Tooth Whitening: The Effects of Tooth Whitening With Peroxide Agents On The Human Dental Enamel

Aim: To provide the dental care professional with an overview of the types of tooth discolouration, including intrinsic and extrinsic staining and to present a literature review which examines the effects of tooth whitening on the human dental enamel.

Objectives: On completion of this verifiable CPD article the participant will be able to demonstrate, through completion of a questionnaire, the ability to:

- Identify the causes of tooth colour variation
- Identify the differences in colour between canines and the rest of the dentition, and the differences in colour between the primary and secondary dentition
- Identify the difference between intrinsic and extrinsic staining
- Know some causes of intrinsic and extrinsic tooth discolouration
- Understand the potential effects of tooth whitening with peroxide agents on the human dental enamel

Introduction

Tooth Whitening is an effective way of making teeth appear whiter. In modern-day society, white teeth are seen as more attractive, therefore, improving first impressions, boost self-confidence and improving professional and dating life (Patterson, 2021).

Social media platforms such as Instagram and Facebook create a picture-perfect culture and cosmetic tooth whitening procedures are becoming increasingly popular among young people and adults (Fleming, 2019). Bleaching products contain peroxide, hydrogen peroxide (HP) or carbamide peroxide (CP). These products remove staining from teeth and can cause teeth to become even lighter than their natural shade (Davis, 2020).

However, many people are unaware of the potential risks and damage tooth whitening can have on dental enamel despite the increasing demands for this procedure (Carey, 2014).

This CPD article is part of a literature review which examines 'The Effects Of Tooth Whitening With Peroxide Agents On The Human Dental Enamel'. This article will discuss tooth discolouration, intrinsic and extrinsic staining and will examine the properties of professional tooth whitening products. A brief summary of the literature review will be presented.

Tooth Discolouration

Teeth are composed of many colours, with natural graduation of colour in an individual tooth from the gingival margin to the incisal edge (Alammari & Vargas, 2014). The gingival margin often has a darker appearance due to the close approximation of the dentine below the enamel (Modi et al., 2010). The colour variation is also affected by the thickness of the enamel, which is notably greater at the incisal or occlusal edge, and translucency of the enamel and dentine as well as the reflectance of different colours and varying degrees of calcification of the overlying enamel (Lacruz et al., 2017).

In the majority of people, canine teeth are darker than central and lateral incisors and younger people characteristically have lighter teeth, especially in the primary dentition (Rayner et al., 2015). Teeth darken in colour as a physiological age change caused by numerous factors such as the incorporation of extrinsic stains, the laying down of secondary dentine and the gradual wear of enamel allowing a greater influence on the colour of the underlying dentine (Haralur, 2015).

Image 1: Mixed dentition showing the colour difference between the primary and secondary dentition

The normal colour of teeth is determined by the blue, green and pink tints of enamel and is reinforced by the yellow through to brown shades of dentine underneath (Sailaja, 2019). In addition, the appearance of teeth depends on their reflective properties of light and this is influenced by the enamel, dentine and pulp (Goldberg et al., 2011). Any alterations to these tooth structures during formation, development and post-eruption can cause a change in the light transmission properties of the teeth and discolouration (Kumar et al., 2012).

A pigment is defined as a coloured substance composed of a colour bearing group (a chromophore) and other molecules (Marzec, 2014). A dye is a pigment with reactive hydroxyl or amine groups that can attach to the organic matter (Benkhaya et al., 2020). Common dyes originate from red wine, curry, coffee, and tea. It is these complex molecules, dyes and pigments that stain the interprismatic substance between the enamel (Kwon et al., 2012). Different colours of stain can be produced when metal compounds interact with dye to form larger compounds. The most common metals involved often involve iron and copper (Bersezio et al., 2018).

Table 1 displays a table showing the colours produced by various types of tooth discolouration and Table 2 displays the types of stains, colour, source, appearance, and common sites.

The most common classification based on the location of discolouration was given by (Dyan et al 1983) and (Hayes et al 1989). According to these authors, tooth whitening was classified into either extrinsic or intrinsic staining.

Table 1: Colours Produced By Various Causes Of Tooth Discolouration

(M. A. M. Sulieman, 2008)

Types of Discolouration	Colour Produced
Extrinsic (direct stains)	Brown to black
Tea, coffee, and other foods	Yellow/brown to black
Cigarettes/cigars	Yellow/brown
Plaque/poor oral hygiene	
Extrinsic (Indirect stains)	Black and brown
Polyvalent metal salts and cationic antiseptics (e.g., chlorohexidine)	
Intrinsic	
Metabolic causes	
(e.g. congenital erythropoietic porphyria)	Purple/ brown
Inherited causes	Banding appearance
(e.g. amelo/dentinogenesis)	
Iatrogenic causes	
Tetracycline	Classically yellow, brown, blue, black or grey
Fluorosis	White, yellow, grey or black
Traumatic causes	
Enamel hypoplasia	Grey black
Pulpal haemorrhage products	Pink spot
Root resorption	Yellow
Ageing causes	Yellow
I**nternalised**	
Caries	Orange to brown

Restorations	Brown, grey, black

Table 2: Types Of Stains, Source, Appearance And Common Sites

(Prathap et al., 2013)

Types of stains	Source and predisposing factors	Appearance on the Tooth surface	Common sites
Brown	The colour is due to tannin. Intake of coffee and tea. Causes-insufficient brushing. Inadequate cleansing action of dentifrice. Chromogenic bacteria.	Thin, translucent, acquired bacteria free pigment pellicle.	(1) Buccal surface of maxillary molars. (2) Lingual surface of mandibular incisors
Black	1) Coal tar combustion products due to smoking. (2) Penetration of pits and fissures, enamel and dentine by tobacco juices. Iron containing oral solutions. Exposure to iron, manganese, silver.	These are tenacious dark brown or black with brown discolouration.	1)Involves all the teeth. (2) Common on pits and fissures.
Black	More common in woman, may occur in excellent oral hygiene. High tendency for recurrence: (1) Associated with low incidence of caries in children. (2) Chromogenic bacteria-e.g. Gram positive rods-Actimomyces species Bacteroides melaninogenicus. Iron containing oral solutions.	This is a thin black line, firmly attached on the tooth surface.	(1) Near the gingival the margin of facial and lingual surface of a tooth. (2) Diffuse patch on the proximal surface may be seen.

Orange	Chromogenic bacteria Serratia Marcescens, Flavobacterium Lutescens. Exposure to chromic acid fumes in factory workers.		Both facial and lingual surface of the anterior teeth.
Green	Children are frequently affected due to inadequate daily plaque removal, chromogenic bacterial deposits or decomposed haemoglobin. (i)Fluorescent bacteria- Penicillium. (ii)Fungi-Aspergillus. (iii) Associated with children with T. B. or cervical lymph node. 3) Copper salts in mouth rinse (Manuel et al., 2010). 4) Exposure to copper and nickel in the environment in factory workers (Manuel et al., 2010).	These are green or greenish yellow stains of considerable thickness. This type of stain is considered as stained remnants of enamel cuticles.	Facial surface of maxillary anterior teeth.
Metallic	This type of stain is caused by metals and metallic salts. Metals are penetrated into tooth substances and produces permanent decolonization, or they bind with pellicle and produce surface stain. Source of metals: (I) Introduction of metals into oral cavity. (II) Metal containing dust inhalation by worker. (III) Oral administration of drugs.	Some metals that cause stains: Copper dust- Green stain Iron dust-Brown stain Magnesium-Black stain Silver- Black stain Iodine- Black stain Nickel- Green stain. Metal penetrating into tooth	Generalised appearance on all the teeth

		substance causes permanent discolouration where that bind with pellicle causes surface stain	
Yellowish brown	Chlorhexidine has an affinity for sulphate and acidic groups such as those found in the pellicle, plaque constituents, carious lesion and bacterial cell walls. It is retained into the oral cavity and stained oral tissues.	Yellowish brown to brownish. The stains are not permanent in nature. It can be removed with proper brushing with dentifrice.	i)Cervical and interproximal area of the teeth. (ii) Plaque and other restorations. (iii) Dorsum of tongue.
Yellow	Essential oil and phenolic mouth rinse.		
Golden brown	Use of stannous fluoride.		
Violet to black	Presence of potassium permanganate in the mouth rinses.		
Red-Black	Seen in adults and children in the Eastern Hemisphere, where betel leaves and nuts are used as stimulants.	Thick, hard, dark brown or black extrinsic stain left on the teeth after chewing the leaves of the betel palm.	Facial, lingual and occlusal surfaces of both anterior and posterior teeth.

Extrinsic stains

Image 2: example of extrinsic staining

Extrinsic tooth stains are external, meaning they affect the outermost layer of the tooth, or the enamel (Hosdurga, 2013). They usually result from the accumulation of chromogenic substances on the tooth surface (Prathap & Prathap, 2018). These stains usually cause discolouration as a result of ingestion of chromogenic food and drinks, tobacco use and poor oral hygiene (Patel, 2020).

Extrinsic staining is usually localised in the pellicle and is either formed by the retention of exogenous chromophores in the pellicle, also known as the 'Maillard reaction' which starts with the reaction of a reducing sugar with an amine, creating glycosylamine and includes complex chemical reactions between amines and sugars, resulting in a chemical change in their structures (Simmons et al., 2011). The chemical analysis of stains caused by chromogenic substances indicates the existence of furfurals and furfuraldehyde derivatives as a result of this reaction (Morimoto et al., 2018)

In addition, the retention of exogenous chromophores in the pellicle occurs when salivary proteins are carefully attached to the enamel via calcium bridges, forming a complex pellicle (Gibbins et al., 2014). During the early stages of staining, the chromogens interact with the pellicle via hydroxide bridges (Alqahtani, 2014).

Extrinsic staining can be relatively easily removed by proper tooth brushing with a dentifrice (Chakravarthy & Acharya, 2012). However, if these are not frequently removed, they can form a pellicle, darken and become increasingly persistent. They may then require routine prophylaxis cleaning for their removal (Sawai et al., 2015).

Intrinsic Stains

Intrinsic stains are those that affect the inner layer of the teeth, the dentine which exists below the enamel (Epple et al., 2019). Common causes include tetracycline medication, ageing, ingestion of chromogenic food and drinks, overexposure to fluoride, dental caries and tobacco usage (Fliss, 2015).

Ageing is natural and a common cause of staining (Alqahtani, 2014). Darkening of the dentine occurs due to the formation of secondary dentine which is darker than the original dentine (Mjör, 2009). The combination of thinner enamel caused by ageing and darker dentine gives the appearance of overall darker teeth (Kunin et al., 2015).

Discolouration from medication ingestion may occur before or after the tooth is fully formed (Thomas & Denny, 2014). If the teeth are exposed to tetracycline at a time of tooth mineralisation or calcification, the tetracycline will bind to calcium ions in the teeth forming tetracycline or orthophosphate, which causes a yellow to brown discolouration of the teeth (Vennila et al., 2014).

Image 3: example of intrinsic staining cause by Tetracycline

Excessive consumption of fluoride in drinking water can cause porosity of enamel which can result in metabolic alterations of enamel ameloblasts, resulting in a defective matrix and improper calcification of the teeth., known as fluorosis (Bronckers et al., 2009).

However, the majority of intrinsic stains are associated with inherited conditions such as amelogenesis and dentinogenesis imperfecta (M. Sulieman, 2005). Dental restorative materials can also release metals that can penetrate the blood and dentinal tubules, ultimately causing intrinsic stains (Rodríguez-Farre et al., 2016).

Image 4: Amelogenesis imperfecta- a congenital disorder which causes developmental alterations in the formation of enamel

Unlike extrinsic stains, intrinsic stains cannot be removed by prophylactic procedures (Li, 2017). However, tooth whitening agents can reduce the appearance of extrinsic and intrinsic stains by oxidising the chromogens (Carey, 2014).

Composition of Commercial Bleaching Agents

Modern tooth whitening agents use a mixture of active and inactive additives (Epple et al., 2019). The active ingredients include either Hydrogen Peroxide or Carbamide Peroxide compounds (Carey, 2014). The main inactive ingredients are the following:

Thickening Agents

Carboprol (carboxy polymethylene) is a common thickening agent used in whitening components (Gouveia et al., 2016). It is a high weight polyacrylic acid polymer, and its concentration is usually between 0.5% and 1.5% (Terao, 2015). This substance increases the viscosity of the bleaching material, allowing for better tray retention. It also causes a slow release of active oxygen from the hydrogen peroxide which increases the efficiency of the bleaching period up to four times (Joshi, 2016).

Carrier

Glycerin is used as a carrier to enhance the viscosity of the material and ease administration of the whitening gel (Singh Wilkhu, 2013). The dehydration and swallowing of glycerin commonly cause sore throat symptoms in patients (Kusukawa et al., 2013). Propylene glycol is also used to help maintain the moisture and aid in dissolving other ingredients (Dionisio et al., 2018).

Surfactant And Pigment Dispersant

Surfactants or pigment dispersants increase the effectiveness of whitening (Alqahtani, 2014). Surfactants allow the active peroxide agent to diffuse through the gel and tooth surface by increasing the surface wetness (Caneppele & Torres, 2011). In addition, the pigment dispersant creates a suspension for the pigments in the gel to be held (Hirsch, 2016).

Preservatives

Sodium benzoate, methyl and propylparaben enhance the stability of the gels and have the ability to prevent bacterial growth within the substance (Talanta, 2014). Interestingly, materials that contain preservatives such as sodium stannate, Cytoxan, phosphoric acids or citric acids block the breakdown of peroxide agents by releasing transitional metals such as iron, copper and magnesium (Repetto et al., 2010).

Flavourings

Flavourings are substances used to increase patient acceptance of the product by giving a different, stronger r more agreeable taste to the substance (Lertsukprasert & Locharoenrat, 2020). Peppermint, spearmint, anise, sassafras and a sweetener such as saccharine are all examples of commonly used flavourings (Calderini et al., 2016).

Additives

Some whitening gels incorporate additive into the gel to minimise side effects (Fiorillo et al., 2019).

Potassium Nitrate

Five percent of potassium nitrate functions as an anaesthetic by halting the nerve from repolarising after it has depolarized (Weaver, 2013). This therefore makes it effective at minimising sensitivity without reducing the effectiveness of the whitening results (Pierote et al., 2019).

Fluoride

Fluoride helps to remineralise enamel, therefore, gels including fluoride result in fewer demineralisation effects without altering the whitening effect of the gel (Borges et al., 2012). Fluoride ions block the dentinal tubules and decrease the sensitivity by slowing down the fluid flow in the tubules (Petersson, 2013).

Amorphous Calcium Phosphate-Casein Phosphopeptide

Some whitening gels include amorphous calcium phosphate- casein phosphopeptide (ACP-CPP) to significantly reduce sensitivity by remineralisation and enhance the whitening results (Penumatsa et al., 2015).

ACP-CCP allows for protein binding and deposition of phosphate and calcium ions in exposed dentine tubules, allowing a rapid block to sensitivity (Ensanya et al., 2016). Another benefit of the addition of this substance is that it adds a gleaming shine to the teeth (Alqahtani, 2014).

Mechanism of Tooth Whitening

Hydrogen peroxide acts as a strong oxidizing agent through the formation of unstable free radicals with unpaired electrons. The free radicals have unpaired electrons which readily react with and attack the organic pigmented molecules between the inorganic salts in tooth enamel. They do this by attacking unsaturated double bonds of chromophore particles, resulting in the disruption of the electron configuration of the molecules. The change in the double bond conjugation results in smaller, less heavy pigmented constituents, usually converting them into alcohols, ketones and terminal carboxylic acids which are expelled through the tooth surface. Ultimately this produces a lightening effect of the teeth as seen in the diagram below.

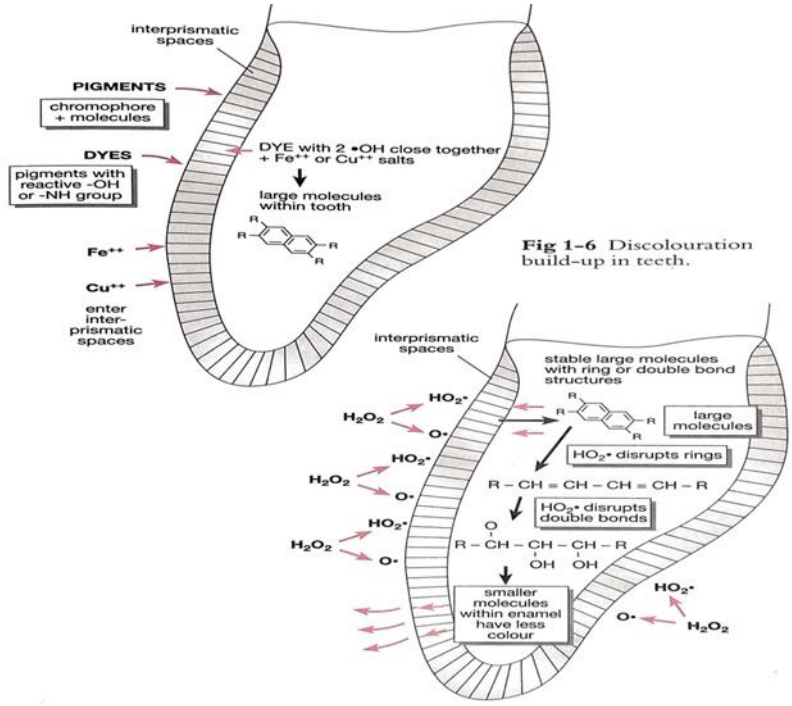


Fig 1–6 Discolouration build-up in teeth.

What Are The Effects Of Tooth Whitening With Peroxide Agents On The Human Dental Enamel?

A literature review was conducted to answer the above question. The following is a shortened version of the complete literature review.

Methodology

Three electronic databases were used to obtain relevant literature. In each electronic database, three sets of key terms associated with tooth whitening, peroxide agents and tooth enamel were used consistently. Articles were excluded based on their title and abstract. The remaining articles were included and excluded based on if the full text fit the inclusion and exclusion criteria and 23 articles were found to be eligible for the critical appraisal. The critical appraisal skills programme cohort tool was used to assess the quality of the 23 cohort studies.

Findings

Thematic analysis revealed three main themes: enamel hardness effects, enamel elastic modulus effects and enamel surface roughness effects from tooth whitening with peroxide agents.

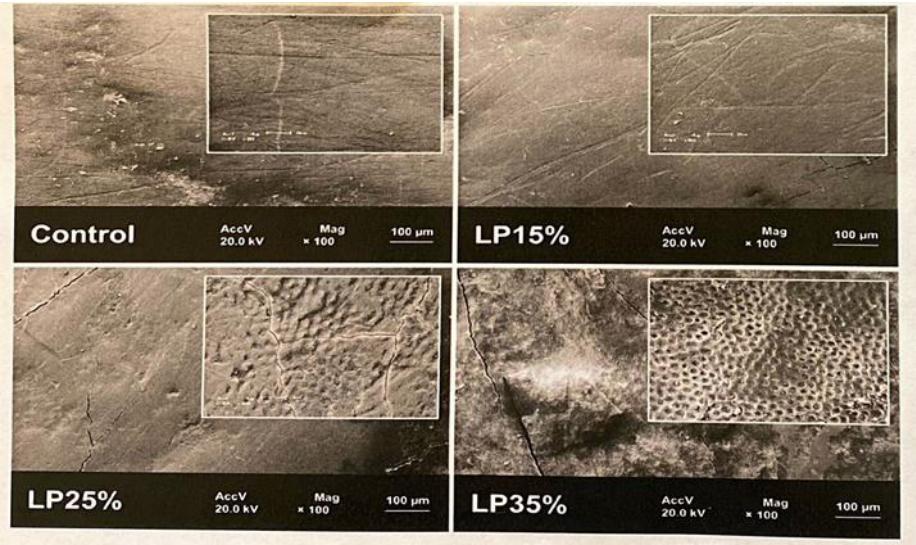
Discussion

Enamel Hardness and Elastic Modulus

The effect of the bleaching treatment on hardness and elastic modulus is controversial. Some studies show a decrease in hardness after treatment, whereas other studies did not reveal any effect. This discrepancy may be related to the exposure time to the bleaching agent, pH of the solutions and/or treatment procedure

The loss of some mechanical resistance after treatment may be due to the combined effect of demineralization and degradation of the organic matrix of the tooth or due to the dissolution of hydroxyapatite and destruction of the protein matrix by the peroxide free radicals, as evidenced by loss of fluorescence particularly at the surface enamel.

Enamel Surface Roughness



The scanning electron microscope micrograph above shows that 15% hydrogen peroxide displays a similar surface pattern when compared to a non-bleached specimen (control), whereas gels containing higher peroxide concentrations caused greater alteration in enamel surface roughness. Enamel alteration seemed greater upon the use of the most concentrated gel (35%).

Overall, all concentrations of peroxide agents have been found to have an effect on the enamel surface roughness due to enamel demineralization. However, concentrations above 15% produced higher surface roughness values.

The Impact of Saliva on the Results

Some of the minimal mechanical changes on the enamel surface after bleaching may have been attributed to the protective effects of human saliva, which provides dilution, buffering capacity, and a supply of calcium and phosphate ions for tooth remineralization. Some studies have found that the immersion of species in artificial saliva for 14 days promoted an increase in enamel microhardness, but the baseline values are not restored.

Conclusions

This literature review discovered that there is conflicting evidence from studies regarding a reduction in enamel hardness and elastic modulus following whitening treatment. However, multiple studies have shown an increase in enamel surface

roughness following tooth whitening treatment regardless of whether the peroxide agent used was hydrogen peroxide or carbamide peroxide.

Peroxide agents have been shown to induce strong oxidation reactions on the protein peptide component of enamel, compromising its mechanical properties and, consequently, reduce its ability to resist deformation.

The presence of natural human saliva could potentially eliminate the demineralization effect caused by the low pH of bleaching agents. It was found that bleaching agents promoted a decrease in enamel microhardness when compared with the baseline values. However, these were recovered during the post-treatment phase, when specimens were kept in artificial saliva or human saliva.

Five of the eight studies found that a 15% peroxide concentration led to the lowest increase in surface roughness and the lowest reduction in hardness compared to the more concentrated peroxide gels. This finding reinforces the idea that low concentrated gels may be used more effectively and safely than the higher concentrated bleaching gels.

Recommendations

Further research exploring the roles that salivary proteins may potentially play, in the repair of bleached enamel would be recommended. The results of this investigation have relevant importance to dental care practitioners (DCP) who routinely perform bleaching treatments on their patients. Therefore, the use of remineralising agents after bleaching is important to recharge the substrate with new minerals and help prevent damage to the enamel.

The addition of fluoride, Amorphous Calcium Phosphate or even hydroxyapatite to the bleaching gels has prevented or minimized mineral content loss from enamel during bleaching treatment. In future studies, the concomitant incorporation of one or more biomaterials onto the bleaching agents would be recommended in an attempt to potentiate their remineralising effect.

Personal Development Plan and Reflective Learning

This CPD is linked to the following GDC Enhanced CPD Development Outcomes:

C. Maintenance and development of knowledge and skill within your field of practice. Reflective learning is now a requirement of the GDC Enhanced Professional Development Scheme. As such, you will now be given the option to answer some reflective learning questions, before your certificate is generated.

Please remember that you can fill this in on completion of the exam, but you can also update this at any time from your CPD log. If you take a few moments to write your reflection on completion, you will have fulfilled the Enhanced CPD requirements.

Further Reading Please email enquiries@cpd4dentalhygienists.co.uk if you would like to read the literature review in full.

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