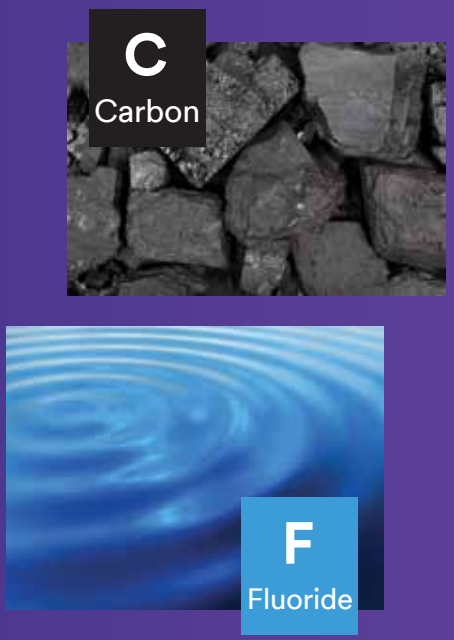
- Active caries in the last 12 months
- Xerostomia
- Active orthodontic treatment
- Sub-optimal fluoride exposure
- Cariogenic diet [8]

In the spotlight: "Natural" toothpastes

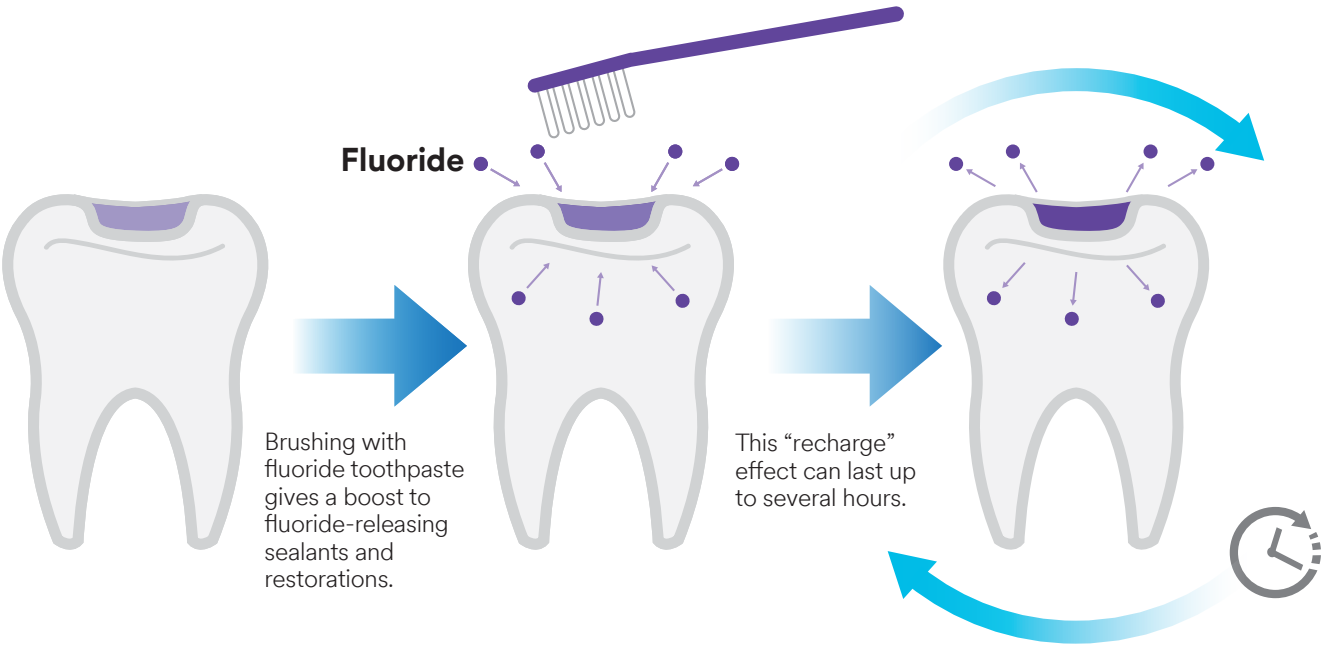
Now more than ever, patients are seeking out their own answers to dental health questions, and unfortunately, the quality of these answers can be mixed. Modern dental patients are exposed to conflicting, confusing and often incorrect information about toothpaste every day, and the walk down the toothpaste aisle certainly doesn't help. The sheer number of options, claims and ingredients is intimidating, so it's no wonder patients want to know more.

"Natural," homeopathic, alternative and DIY toothpastes have grown in popularity in the last few years, and it's important to remind patients to be wary of opinion pieces, unscientifically-based conclusions and works with obvious biases or unreliable sources when it comes to their oral health. None of the common "natural" suggestions – for example, charcoal, bentonite clay, bar soap, sea salt, coconut oil – have been clinically demonstrated to have any kind of benefit to dental health. In addition, DIY toothpastes may be dangerous for a number of reasons. The recipes are often untested and come from unreliable, unacademic sources; may be too abrasive or acidic; and could cause more harm than good.[9, 10] Counseling patients away from these options and toward toothpastes from reputable manufacturers is in everyone's best interest.

As mentioned earlier, fluoride has become a controversial topic over the last few years, called an "unnatural" or "hazardous" ingredient in toothpaste. Fluoride, however, is a naturally-occurring mineral present in the earth's crust, plants, air and water.[11] Fluoride is also the only ingredient scientifically proven to prevent cavities, and the only ingredient recognized by the FDA for caries prevention.[12] The risks of fluoride – fluorosis, poisoning, rashes and impaired glucose metabolism – all require excessive consumption, similar in nature to the risks of any over-the-counter drug.[13]



Fluoride is the only ingredient scientifically proven to prevent cavities.



Recharge

A widely under-discussed benefit of fluoride toothpaste is its ability to “recharge” fluoride-releasing sealants, cements and restorations. This means that every time a patient brushes their teeth, their fluoride-releasing restorations or sealants absorb fluoride and can release another round of fluoride into the mouth. This ability addresses immediate fluoride needs as well as long-term fluoride delivery.

Liquid medium

From a physical chemistry standpoint, toothpaste is a sol colloid. A colloid (Greek for “glue-like”) is a heterogenous mixture of molecules larger than an atom but still a microscopic substance and invisible to the naked eye. The mixture is unique in that it is neither a solution nor a suspension, meaning it will not separate or settle. A sol, such as toothpaste, is a mixture of minute solid particles in a liquid medium.[14] Most toothpastes use water as their medium, as a readily available resource that also helps maintain moisture; however, some water-free options exist.[15]

Calcium and phosphate

Calcium and phosphate are minerals that naturally occur in the mouth in both teeth (as hydroxyapatite) and saliva. These minerals are the “building blocks” of healthy teeth and work to combat the acids and sugars patients consume every day. However, the mouth doesn’t always produce enough of these minerals to make a substantial difference – especially for patients with clinically dry or particularly acidic mouths. The addition of calcium and phosphate directly into toothpaste gives the mouth a twice-daily boost of these critical minerals – in effect adding more resources to build healthier teeth.

Sensitivity agents

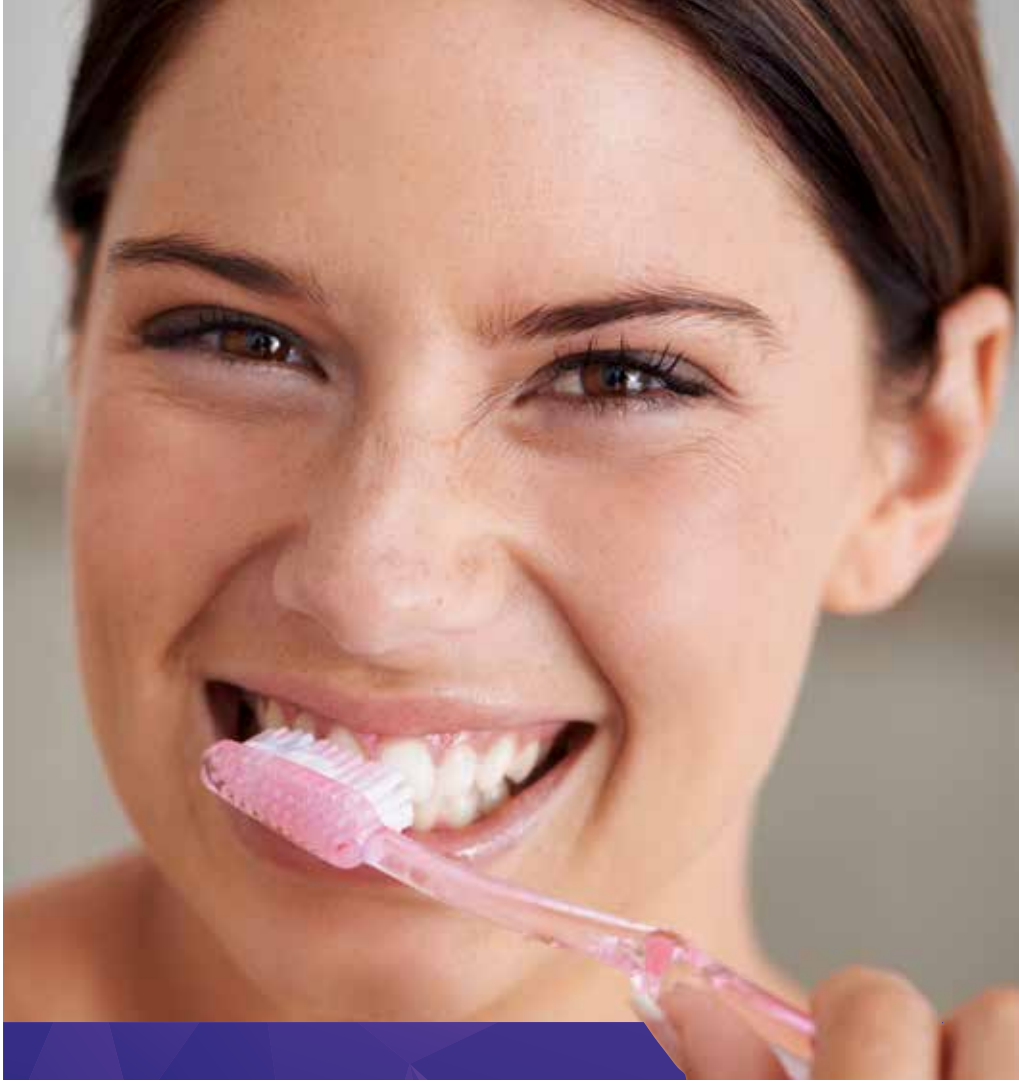
Sensitivity toothpastes have become increasingly popular over the years – but how exactly do they work? And how are the ingredients different? Sensitivity occurs when the inner layers of the tooth become exposed to external stimuli. The outer enamel protects the dentin, which is comprised of a series of fluid-filled tubules that reach the inner dental pulp. This pulp contains nerves that send signals to the brain. When a dentin tubule loses its protective enamel coating, heat, cold and other stimulants can reach the nerve and cause pain.

Sensitivity agents in toothpaste serve to block transmission of sensation from the tooth surface to the nerve, by covering or filling the dental tubules. The most common options in toothpaste are potassium nitrate, stannous fluoride and strontium chloride. Potassium nitrate reduces or eliminates the gradient of potassium ions across the nerve cell membrane. Stannous fluoride and strontium chloride, on the other hand, create a layer over exposed dentin tubules – limiting the stimulation of nerve endings.[16]

Antibacterial and antimicrobial agents

Antibacterial and antimicrobial agents serve to reduce plaque, bad breath and the risk of gingivitis, and are categorized as "therapeutic agents." Several popular options include stannous fluoride and triclosan. Stannous fluoride, in addition to its role in preventing tooth decay, inhibits metabolic enzymes to reduce bacterial growth and the ability of bacteria to adhere to tooth surfaces, as well as decreasing plaque buildup in biofilm.[17]

Abrasives



While inactive, abrasives are key ingredients that make up a large percentage of each toothpaste formulation. In addition to toothbrush bristles, abrasives are responsible for cleaning and polishing teeth by removing debris, deposits and stains. The hardness of the abrasive (its degree of abrasivity) is critical to how well it works. Too gentle and it may not remove debris effectively, but if too highly abrasive, it may harm dentin and enamel. This is particularly important when considering the percentage of patients who brush incorrectly, with too hard of a brush, or over-brush (10-20% of Americans, according to the *Wall Street Journal*).[18]

Common abrasives include calcium carbonate, calcium phyrophosphate, sodium bicarbonate, dehydrated silica gels and hydrated aluminum oxides, which are usually selected in conjunction with the fluoride used in the formulation to avoid unnecessary interactions.

The abrasivity of any given toothpaste is determined by its Relative Dentin Abrasion (RDA) and Relative Enamel Abrasion (REA) values, which measure a given dentifrice's abrasive effect on dentin and enamel, respectively. These standards were set by the ADA, made international standards by the International Organization for Standardization (DIN EN ISO 11609) and are updated regularly.[19, 20, 21] According to ISO 11609, RDA values may range from 0 (low abrasive) to 250 (harmful limit). Similarly, REA values may range from 0 to 40.[21] It's important to note that these numbers do not correlate with how safe a given toothpaste is, as all compliant toothpastes are considered safe for lifetime use. However, since there is no disclosure requirement for these values at a commercial level, knowing these values can help you make abrasive decisions based on other patient factors, such as diet and brushing habits.

Whitening toothpastes, however, tend to have higher RDA levels and may contain abrasives with bleaching agents, such as calcium peroxide, carbamide peroxide and hydrogen peroxide to address staining.[1] The stain removal ability of a toothpaste is determined using the Pellicle Cleaning Ratio (PCR) test, also set by the ADA and ISO.[21] This test evaluates how well a formulation removes stains from the pellicle – a thin protein-based film that forms on enamel when exposed to saliva, which serves as lubrication and additional protection for the tooth.[22] Higher PCR values indicate higher cleaning power. This number in relation to a formulation's RDA value results in its Cleaning Efficiency Index (CEI). Finding the correct ratio between these values (a high CEI) can be a challenge: the ideal formulation cleans effectively (high PCR) with low abrasivity (low RDA).[23] Whitening toothpastes, while very popular in the dental marketplace, typically lean toward a higher PCR and RDA, and can cause some sensitivity or irritation issues. What many patients aren't aware of is that these toothpastes only remove extrinsic stains, which can lead to poor, over-abrasive toothpaste choices that only lead to more erosion.

History

Toothpaste has a surprisingly long and strange history, stretching back thousands of years. The progression of toothpaste technology has moved along with our understanding of dental health – beginning with a general idea of "scrubbing clean" to a much gentler, chemically-based process to complement tooth chemical structure.

5000–3000 BCE: Egyptians create powder toothpaste

1100s–1800s: Charcoal and other ingredients added to tooth powders

1866: Dr. Sheffield invents collapsible toothpaste tube

1890: W.D. Miller develops theory around cause of caries

1914: Fluoride added to toothpaste for first time

1955: Fluoride becomes standard toothpaste ingredient

The first toothpaste was actually a powder, created by Egyptians somewhere between 5000-3000 BCE, and was comprised mostly of abrasives in the form of hooves, myrrh, egg shells and pumice. This trend of highly abrasive tooth care continued with the ancient Greeks and Romans, who incorporated crushed bones and oyster shells.[24] Ancient China is credited with adding the first flavorings to toothpaste, and for good reason – some of the major components used for clean teeth were salt, musk and ammonia. Hippocrates is actually considered the first individual to recommend a dentifrice. In his text *De Morbis Mulierum*, he describes preparing the solution for clean teeth, which involves burning several dead rodents.[25]

The concept of cleaning the teeth specifically to avoid decay and discoloration grew in popularity from the 12th century onward, with each (fairly horrific and questionable) ingredient added attending to a specific purpose – for cavity prevention, "sweet breath", achieving a white smile, to strengthen the gums or to "eradicate scurvy."[25] Between 1600-1800, everything from ground china, charcoal, chalk, ammonia and powdered coral were added to tooth powders and touted as critical to a healthy, white smile. However, toward the end of the 17th century, formulations moved a bit closer to toothpaste as we know it today. In 1866, Dr. Washington Sheffield, inspired by painters in Paris, manufactured the first modern-style collapsible tube of toothpaste.[26] And in 1890, W. D. Miller developed a theory around caries that changed the course of dentifrice development. His 'chemo-parasitic' theory held that caries were caused by acids produced by oral bacteria interacting with tooth enamel, which, in turn, led to new formulations surrounding this specific reaction.[27]

Entering the 20th century, toothpaste continued to advance. In 1914, fluoride was added to toothpaste for the first time (though it wouldn't become the standard until 1955), and public awareness shifted from keeping teeth clean and white to new oral health issues, such as gingivitis. Before World War II, toothpaste tubes were made of metals, such as tin or lead, but restrictions forced manufacturers to create new tubes from aluminum and plastic – which helped create new formulations that didn't react with their metal containers.[24] From here, abrasion was reduced and more elements made their way into formulation – including surfactants, sweeteners, sensitivity agents, stain removers and more – until we reach today's modern paste.

It's interesting to note that throughout this complex history, many ingredients rose to popularity, fell into controversy or skepticism, or simply passed through the public consciousness without a second thought. But the overarching theme of keeping a healthy, clean smile has persisted from day one – and that's what each of our modern ingredients, controversial or not, is intended to do.

Surfactants

When added to a liquid, these compounds reduce surface tension. Along with their unique hydrophobic and hydrophilic properties, this helps to loosen plaque deposits and suspend the debris, thereby preventing it from redepositing on the clean surface.[28] It also creates a foaming effect when agitated, which allows the toothpaste to distribute evenly throughout the mouth and between teeth, not just on the brushed surface. Moreover, they can have other properties, such as acting as emulsifiers to help water- and oil-based ingredients stay mixed.

The most common surfactant used in toothpaste is sodium lauryl sulfate (SLS), though there are several other options, including sodium N-lauroyl sarcosinate, cocoamidopropyl betaine (CAPB) and sodium lauryl sulfoacetate (SLSA).

Humectants

Humectants are chemicals with hygroscopic properties, i.e., they naturally absorb moisture. When dissolved into a toothpaste formulation, these chemicals hold onto water and help keep toothpaste from drying out in the tube or when exposed to air. This helps to maintain the same texture from the first squeeze through the entire tube. Common humectants include polyethylene glycols, sorbitol, glycerol and even aloe vera gel. Some humectants may have additional benefits, such as sorbitol and glycerol, which are naturally sweet.

Thickeners

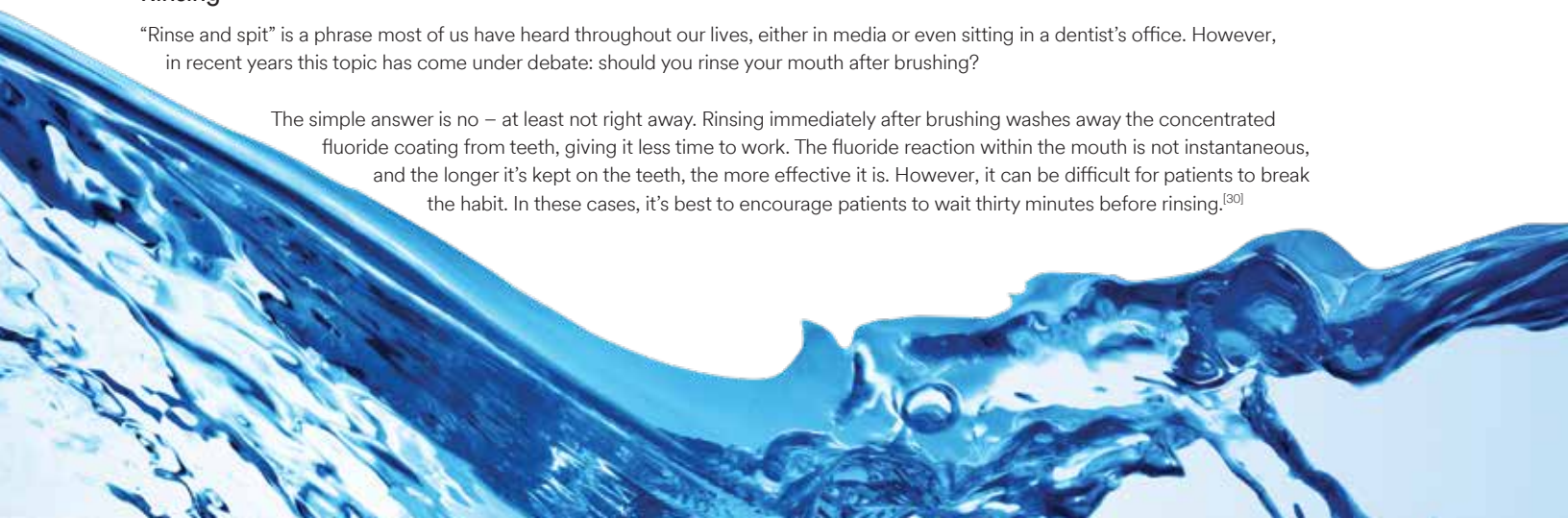
Thickening agents, or binders, form strong interactions with water and are necessary to stabilize the toothpaste formula (keep ingredients from separating) and also provide texture, body and flow. While there are many binder options – carrageenan, synthetic cellulose, mineral colloids, sorbitol, fumed silica and xanthan gum, among others – they all help to provide toothpaste with its familiar consistency when squeezed from the tube and brushed in the mouth. Some thickeners serve multiple purposes, such as sorbitol, which also has sweetening and humectant properties.

The thickness of a toothpaste allows it to flow easily from the tube onto the brush and rest on top of the bristles – providing a quick visual for dosing purposes (e.g., the smear or rice-sized amount for ages three and under and pea-sized amount for ages six and up recommended by the ADA).[19, 29] Most patients are familiar with and accustomed to a particular toothpaste viscosity, particularly in terms of mouthfeel, which is important to keep in mind when making recommendations.

Rinsing

"Rinse and spit" is a phrase most of us have heard throughout our lives, either in media or even sitting in a dentist's office. However, in recent years this topic has come under debate: should you rinse your mouth after brushing?

The simple answer is no – at least not right away. Rinsing immediately after brushing washes away the concentrated fluoride coating from teeth, giving it less time to work. The fluoride reaction within the mouth is not instantaneous, and the longer it's kept on the teeth, the more effective it is. However, it can be difficult for patients to break the habit. In these cases, it's best to encourage patients to wait thirty minutes before rinsing.[30]



Flavors, sweeteners and coloring agents

When one thinks of toothpaste, the classic “minty-fresh” taste probably comes to mind. However, flavorings take up only a minuscule fraction of toothpaste formulations and have no health benefits. The mint flavoring we’ve all come to expect first became popular in the early 1900s, as the mint oil (along with citric acid) created a tingly, cool feeling customers quickly associated with cleanliness.[31] Today, mint and other flavorings such as cinnamon, spearmint and bubblegum are added primarily for patient appeal, familiarity or to mask other flavors – as many necessary components aren’t particularly palatable (stannous fluoride, for example, has a naturally bitter or metallic taste).

Similarly, sweeteners are added to make toothpaste more pleasant, though some ingredients are inherently sweet, such as xylitol, sorbitol or glycerin. However, in order to be approved by the ADA, flavoring agents cannot cause or contribute to tooth decay – which is why artificial sweeteners are used instead of sugar.[19] There are six artificial sweeteners approved by the FDA, four of which are currently marketed in toothpaste. In addition to these, stevia and siraiti grosvenorii (monk fruit) extract fall under the FDA’s GRAS (Generally Recognized As Safe) notice and are often labeled as “natural” alternatives to artificial sweeteners.[32]

Dyes and colorings (such as titanium dioxide) are minimally used and are mainly for consumer appeal – to produce a paste in the bright whites, blues, greens and even stripes that patients have come to expect. While none of these elements have a discernible effect on teeth, patient habits and expectations will dictate their toothpaste choices and are important to keep in mind when recommending one brand over another.

Conclusion

What's the best recipe for success?

Within every familiar tube of toothpaste, there is a highly complex and well-thought-out recipe of very precise ingredients – all designed to work together and in the mouth to produce a specific, expected result. So what's the formula for success? It likely depends on the indication. But the more familiar you are with what's in your toothpaste – and why it's there – the more you can serve as an expert resource for your increasingly curious patients. And the more confident you can be in making recommendations to help protect their healthy smiles.

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