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Conflict of Interest Disclosure Statement

- Donald J. White, Phd is a retired employee of Procter & Gamble.
- Beth Jordan is a current employee of Procter & Gamble.

Introduction – How Whitening Works

The growing array of tooth whitening product options with varying efficacy, safety, cost, and differences in application methods and settings elicit patient queries. Understanding tooth color etiology, the relative strengths and limitations of treatment options, and patient goals is important for effective guidance. This course discusses mechanisms that influence efficacy and tolerability of whitening products including concentration, dose and contact time as well as strengths and limitations of different whitening delivery systems.

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Overview

The growing array of tooth whitening product options with varying efficacy, safety, cost, and differences in application methods and settings elicit patient queries. Understanding tooth color etiology, the relative strengths and limitations of treatment options, and patient goals is important for effective guidance. This course discusses mechanisms that influence efficacy and tolerability of whitening products including concentration, dose and contact time as well as strengths and limitations of different whitening delivery systems.

Learning Objectives

Upon completion of this course, the dental professional should be able to:

- Articulate the various factors associated with the appearance of color of teeth.
- Explain the different origins of tooth stains.
- Differentiate between extrinsic and intrinsic colored tooth stains.
- Explain approaches to tooth whitening.
- Describe different types of oxidative tooth whiteners and how they work, including how peroxide oxidizes stains.
- Describe why peroxides are safe for use in patients including toxicology, soft tissue safety, and hard tissue safety.
- Describe the origins of dental hypersensitivity associated with oxidative whitening.
- Describe and critically assess different delivery vehicles for whiteners.
- Understand approaches in clinical testing and various indices to measure tooth whitening.
- Describe three of the newest introductions in oxidative whitening available to patients.

Introduction

The appearance of a white, clean dentition is important to many consumers. A whiter smile builds self-esteem and boosts personal confidence. Tooth whitening also provides patients with the opportunity to counteract the effects of aging and their lifestyle habits on their dentition. The addition of cleansing abrasives and surfactants to toothpastes has provided these topical forms with some modicum of control for the deposition of stains on the teeth for centuries. However, toothpaste, topical mouthrinse and gels are typically limited in the amount of whitening which can be provided to consumers. The removal of tougher stains and the changing of the intrinsic color of the teeth has demanded more effective treatments than typical toothpaste abrasives and surfactants can provide. Oxidative technologies, like tooth bleaches have met this need and provide a useful innovation to assist patients in the achievement of whiter teeth.

While a variety of oxidative whitening approaches had been tried for close to a century, the nightguard vital tooth bleaching technique introduced in 1989 heralded a new era for tooth whitening.[1] The method employed a carbamide peroxide gel which was applied by patients in fabricated trays prepared by the dentist. Subsequently, manufacturers have introduced dozens of tooth bleaching procedures and products to the marketplace including in-office rapid whitening techniques, dentist-fabricated and boil and bite home use whitening trays, whitening strips and a variety of 'paint on' whitening products available over-the-counter (OTC). Since their introduction, the challenge for vital tooth bleaching has remained the same, achieving a patient/consumer acceptable whitening response while maintaining good patient tolerability – especially with respect to tooth sensitivity.

The Basics: How we see color

To understand the principles behind oxidative whitening we must first consider the fundamentals of color vision2 – shown below (Figure 1) with the observation of a red apple.

Light (from sunlight, fluorescent or incandescent light bulbs etc.) projects on an object. This light contains a variety of wavelengths. Some light is absorbed by the object and some light is reflected. We see the reflected light. Reflected light is processed by the retina, which transmits the signals of the reflected light to the brain. Human beings see light as three sets of colors and combinations of colors – Yellow - Blue - Red –which are a collection of color families defined as the hue. The intensity of the color we see is defined as Chroma and is demonstrated by the shift from pink to crimson. Lastly, the colors we see are described in terms of lightness –a parameter defined as the value – which ranges from 0 (totally black) to 100 (totally white).

We must also consider that observed tooth color can also be affected by additional optical phenomena. This includes metamerism (color appears different in different conditions of light), opalescence (observed shifts in reflected and absorbed light based on wavelength), fluorescence (absorption of light and

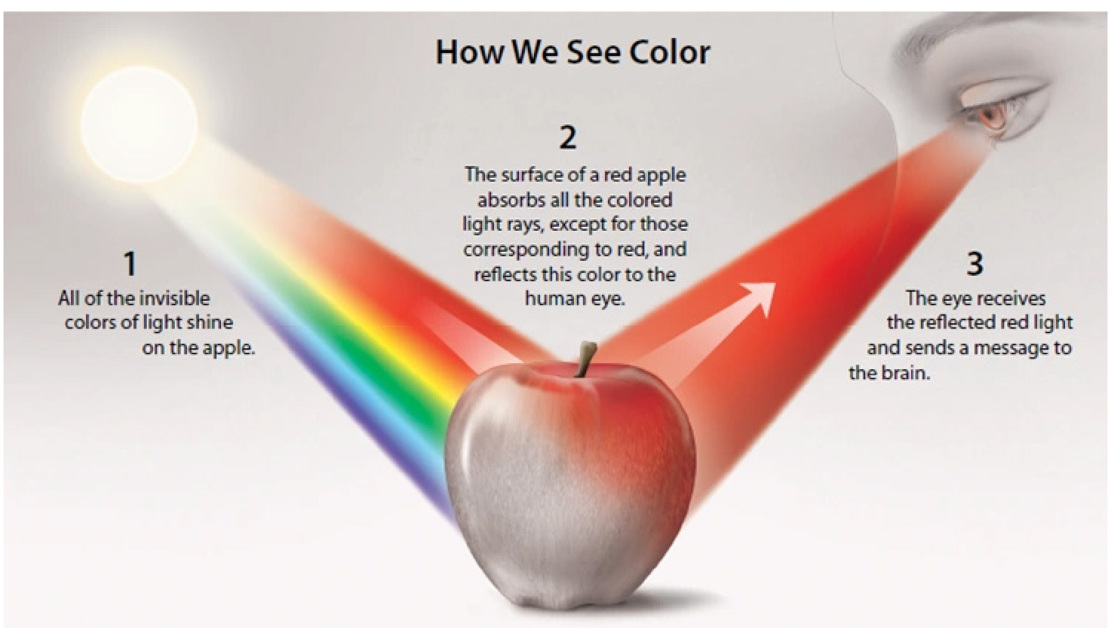


Figure 1.

chemiluminescent transmittance of light at a longer wavelength) and translucence (the diffusion of light into a material to variable depths – and reflection back to the observer with variable scattering). An example of these phenomena acting in concert to affect tooth color is the bright white appearance of teeth in the blue light in a discotheque. Importantly, tooth color is also influenced by the background against which it is observed – this is a phenomena well known to those in artistic fields as simultaneous contrast. Simultaneous contrast is the reason some patients' teeth appear whiter against different backgrounds of

Figure 2 below shows examples of simultaneous contrast for a number of different color combinations. The insert block of color is exactly the same in each quadrant – but appear different.[2-4]

Figure 2 - Simultaneous Contrast

With respect to tooth color, this means that skin tone and color of gingiva can have an impact on shades associated with teeth by professionals and individual patients.[2-4]

Factors Influencing the Appearance of Teeth

The basic understanding of tooth color is important to many aspects of restorative dentistry, including the preparation of crowns and veneers. Tooth color and appearance are affected by factors both in and on the teeth.

Because teeth are translucent, color is observed from both on and within the teeth. This can be seen clearly in the close-up image below (Figure 3).

The diagrams below (Figure 4) show how tooth appearance is affected by light reflecting from the tooth surface stain and from areas inside of the translucent tooth.

Teeth can be considered to have a natural color – which is derived from structural and compositional factors – as well as an acquired color, which is derived from a combination of natural color supplemented by the deposition on and incorporation into enamel of colored materials (stains) acquired throughout their life span.

Natural Color of Teeth – The Shade of a Clean Tooth

Teeth have a range of colors naturally – without the effects of any external or internal sources of stain. For the purposes of this course, we define a stain as a source of discoloration that is not of natural origin (Intrinsic stain is of natural origin – blood origin). The sources of natural tooth color include structural features of the teeth including thickness, translucency, dentin color, and in the absence of staining may be dominated by genetic factors.[5] Teeth also vary in color between each other, with incisors, canines and molars typically exhibiting different shades.

Historically, the variety of colors seen in natural dentition is generally encompassed by commercial shade guides – including the commonly used Vita Shade. Although visual assessment using shade guides is very useful and used in daily practice, there are some limitations such as incorporating differences in lightness, chroma and hue, as well as accounting for changes seen with the entire tooth versus only certain areas of the tooth. More recently digital shade measurements are taken which removes subjectivity associated with these limitations.

IIn digital image analysis (Figure 5) , images of the dentition are captured under controlled and calibrated lighting conditions with cross polarization to eliminate glare. From these images, the color of teeth can be determined for the dentition of interest. Typically, the color values of the teeth are reported in L* a* b* color space where L* measures luminescence (e.g., how bright), a* is the chroma ranging from red to green, b* is the chroma ranging from yellow to blue, as shown in Figure 6. With respect to teeth, they are on the yellow side of b*, the red side of a* and in the upper range on L*. Tooth color changes are quantified by comparing the L*, a* and b* values before and after treatments to establish changes in the color values designated as ΔL*, Δa* and Δb*.

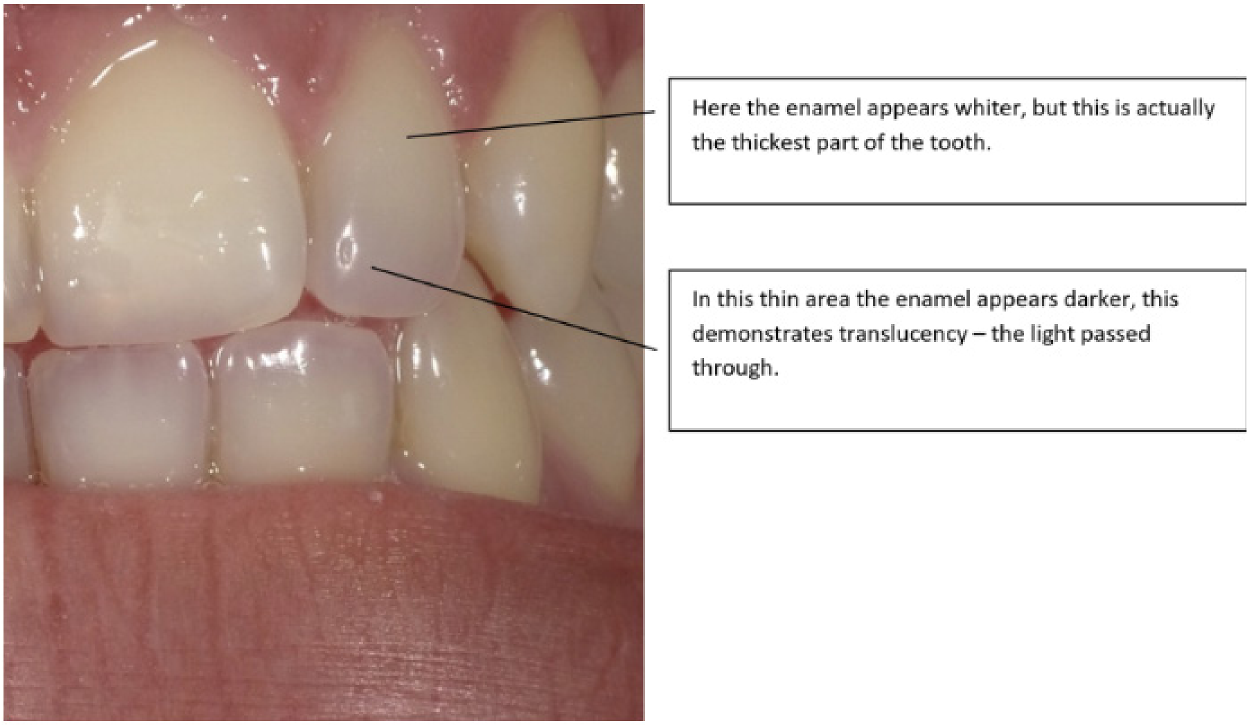


Figure 3.

Image Source: Dr. Gerald Kugel, DMD, MS, PhD

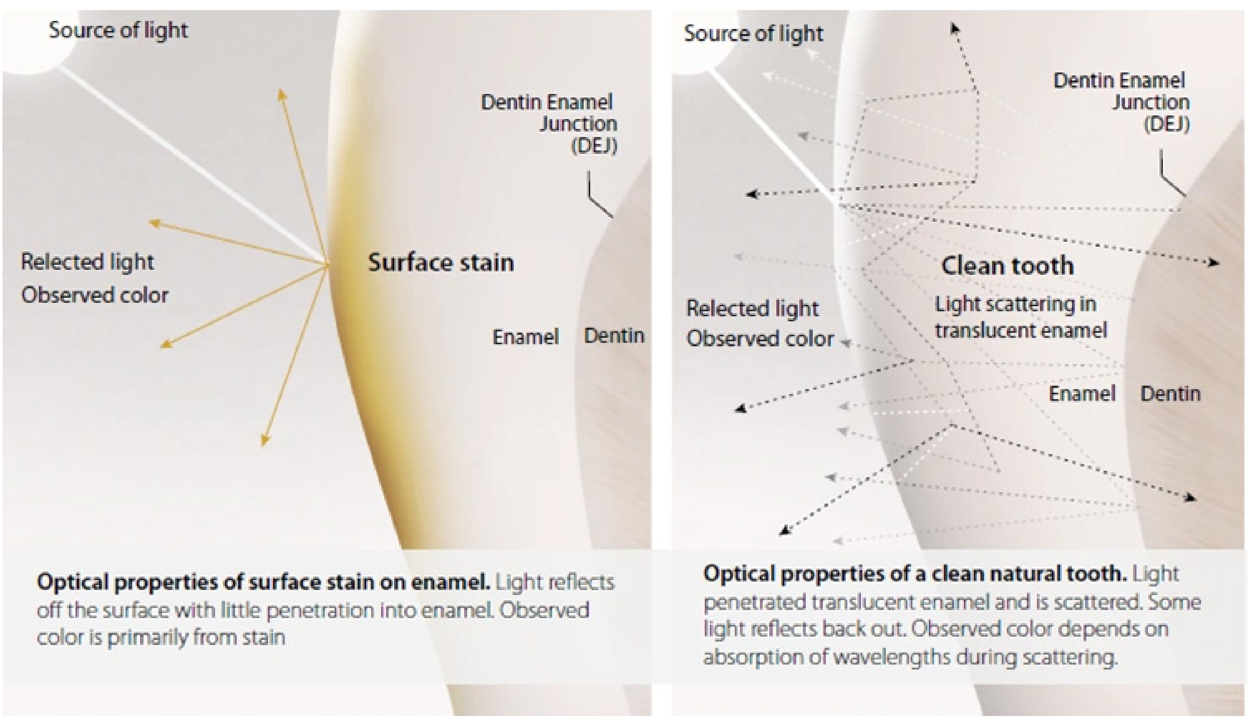


Figure 4.

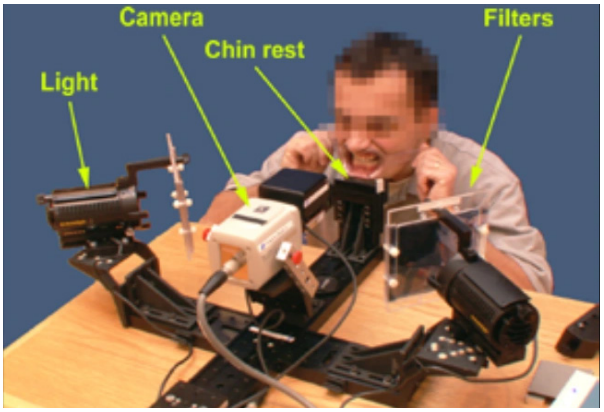


Figure 5. A typical imaging system is comprised of a 3-chip CCD camera, a d50 polarized lighting setup, computer and fixed positioning of the patient.

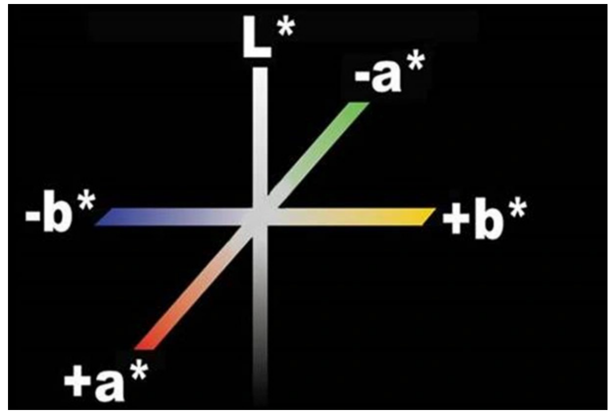


Figure 6.

Steps to an Effective HazCom Program

Molecules that can alter reflected light are defined as chromogens. They can be of natural origin or from external sources. Definitions follow below for sources of tooth color.

Intrinsic discoloration: Intrinsic discoloration of teeth arises from a variety of factors including chromogens in the enamel, in the dentin, and structural characteristics of the enamel. Sources of intrinsic natural coloration primarily originate during tooth development or through aging and the continual yellowing of dentin over time. This is thought to be related to the on-going production of secondary dentin. In some unique cases, intrinsic discoloration can arise from the use of antibiotics by either the mother or at a time when permanent dentition is developing. This is most commonly associated with the use of tetracycline and minocycline in the 1960s and 1970s. Structural defects in enamel impact the appearance of teeth, including dental fluorosis, enamel hyperplasia, and amelogenesis imperfecta. An image of a tetracycline-stained tooth and teeth with fluorosis are shown below (Figure 7).

Although the source of intrinsic discoloration is not from external origins, discoloration can be quite pronounced, this can be challenging to treat even with tooth bleaching techniques. Tetracycline, for example, requires chronic bleaching to obtain satisfactory levels of tooth whitening for patients.[6-8]

Extrinsic Stains: Here the source of tooth discoloration resides *on* the tooth surface and the source of the stain is from external origin. Sources of extrinsic stain are variable and related to the diet, habits and practices of patients. The most common sources of stain include tobacco, tea and coffee. Extrinsic stains accumulation can be promoted by using cationic antimicrobials such as chlorhexidine and cetylpyridinium chloride.[9-11]

Tetracycline-stained tooth

Fluorosis-stained tooth

Figure 7.

Image Source: Dr. Gerald Kugel, DMD, MS, PhD

Chlorhexidine Stains

Stains in a Cigarette Smoker

Stains on and around dental calculus

Figure 8.

Extrinsic stains vary in their tenacity, with some bonding strongly to the dental pellicle while others are incorporated into other deposits found on the teeth such as plaque and tartar. Some examples of common extrinsic stains are shown in the images above (Figure 8).

Extrinsic stains are often quite noticeable due to their contrast with adjacent areas of a non-stained tooth. This often occurs due to actions of mastication or areas with lack of proper oral hygiene (toothbrushing).

Variations in Observed Tooth Discoloration in Aging Patients – Impact on Whitening Commercialization

Professionals and patients know that teeth generally change their shades as people age. This age-related phenomenon is important since it is a common feature of marketing positioning for consumers. In fact, the shade changes in teeth as a function of age have been extensively studied.[12-16] These color changes are even used in archeology and forensics for estimations of age of individuals.[16]

The yellowing and darkening of teeth with age is hypothesized to be associated with changes internal to the tooth, thought to be the deposition of secondary dentin as layers within the pulp chamber.

Tooth Whitening – Approaches

Approaches to tooth whitening are based on two main principles:

- Removal of extrinsic colored stained components
- Decolorization of colored (stained) components

Removal of Extrinsic Stains

Removal of extrinsic stained components can be accomplished through the use of an abrasive or through the use of chemical agents such as chelants and peroxides. Though not the primary focus of this review, we discuss it briefly here. The removal of stained components is restricted to stains on the tooth surfaces. Abrasives mechanically remove stains from the tooth surface through a polishing action.[17-21] The key to this technology is finding materials which can effectively remove stain and not cause wear damage to the teeth – particularly to exposed dentin. This is managed through established safety standards developed in the industry with the ADA and FDA for over 40 years.[22] Products with a relative dentin abrasions (RDA) score of 250 or less are considered safe for use for a lifetime by the ADA.

Other technologies to mitigate extrinsic stain are chelant technologies. These ingredients function by disrupting the connection between the stain and the tooth surface. For simplicity, tooth surface here includes the acquired pellicle.[23-25] An advantage of this technology is that because they work with chemical action, they can also reduce stains from non-brushed as well as brushed areas.

The efficacy of both abrasives and chelants are limited to surface or extrinsic stains. As a result, their effects on overall whitening of teeth are quite different. Extrinsic stains often accumulate along the margin, while intrinsic stains tend to cover the entire tooth. Extrinsic stain removal products are highly useful in maintaining tooth whiteness between dental cleanings, or after oxidative bleaching.[26] Stain prevention can be reasoned to be particularly important following oxidative bleaching since whiter teeth may visually show extrinsic staining more acutely.

Decolorization of Stains: Mechanisms of Oxidative Tooth Whitening

By far the most comprehensive and often the most effective form of tooth whitening involves decolorization of stained/colored components on and in teeth. This is primarily achieved though oxidative tooth whitening – also called bleaching. Oxidation achieves decolorization through chemical reactions with stain components.

Common organic compounds in teeth that produce yellowish color include porphyrins. Porphyrins are a class of natural biological chelators that chelate ions like iron in our body to control their levels. As it turns out, iron is also a catalyst for peroxide reactions. Because porphyrin is often associated with iron, the stains often have a catalyst with them that helps enable the peroxide bleaching process.

When peroxide encounters a stain such a porphyrin, it takes electrons from the molecules in a process called oxidation. When an electron is removed from a molecule, most often it changes its ability to filter light, rendering it colorless. However, for this process to occur, the peroxide must be right next to the stain. Hence, the peroxide must have sufficient time to travel to the stain during the treatment process. This process of traveling to the stains is called diffusion. Diffusion is driven by concentration. The higher the concentration, the faster a molecule will diffuse to areas of lower concentration. This phenomena was discovered by Adolf Fick in 1855 and commonly referred to as Fick's Law. Fick's Law governs the efficiency and efficacy of all bleaching products. Concentration and contact time are essential to achieve whitening!

Vital tooth bleaching works through oxidation reactions. What is unique about peroxide-based tooth bleaching is the ability to decolorize (whiten) the tooth internally – by reacting with chromogens within the existing tooth structure, within enamel, and at the dentin enamel interface, without oxidizing the tooth structures themselves. Depending on how the peroxide is applied (concentration, volume, etc.) diffusion occurs within the tooth and penetrates through enamel and dentin. The diagram below (Figure 9) shows peroxide penetrating the tooth during the application of peroxide.

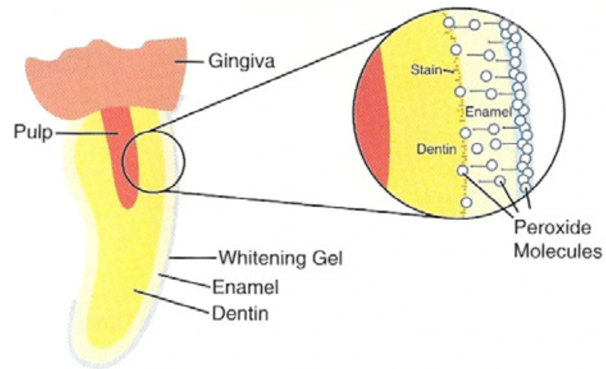


Figure 9. Peroxide diffusion into tooth from a whitening gel applied with a strip to exterior of tooth.[27]

In addition to decolorization of chromogens it other optical properties of the tooth including light scattering and fluorescence.[28]

Obviously, sources of extrinsic staining – coffee, tea, nicotine, etc., – can be oxidized directly. For intrinsic stains such as tetracycline stains to be eliminated, however, typically requires extended treatment. It should be noted that other forms of oxidation are used in tooth bleaching, such as peroxyacids or chlorite. Ultimately however, the efficacy of these other forms may be affected by the formulation and diffusivity of the agents. This may affect the level of efficacy observed, also the type of tooth whitening which can be achieved (for example focusing on certain types of stains, or stains on the exterior of the teeth). The agent with the longest-term proven record of safety and efficacy is peroxide-based whitening.

Design Principles for Oxidative Tooth Whitening – Factors Affecting Efficacy

Now that we have reviewed how and why teeth are colored and the mechanisms whereby these chromogens can be removed or decolorized, we are prepared to consider how innovators design oxidative, especially peroxide-based tooth whiteners. The design chemistry of effective formulations for tooth bleaching depends on many factors, including those listed here:

- Ingredients used in Oxidative Whitening
- Concentration of Ingredients Used in Oxidative Whitening
- Dose of Ingredients Used in Tooth Whitening
- Duration of Treatment – Retention of Ingredient (contact time)

Ingredients used in Oxidative Whitening

Hydrogen peroxide: Hydrogen peroxide is the most common ingredient used for oxidative tooth whitening. A PubMed search of hydrogen peroxide and tooth whitening reveals over 2000 peer-reviewed citations. Hydrogen peroxide is used in numerous whitening applications including in-office based whitening systems, toothpastes and gels, strip delivery systems, and in some paint on tooth whitening systems. Its chemical structure is shown below (Figure 10).

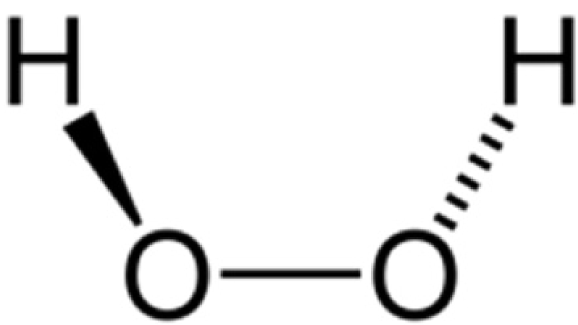


Figure 10. Hydrogen Peroxide - H^2O^2

As described earlier, oxidation is primarily directed at the reactivity with organic stain components within the teeth. It is possible that this occurs due to the presence of catalytic levels of trace metals within the teeth (e.g., iron), which can promote formation of radical intermediates, a highly active form for oxidation.

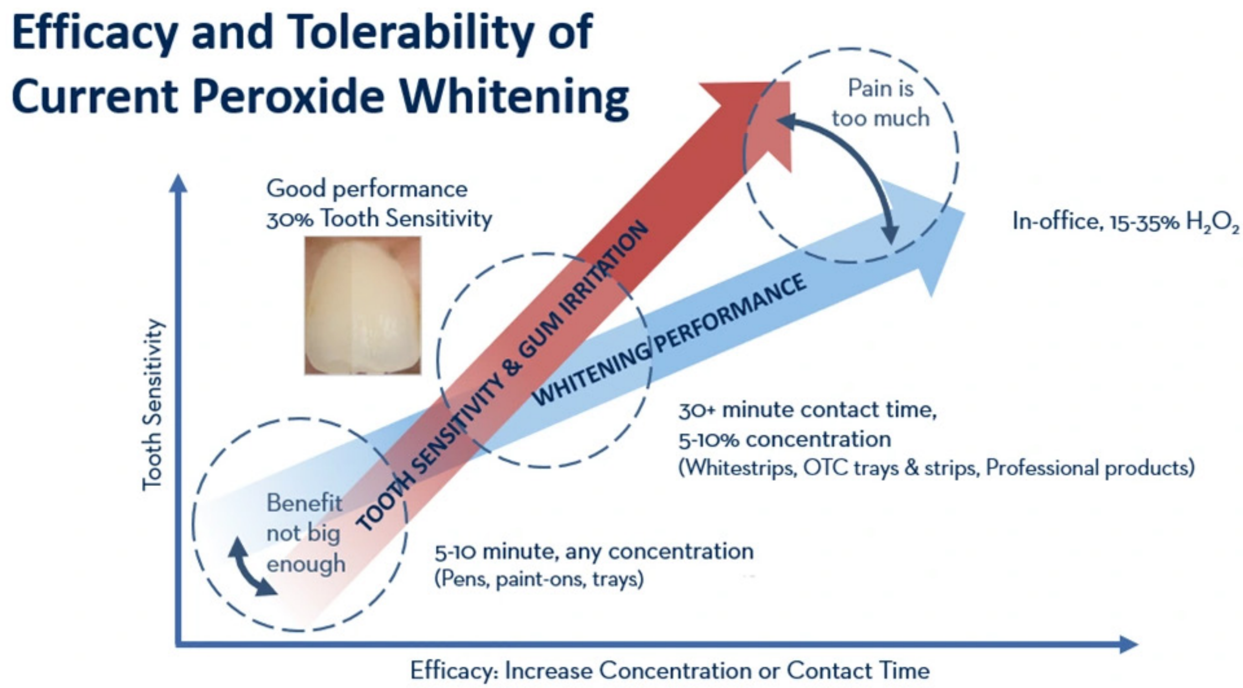
Concentration of Ingredients Used in Oxidative Whitening

There are a wide range of concentrations of applied bleaching ingredients in the dental field. Hydrogen peroxide concentration ranges from up to 35% (in-office applications with rubber dams) to lesser amounts in take home and OTC preparations. Originally, the dentist-applied tray systems were limited to concentrations of carbamide peroxide of 10% or so (about 3.3% peroxide) because of soft tissue tolerability, although today various kits used at home have concentrations up to 35% carbamide peroxide – around 11.7% as hydrogen peroxide and up to 14% hydrogen peroxide in strip applications where the total dose of whitening chemistry is highly controlled.

High concentrations of bleach tend to produce more robust whitening in shorter time – however improved whitening speed is accompanied by side effects of sensitivity and soft tissue irritation. The relation of efficacy with side effects has been summarized by Kugel et al.30 as a tradeoff between performance, in particular the rate of whitening with the development of side effects of hypersensitivity.

Dose of Ingredients Used in Tooth Whitening

In 2000, Procter and Gamble created a step change in 'at home' whitening with their development of strip-based peroxide tooth whiteners.31 Consumers could achieve safe, significant whitening at home for a lower cost than professionally administered trays. The reason for the success of this innovation was related primarily to controlling of the dose of applied peroxide. The dose of applied bleach is the total quantity of the ingredient being used. It is described by the concentration of the bleach multiplied by the mass of the delivery vehicle used. The innovation of strips holding the finite dose of bleaching gel allowed concentrations of peroxide to be used in strips of over 10% in some applications without side effects of soft tissue irritation. By controlling the total dose of peroxide, strips use higher concentrations of peroxide due to this feature of dose control. By controlling dose and maintaining a low total dose per unit area, the



higher concentrations do not lead to excessive tissue irritation as the amount delivered per unit area is well within the ability of the soft tissue to rapidly decompose the peroxide into oxygen and water. While the efficacy is largely driven by concentration, soft tissue tolerability is driven by the amount of peroxide applied per unit area. For example, a 12% composition applied at half the thickness of a 6% peroxide composition applies the same amount of peroxide per unit area even though the concentration is 2X. In this example, the 12% peroxide composition will whiten faster with the same soft tissue tolerability profile.

Duration of Treatment – Retention of Ingredient (contact time)

Earlier, the concept of diffusion was described as being important for topically applied oxidative tooth whiteners. In order for diffusion to do its work – peroxide must be retained at the tooth surface. This is because diffusion requires a concentration gradient to be effective. Maintenance of this gradient is what retention is all about. The ability of each product to maintain peroxide concentration on the tooth surface varies significantly and is strongly affected by the delivery vehicle employed. In some cases, such as in office higher concentration systems, retention is controlled by the dental professional. In the case of take-home trays, retention is maintained by placing the bleach in a well within the tray and relying on the consumer to put the correct quantity of agent inside. In strip applications, the adhesive strip is what ensures retention on the tooth surface.

Overall, concentration, dose and retention are linked in predicting the effectiveness of tooth whitening systems.

Design Principles for Oxidative Tooth Whitening: Factors Affecting Soft Tissue Tolerability

As mentioned, hydrogen peroxide (along with carbamide peroxide which produces hydrogen peroxide) is the most used oxidative tooth whitener. One of the reasons for this is the excellent patient tolerability for the use of this ingredient. After all, oxidation from any source can affect human tissues in numerous negative ways.[32-35] We are all familiar with the use of nutritional supplements “antioxidants” to help fight damage caused by oxidative processes in respiration.[36-37] So we come to the question: why is hydrogen peroxide safe for the soft tissues? The surprising answer is that hydrogen peroxide is created naturally by the human body’s own immune systems as part of our protection against pathogens.

In the human body, immune system cells such as macrophages create hydrogen peroxide to help kill pathogens such as bacteria and viruses.

If the body produces too much peroxide, Mother Nature has found a fascinating manner to deal with this – enzymes, for example catalase.[38]

Catalase converts unused hydrogen peroxide into water and oxygen. The production of and elimination of hydrogen peroxide in our bodies is a normal function of our immune system. In fact, protection against too much peroxide reactivity is a priority for our health. We can see catalase in action when we use peroxides in wound cleaning; it is the catalase in our blood plasma which causes oxygen generation and foaming when it is applied at the sites of cuts and scrapes. Likewise, it is catalase that can protect the soft tissues from damage when we are using tooth whiteners containing hydrogen peroxide. However, even though catalase is ubiquitously expressed in our body, the local quantities are naturally finite, particularly on our soft tissues.

Design principles for the management of peroxide tolerability to soft tissues include formulation features including pH and control of quantity of hydrogen peroxide on the tissues of the gingival during bleaching procedures, which is a function of applied concentration and dose to tissues. For conventional whitening gels, delivery of ~2.0 mg/cm,[2] enables concentrations as high as 15% to be used provided that the applied layer is thin and consistent.

Design Principles for Oxidative Tooth Whitening: Factors Affecting Dentinal Hypersensitivity

Transient dental hypersensitivity is a common side effect of topical bleaching.[39] Tooth sensitivity can be a significant barrier to full utilization of vital tooth bleaching by many patients.[40-42] It is important to understand that the etiology of tooth bleaching sensitivity is an entirely separate mechanism from dentinal hypersensitivity via thermal/tactile stimuli.

The etiology for the development dentinal hypersensitivity has been extensively studied. The prevalence of sensitivity with bleaching depends on a variety of factors, however concentration of bleaching is often associated with hypersensitivity complaints, as highlighted earlier. While still not completely understood, a few aspects are clear. First, the source of the increased hypersensitivity is clearly in the pulp, as this is where the nerves are located within the teeth. Hypersensitivity is commonly observed in patients without exposed dentin; hence the bleaching does not have to expose dentinal tubules to produce the effects. In animal studies, application of peroxide solutions to the teeth produced inflammatory responses in the pulp of treated animals.[43-46] This was confirmed in human studies with bleaching of teeth in adolescents scheduled for orthodontic extraction.[46-51]

The picture that emerges is that bleaching treatments produce minor inflammation of pulp, which in turn elevates the response of pulp nerves. The inflammation could be caused by the over diffusion of peroxide into the pulp itself or it has been proposed that it may be accentuated by dehydration effects which occur from anhydrous thickening agents in the gel that deliver the bleach. Even though these compositions are hydrophilic, they in fact pull water from and dehydrate the teeth.

With this increased inflammation the nerves may become more responsive to external stimuli, including temperature changes. The response to this minor inflammation includes expression of increased catalase in the pulp which can act to degrade further influx of peroxide in the interior of the tooth. This mechanism explains multiple clinical observations including: elevated hypersensitivity during application of the bleach; hypersensitivity directly following application of the bleach; development of resolution of hypersensitivity during chronic bleaching procedures; and lastly, the resolution of hypersensitivity following bleaching.

While tooth whitening with peroxidative methods has a good record of safety, researchers continue to innovate with treatments which are designed to reduce side effects of dentinal hypersensitivity. There is no contraindication for treating dentinal hypersensitivity via a product whose mechanism of action is tubule occlusion, and it does not impact efficacy as the peroxide is able to diffuse to the chromogen. In fact, using a product that occludes tubules or contains potassium salts may reduce the sensitivity associated with hydrodynamic pull on pulpal fluid while the pulp is inflamed.[61]

Design Principles for Oxidative Tooth Whitening: Factors Affecting Safety to Hard Tissues and Restorations

Following the development and publication of the nightguard vital bleaching technique, an explosion of research focused on the safety of the oxidizing agents from various products to tooth enamel, dentin and restorative materials.[62-67] This research has established that tooth bleaching is typically safe for hard tissues and restorative materials, particularly in systems developed by reputable manufacturers. Four aspects of hard tissue safety warrant continued follow up.

First, professionals must realize that bleaching does not provide intrinsic whitening to restorative materials such as tooth crowns or veneers. Although bleaching may certainly whiten stains on crowns/veneers/restorations it will not change the shade of the crown material itself. Patients should be bleached before restorative work is undertaken and the color should be matched to the bleached teeth. It is important that dental professionals counsel patients about this if they are considering OTC oxidative whitening.[68-71]

Second, when bleaching is performed prior to restorative work – the teeth should be allowed to equilibrate for a time period (several weeks to a month) prior to placing restorations. Research has shown that restorative adhesion is marginally reduced immediately after tooth bleaching, and a 2-week period of recovery can compensate for this phenomenon.[72-75]

Third, professionals should follow closely patient response to bleaching to assess effects of dental hypersensitivity on the patient's hygiene practices. Patients may benefit for short periods from utilization of hygiene products which may reduce sensitivity during and following bleaching procedures.[75-78]

Lastly, professionals should follow up patients to assess color stability following their bleaching treatments. Numerous products are available which can be used to touch up teeth which may not retain color stability permitting local treatment. For consumers who exhibit habits (e.g., smoking) which may stain teeth following whitening – it is recommended that they maintain their tooth color with whitening toothpastes or rinses, a number of which provide excellent efficacy for the prevention of the development of tooth stains.[79-84]

Design Principles for Oxidative Tooth Whitening: The Addition of Light

The influence of light in enhancing oxidation processes has been well known for centuries – the process is called photooxidation. This process is responsible for the degradation of polymers in industrial applications (e.g., automobile dashboards) as well as fading of dyes in various plastic products.

Some authors have reported improvements in whitening efficiency with the use of various light activation systems.[85] However, it is fair to say that the performance of light activated bleaching has been controversial. Some light activated in-office bleaching systems have been criticized for patient tolerability and efficacy in improving bleaching performance.[86-96] It is likely that some of the original light activated systems were not fine-tuned for the proper intensity or wavelengths to activate bleaching and may have relied on simple heating to enhance bleaching. Oxidation reactions are quite sensitive to temperature – although heat activation may negatively influence the response of dental pulps.[97-99]

Overall, light sources can act to enhance oxidative processes; this is the principle of photooxidation. Certainly, technological advancements in the field of marketed light activated systems have become more fine-tuned in choice of wavelength and intensity. In addition, most of the light activated systems have been employed in office settings where short-term high-efficacy bleaching is carried out at ultra-high concentrations of peroxide. Under these conditions it may be difficult to readily observe any improvements in whitening performance. It is possible that the acceleration of whitening with bleach is better suited to application in lower-concentration bleaching settings, including recently introduced light activated home tooth bleaching.

In photo-oxidation (light enhanced) molecules absorb light energy, once a stain molecule absorbs a sufficient amount of energy its electrons reconfigure and it becomes easier for the peroxide to remove them from the molecule, rendering it colorless. For light to be effective peroxide has to be in close proximity to the stain molecule. For this reason, it is best to optimize and protect diffusion time to the chromogen stain first before applying the light (i.e., apply light at the end of the treatment, after diffusion).

Design Principles for Oxidative Tooth Whitening – Delivery Vehicles – Types of Products

The goal of manufacturers of whitening products is to design bleaching systems to maximize whitening efficacy, reduce time required to achieve desired efficacy, minimize cost and time required to treat patients (for office systems), reduce cost and time to achieve whitening in take home applications for patients/consumers, and minimize side effects including soft tissue irritation and dentinal hypersensitivity. The delivery vehicle for the bleaching agent has an important effect on how these goals are simultaneously met – and must account for the kinetics and physics of reactivity in the mouth. Various delivery systems are briefly discussed including:

- In Office Treatment
- Mouthguard/Tray-Based Bleaching
- Strip Based Systems
- Paint on Whitening - Pens & Applicators
- Emulsions
- Toothpaste, Mouthrinse & Tooth Gels

In Office Treatment

Liquid dams/mouth shields: Liquid dams are used in practice-based bleaching procedures which apply high concentrations of hydrogen peroxide directly. Images of patient preparation of peroxide whitening applied via this procedure are shown below.

In contemporary systems these may be adjunctively used with light applications. The goal is to provide patient-satisfactory whitening in a single rapidly applied office procedure. In these office-applied systems, concentrations of peroxide as high as 35% may be used. Great care must be taken to protect office personnel and the patient during high concentration applications including eye shields, face coverings, etc. Due to the rapid nature of bleaching, dentinal hypersensitivity is commonly observed. Whitening efficacy of these high-concentration, short-duration treatments is quite good.

Mouthguard/Tray-Based Bleaching

A second delivery system common for oxidative whitening includes office prescribed/fabricated (but at home applied) tray/mouthguard-based systems. Newer forms of these tray-based options are available over-the-counter today as well. These bleaching systems historically have often used carbamide peroxide as the oxidation source, though hydrogen peroxide is used in some recent forms. In the original nightguard system the dentist would prepare fabricated trays to hold the bleaching agent and the patient would apply the bleach at home.[1] Today, form fitting trays and boil and bite are marketed which enable the dentist to skip fabrication.

The levels of efficacy and tolerability are dependent on the concentration of applied peroxide, although good levels of tooth whitening can be obtained with these systems when used for the appropriate time periods.

Like other forms of treatments, these often invoke significant levels of transient dentinal hypersensitivity. The quantity of gel used in mouth guards is dictated by the fit of the mouthguard – often there is oozing around the edges of the guard while bleaching, which can create localized inflammation of gingival in some cases.[100-106]

Strip Based Systems

Crest® Whitestrips™ and Generic Strips: The Whitestrips™ form of bleaching eliminates the need for various trays and uses a flexible strip to apply a finite dose of bleach.[31] The strip form for whitening is shown below (Figure 17) from the introductory material associated with the introduction of the innovation.

The original system had a hydrogen peroxide gel applied on a flexible strip which was flexible to apply a form fit on the teeth. Efficacy and tolerability were good owing the control of dose and concentration. Numerous generic forms of whitening strips have been introduced in recent years, though the efficacy of the branded product has the most evidence. Whitening strips were also shown to provide efficacy in long-term bleaching of hard-to-treat tetracycline stains.[106-115] Clinical effects are shown below (Figure 18).

Paint on Whitening - Pens & Applicators

An additional form of oxidative tooth whitening has been attempted with the use of paint on systems. Typically, these use applicators such as small brushes or pen-like applicators to put thin films of whitening ingredients on the teeth. Peroxides are commonly included in contemporary applications. Paint on systems have an advantage of convenience and ease of application on the go. They are positioned as being easier to use than strips or tray systems, but they have a checkered history in tooth whitening. An obvious limitation of paint

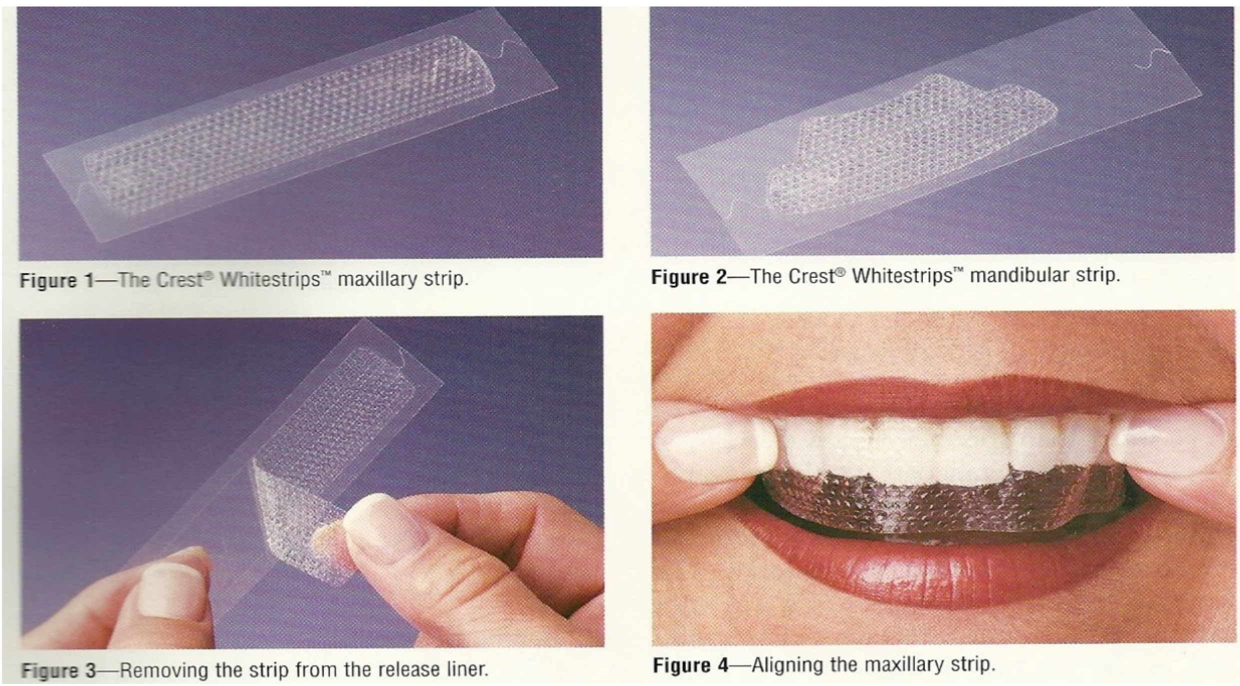


Figure 17. Original strip form of bleaching from Crest Whitestrips[27]

Pre-treatment

Immediate post-treatment

Figure 18.

Image Source: Dr. Gerald Kugel, DMD, MS, PhD on systems is the lack of a route to permit sustained application and retention for contact time on the teeth, and many forms run the risk of being washed out prior to providing meaningful efficacy. Some forms have attempted to compensate for this by directing use at night – where the gel might be retained to produce some levels of whitening.[116-127]

Emulsions

An emulsion is the combination of a two-phase system where one phase is insoluble to the other. In the case of Whitening Emulsions™, a hydrophobic carrier (water repelling) contains microdroplets of peroxide which are hydrophilic (water attracting). The Procter & Gamble Company has developed Whitening Emulsions™ as a breakthrough innovation to the market. While the professional applied and prescribed systems represent variations on concepts associated with the design of effective tooth whiteners, this new technology is a new delivery system leave-on whitening technology using chemistry to provide the hydrogen peroxide with its own protective barrier.

This new on the go, leave-on technology has recently been introduced, which uses a novel emulsion-based vehicle to facilitate peroxide delivery while minimizing dehydration. In this emulsion, a petrolatum base which is hydrophobic suspends microdroplets of the hydrogen peroxide until they come in contact with the tooth surface. The tooth surface is hydrophilic, as are the peroxide microdroplets (~25 microns), therefore the peroxide is drawn out of suspension to the tooth surface where it creates a diffusion layer to begin the diffusion process through the enamel. The petrolatum base protects the microdroplets and renders them 100% available; there is no inhibition of peroxide droplets to diffuse, like in prior delivery systems. In addition, the hydrophobic carrier ensures the peroxide isn't washed away via saliva allowing additional contact time.

Another distinction from traditional peroxide gels is that because there are no thickening or adhesive agents which can chemically bond to the peroxide, the peroxide delivery in an emulsion is uninhibited and available toward the hydrophilic surface.

Toothpaste, Mouthrinse & Tooth Gels

A variety of dentifrice and mouthrinse products are commercially sold containing ingredients that are associated with oxidative tooth whitening. These products can contain various sources of oxidation, though 1-3% hydrogen peroxide is common. Hydrogen peroxide gels are also sold as an ancillary to be added to regular toothpastes to promote whitening. Clinical data is available for a number of these products so some levels of tooth whitening are possible.128-133 It should be realized that these products are limited in many ways compared to other forms of oxidative tooth whitening. First and foremost, the duration of treatment in brushing and rinsing forms is obviously quite low. In addition, the concentration of ingredient which can be safely used in toothbrushing is limited as well. Though efficacy claims in the marketplace are dramatic, toothpastes are typically not the most effective routes to true intrinsic whitening. These forms can be highly valuable in maintaining tooth whiteness through the control of stain formation on the teeth between prophylaxis or following tooth bleaching with more effective forms.

Key Considerations for the Evaluation of Clinical Studies for the General Practitioner

Don't be confused by shade claims, look for technical color change.

- "5 shades whiter in three days".
- "95 % reduction in tooth stain".
- "Removes 10 years of yellow stains in two weeks".

The claims for tooth whiteners create a challenge for the dental professional – how to interpret the science and how to counsel their patients. A comprehensive review of methods used in the clinical evaluation of whitening products is beyond the scope of this CE review – however some general principles can be outlined for the professional to assist in recommendations for their patients.

Why is it hard to know what the efficacy of a whitening product truly is? The answer is that clinical studies on whitening are relatively easy to do – patient selection and choice of index can create a seemingly remarkable level of tooth whitening for even an ordinary product with minimal efficacy. In addition, there are no established guidelines for indices used in tooth whitening clinical evaluations.

A few principles can be helpful here:

- Studies that use stain indices (e.g., Lobene) are often used for efficacy studies of toothpastes and rinses. The high % of stain reductions observed in studies is not indicative of any degree of intrinsic whitening. The % are often obtained by careful patient selection. To be clear, pastes and rinses are effective in reducing surface stains and they are extremely useful in preventing tooth stains from recurring.

- Use of shade guides can be misleading. The shade guide index is not linear in tooth color and clinician application of shade guides can be problematic at best. Seek research that employs objective digital measurements.

- The clinical population where efficacy is seen can be very important in determining observed efficacy. Hard-to-treat populations including those with stains from tetracycline, cigarette smoking, or demonstration of whitening efficacy in a population post-prophylaxis, can be relied on to reinforce the efficacy claims of products.

Summary

The growing array of tooth whitening product options – with varying efficacy, safety, cost, and differences in application methods and settings – elicit patient queries. Understanding tooth color etiology, the relative strengths and limitations of treatment options, and patient goals is important for effective guidance. Whitening can sometimes be achieved solely using OTC products with optimal abrasivity and/or chelant technology, such as specially-formulated toothpastes and rinses to aid in the removal and prevention of surface level extrinsic stains. Intrinsic tooth discoloration, however, requires oxidative technologies (e.g., peroxides, chlorites, peroxy acids) to achieve whitening via chemical reactions with stain components that decolorize teeth internally. Peroxide has the longest record of proven safety and efficacy; hydrogen peroxide is the most commonly used whitening agent today.

The efficacy and tolerability of bleaching products is contingent upon the agent's concentration, dose, and contact time. Retention is imperative for effectiveness and varies by delivery system. Higher levels of bleach concentration and dose produce greater whitening more rapidly, but this must be balanced with the potential for teeth sensitivity and soft tissue irritation. For example, the innovation of at-home adhesive whitening strips with 'controlled dose' applied bleach at higher concentration allowed for optimal results while maximizing tolerability.

The specific bleaching agent's delivery vehicle also impacts the intraoral reactivity and results. In-office treatments utilize short-term, high-concentration peroxide for maximum whitening, but with frequent sensitivity. Prescribed/OTC home use mouthguard/tray-based systems typically produce good results, they are dependent on fit and bleach concentration may similarly bring adverse effects. Professionally-applied Whitening Emulsions™ systems are a new two-phase technology, leave-on treatment formulated with a hydrophobic carrier to stop saliva from washing out the peroxide. Strip-based systems for home use have shown favorable tolerability with proven whitening efficacy. Paint-on systems and whitening pens are convenient, though they may be hindered by a lack of sustained retention for meaningful efficacy. Whitening toothpastes containing low levels of hydrogen peroxide can generate some benefit, but are again limited by the allowable concentration and contact time.

When evaluating clinical research claims for whitening products/treatments, keep in mind that some are related solely to extrinsic stain removal. Additionally, studies utilizing more objective measurements (e.g., digital imaging versus shade guides) are more likely to represent accurate whitening results.

Course Test Preview

To receive Continuing Education credit for this course, you must complete the online test. Please go to: www.dentalcare.com/en-us/professional-education/ce-courses/ce502/start-test

1. **When we see a red apple in sunlight which of the following has occurred:**
   A. Red wavelengths of incident light have been absorbed by the apple
   B. Ultraviolet light as been reflected from the apple
   C. Multispectral wavelengths of light have been absorbed the the apple and red light has been reflected back
   D. Red light wavelengths are absorbed by the apple and not reflected back

2. **Additional optical phenomena factors to consider in observed tooth color include all of the following EXCEPT one, which is the exception?**
   A. Metamerism
   B. Opalescence
   C. Fluorescence
   D. Translucence
   E. Simultaneous contrast

3. **Tooth color is influenced by the background against which it is observed (e.g., color of gingiva and surrounding skin). This is an example of:**
   A. Metamerism
   B. Translucency
   C. Simultaneous Contrast
   D. Specular reflectance

4. **Structural features affecting natural tooth color include all of the following EXCEPT one, which is the exception?**
   A. Thickness
   B. Translucency,
   C. Dentin Color
   D. Genetic factors
   E. Gingival color

5. **Which is an example of a chromagen of internal origin in tooth stain?**
   A. Cigarette smoke
   B. Tetracycline
   C. Coffee and tea stain
   D. Chlorhexidine

6. **Removal of extrinsic tooth stain can be accomplished with all the the methods below EXCEPT one, which is the exception?**
   A. Toothpaste abrasives
   B. Chelants and surfactants
   C. Oxidative compounds
   D. Internal bleaching

7. **Diffusion is driven by?**
   A. The dilution of peroxides in the mouth
   B. Change in the color of the tooth
   C. Concentration
   D. Scattering of light from the tooth

8. Peroxide based tooth bleaching has the ability to whiten the tooth internally by?
A. Reacting with chromogens within the existing tooth structure
B. Reaching with chromogens at the dentin enamel interface
C. Oxidizing the tooth structure itself
D. Both A & B

9. Tetracycline stained teeth can be whitened by?
A. Abrasive toothpastes
B. Chelant mouthwashes
C. Hydrogen peroxide treatments
D. Light only therapy

10. Which ingredient(s) produce hydrogen peroxide for tooth whitening?
A. Silica
B. Hexametaphosphate
C. Chlorite
D. Carbamide Peroxide

11. In office 35% carbamide peroxide will provide approximately what % of hydrogen peroxide?
A. Around 11.7%
B. 35%
C. 17.5%
D. 3%

12. In order for diffusion to do its work peroxide must be?
A. A high enough concentration of peroxide
B. The correct pH for peroxide treatment
C. Retained at the tooth
D. High enough dose of peroxide

13. Factors linked to predicting the effectiveness of tooth whitening systems include all of the following EXCEPT one, which is the exception?
A. Dose
B. Retention
C. Concentration
D. Temperature

14. An enzyme system protects patients from damaging effects of peroxides and ensures toxicological safety of peroxides. This enzyme is?
A. Amylase
B. Lypase
C. Catalase
D. Trypsin

15. The most common side effect of oxidative whitening is?
A. Sore gums
B. Cavities
C. Failed restorations
D. Transient dentinal hypersensitivity

16. Bleaching can whiten the internal color of tooth crowns.
A. True
B. False

17. When should bleaching be carried out?
A. Before restorative work
B. After restorative work
C. During Healing
D. Patients should not bleach if they are getting tooth restorations

18. Light can accelerate the whitening reactivity of?
A. Chelants
B. Abrasives
C. Surfactants
D. Oxidizing agents

19. Toothpastes are typically capable of what?
A. Removing extrinsic tooth stain
B. Prevention of new stain formation
C. Intrinsic whitening of teeth
D. A and B

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Additional Resources

- No Additional Resources Available

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