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Developing Oral Care Products: The Effectiveness of Selected Whitening Agents in Toothpastes - A Review

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Abstract

Whitening toothpastes are becoming increasingly popular in the market since the appearance of healthy white teeth (aesthetics) when smiling etc are relevant to consumers. Numerous toothpastes advertise different formulations to give the best whitening results albeit with different ingredients. The purpose of this literature review is to consider the available whitening agents in over-the counter (OTC) toothpastes and determine the effectiveness of these whitening agents in improving the natural colour of the teeth.

Introduction

The first mention of toothpaste was by the ancient Egyptians as early as 4 A.D. (Prichard, 2012). The cleaning powders primarily consisted of abrasives such as crushed rock salt, ground-up ox hooves and eggshells, or pumice, in combination with flavourings such as mint, dried iris, crushed pepper, and myrrh added for taste (Prichard, 2012). Other ancient societies provided their own formulations, such as the Chinese, who used ingredients such as ginseng, mint, and salt, as well as the Greeks and Romans who opted for crushed bones, oyster shells, charcoal, and tree bark (Colgate Global Scientific Communications, 2023). The primary purpose of these dentifrices was to clean the teeth and gums, freshen the mouth, and whiten teeth. Toothpaste manufacturers have continued to develop specific formulations appealing to different markets, such as those with gum diseases, dentine sensitivity, halitosis, and those who want to improve the colour of their teeth.

The global teeth whitening market is valued at USD 6.4 billion (as of 2021), accounting for 23.6% of the global cosmetic dentistry market (Ghosh, 2022) indicating the desire of consumers to improve the appearance of their smile (aesthetics). This demand has also led to innovation of ingredients within tooth whitening products as manufactured by the various dental health care manufacturers.

A survey on dental oral care products in a local UK supermarket was conducted by one of the authors (JC) who recorded the various products, their ingredients, and claims of efficacy of the whitening effect on the packaging (Table 1). The whitening toothpastes were, for the purpose of this review divided into three groups, based on their primary whitening ingredients: abrasives, pigments, and bleaching agents. Following this initial grouping, one ingredient was selected from each group, such as 1) activated charcoal to represent the abrasives, 2) blue covarine to represent pigments, and 3) peroxides to represent bleaching agents. In this literature review, the effectiveness of selected whitening ingredients within the toothpaste formulations will be discussed and evaluated.

Toothpaste	Ingredients	Claims as advertised on the packaging
Oral-B 3D White Vitalizing Fresh	Aqua, Sorbitol, Hydrated Silica, Disodium Pyrophosphate, Sodium Lauryl Sulfate, Aroma, Sodium Hydroxide, Cellulose Gum, Sodium Saccharin, Carbomer, Glycerin, Limonene, Polysorbate 80, CI 73360, CI 74160, Sodium Sulfate, Sodium Chloride, Sodium Fluoride (1450 ppm)	Clinically proven. Removes up to 87% of surface stains. Starts whitening after one brushing.
Oral-B 3D White Luxe Perfection	Glycerin, Hydrated Silica, Sodium Hexametaphosphate, Aqua, PEG-6, Aroma, Trisodium Phosphate, Sodium Lauryl Sulfate, Cocamidopropyl Betaine, Sodium Saccharin, PVP, Xanthan Gum, Carrageenan, Sodium Chloride, Limonene, Sucralose, Sodium Benzoate, Sodium Hydroxide, CI 74160, Citric Acid, Sodium Citrate, Potassium Sorbate, Sodium Fluoride (1450 ppm)	Clinically proven. 24-hour stain prevention. Up to 100% stain removal.
Oral-B 3D White Luxe Glamorous White	Glycerin, Hydrated Silica, Sodium Hexametaphosphate, Aqua, PEG-6, Aroma, Trisodium Phosphate, Sodium Lauryl Sulfate, Cocamidopropyl Betaine, Sodium Saccharin, PVP, Xanthan Gum, Carrageenan, Sodium Chloride, Limonene, Sucralose, Sodium Benzoate, Sodium Hydroxide, CI 74160, CI 73360, Citric Acid, Sodium Citrate, Potassium Sorbate, Sodium Sulfate, Sodium Fluoride (1450 ppm)	Clinically proven. 24-hour stain prevention. Up to 100% stain removal.
Oral-B 3D White Arctic Fresh	Aqua, Sorbitol, Hydrated Silica, Disodium Pyrophosphate, Sodium Lauryl Sulfate, Aroma, Sodium Hydroxide, Cellulose Gum, Sodium Saccharin, Carbomer, Glycerin, Limonene, Polysorbate 80, Ci 42090, Sodium Fluoride (1450 ppm)	Clinically proven. Starts whitening after one brush. Removes up to 87% of surface stains.
Arm & Hammer Charcoal White Pro	Sodium Bicarbonate, PEG-8, Hydrated Silica, Glycerin, Calcium Sulfate, Sodium Lauryl Sulfate, Aroma, Alumina, Dipotassium Phosphate, Sodium Saccharin, Sodium Carbonate, PEG/PPG-116/66 Copolymer, Calcium Peroxide, Charcoal Powder, Calcium Hydroxide, Aqua, Calcium Carbonate, Sodium Silicate, Limonene, CI 74160, Sodium Fluoride (1450 ppm)	Clinically proven. Removes 100% more stains than a regular toothpaste in 14 days. Restores gloss. Whiter teeth. Outstanding results in just three days.
Arm & Hammer	Aqua, Sodium Bicarbonate, Hydrogenated Starch Hydrolysate, Hydrated Silica, Glycerin, Tetrasodium Pyrophosphate, Aroma,	Clinically proven. Up to three shades whiter.

Advanced White Pro	Alumina, Sodium Saccharin, Sodium Lauryl Sulfate, Cellulose Gum, Limonene, CI 74160, Sodium Fluoride (1450 ppm)	Whiter teeth. Stain prevention shield for long lasting whitening. Deep stain removal.
Mentadent Protect + Whiten	Aqua, Calcium Carbonate, Hydrogenated Starch Hydrolysate, Hydrated Silica, Sodium Lauryl Sulfate, Aroma, Sodium Bicarbonate, Potassium Citrate, Cellulose Gum, Benzyl Alcohol, Trisodium Phosphate, Sodium Saccharin, Mentha Arvensis Leaf Oil, Mentha Piperita Oil, Mentha Spicata Flower/Leaf/Stem Oil, Sodium Laureth Sulfate, CI 42051, CI 74160, Sodium Monofluorophosphate (1450 ppm)	Whiter teeth after one week. Gentle stain removal.
Macleans White & Shine	Aqua, Sorbitol, Hydrated Silica, Glycerin, Pentasodium Triphosphate, Sodium Lauryl Sulfate, Aroma, Alumina, Xanthan Gum, Cocamidopropyl Betaine, Carrageenan, Sodium Saccharin, Sodium Hydroxide, Limonene, CI 74160, Sodium Fluoride (1450 ppm)	Shinier and smoother teeth in one week.
Colgate Max White Ultra	Poloxamer 105, Calcium Pyrophosphate, PEG-8, PEG/PPG-116/66 Copolymer, PVP, Silica, Tetrasodium Pyrophosphate, Aroma, Potassium Caroate, Sodium Lauryl Sulfate, Disodium Pyrophosphate, Sodium Saccharin, Cocmidopropyl Betaine, Sucralose, Magnesium Carbonate, Eugenol, Sodium Monofluorophosphate	Whiter teeth in just three days. Removes up to 100% of surface stains.
Colgate Max White Expert	Glycerin, Propylene Glycol, Calcium Pyrophosphate, PEG/PPG-116/66 Copolymer, PVP, PEG-12, Pentasodium Triphosphate, Sodium Lauryl Sulfate, Silica, Aroma, Disodium Pyrophosphate, Sodium Saccharin, Hydrogen Peroxide, Limonene, Sodium Monofluorophosphate (1450 ppm)	Whiter teeth in five days. Clinically proven to reverse years of yellowing.
Colgate Max White Ultimate	Poloxamer 105, Calcium Pyrophosphate, PEG-8, PEG/PPG-116/66 Copolymer, PVP, Silica, Tetrasodium Pyrophosphate, Aroma, Potassium Caroate, Sodium Lauryl Sulfate, Disodium Pyrophosphate, Sodium Saccharin, Cocamidopropyl Betaine, Sucralose, Magnesium Carbonate, Eugenol, CI 74160, Sodium Monofluorophosphate (1450 ppm)	Colgate's most advanced whitening toothpaste. Reverses 15 years of stains. Prevents new stain formation. Removes deep-set stains below enamel. Makes teeth appear instantly whiter by reflecting blue light. Removes surface stains.
Colgate Max White One	Aqua, Sorbitol, Hydrated Silica, PEG-12, Tetrapotassium Pyrophosphate, Pentasodium Triphosphate, Aroma, Sodium Lauryl Sulfate, Cellulose Gum, Potassium Hydroxide, Phosphoric Acid, Cocamidopropyl Betaine, Sodium Saccharin, Xanthan Gum, Limonene, CI 74160, Sodium Fluoride (1450 ppm)	One shade whiter teeth in one week. Clinically proven to remove up to 100% of surface stains.
Colgate Advanced White Charcoal	Aqua, Hydrated Silica, Sorbitol, PEG-12, Aroma, Sodium Lauryl Sulfate, Xanthan Gum, Potassium Hydroxide, Cellulose Gum, Tetrasodium Pyrophosphate, Phosphoric Acid, Sodium Saccharin, Benzyl Alcohol, Charcoal Powder, Limonene, Sodium Fluoride (1450 ppm)	Clinically proven. Restores natural teeth whiteness. Whiter teeth in 10 days.

Colgate Advanced White	Aqua, Hydrated Silica, Sorbitol, PEG-12, Aroma, Sodium Lauryl Sulfate, Xanthan Gum, Potassium Hydroxide, Cellulose Gum, Tetrasodium Pyrophosphate, Phosphoric Acid, Sodium Saccharin, Benzyl Alcohol, CI 74160, Limonene, Sodium Fluoride (1450 ppm)	Clinically proven. Whiter teeth in 10 days.
White Glo Whitening Toothpaste	Calcium Carbonate, Sorbitol, Aqua, Glycerin, Hydrated Silica, Sodium Lauryl Sulfate, Cellulose Gum, Aroma, Sodium Benzoate, Hydroxyethylcellulose, Sodium Phytate, Sodium Saccharin, Sodium Bicarbonate, Phthalimidoperoxycaproic Acid, Hydrogen Peroxide, Bromelain, Sodium Phosphate, Mica, Rosa Canina Fruit Oil, Strontium Chloride, Sodium Monofluorophosphate (1000 ppm)	Whiter teeth in seven days.

Table 1: Whitening toothpastes observed in a UK dental oral care aisle; listing product name, ingredients, and claims advertised on the packaging of individual products.

Activated Charcoal

A nanocrystalline form of carbon, this porous substance is considered to have the ability to absorb chromophores, pigments and extrinsic stains which cause alteration in tooth colour (Zamudio-Santiago et al., 2023). This ability to reduce and reverse changes in tooth colour, paired with its abrasive properties helps to remove extrinsic stains and is being currently advertised as a 'natural' ingredient and as such appeals to consumers who prefer to use 'natural products'.

The abrasive nature of charcoal within toothpastes depends largely on the method of preparation, the size of particles, and the concentration within the toothpaste; meaning the whitening effect can vary between products due to these differences in compositions used in toothpastes (Greenwall et al., 2019).

A study by Dionysopoulos et al., (2020) examined the Black and Polish Toothpaste from Frezyderm, which contains 1% w/w active charcoal (Table 2). The study reported that following a simulated toothbrushing period of 90 days on extracted human canines previously stained in a coffee solution for 24 hours, demonstrated a colour change of 40.5 %. This colour change is described as ΔE, a colour difference analysis metric formulated by the International Commission on Illumination (CIE) (Bittencourt de Abreu et al., 2020). There was a statistically significant colour change when compared to the control, a non-whitening toothpaste, Colgate Total. It was noted that this difference was not perceived by the human eye, although the study concluded that charcoal-containing toothpastes had a superior whitening effect compared to a regular toothpaste, this difference would not necessarily be noticed by the human eye, and as such would not satisfy consumer expectation.

Type of Toothpaste	Toothpaste	Ingredients	Active Agent
Control (non-whitening)	Colgate Total® Colgate-Palmolive Co., Greece	Water, glycerin, hydrated silica, PVM/MA copolymer, sodium lauryl sulfate, cellulose gum, aroma, sodium hydroxide, carrageenan, sodium fluoride, triclosan, sodium saccharin, limonene, CI 77891	Hydrated silica
Charcoal (whitening)	Black and Polish Frezyderm Ltd, Greece	Deionized water, sorbitol, sodium saccharine, sodium fluoride (0.32% w/w), sodium benzoate, polyglycol 1500s, Blanoz 7M1F Pharm, Tixosil 73, Tixosil 43, Pearlwhite 19, flavor spearmint	Active charcoal (1% w/w)

		frost EAB24297/00, biosol, citric acid, Speckare CAC3, sabosol L30	

Table 2: Ingredients of toothpastes used in the study by Dionysopoulos et al., (2020)

A subsequent study by Rashid et al., (2022), was conducted on extracted human teeth (Table 3), however the colour change was measured using a 1) a VITA classical shade guide and 2) a VITA Easyshade V digital spectrophotometer, instead of calculations measuring ΔE as used by Dionysopoulos et al., (2020). The Rashid et al. study also used a hydrogen peroxide-containing whitening toothpaste as a comparison, without a control non-whitening toothpaste. These differences between the two studies by Rashid et al., (2022), and Dionysopoulos et al., (2020) therefore make the results difficult to analyse effectively since both the control group and methodologies of assessing whiteness were different. Comparison of the optical benefits of the charcoal toothpastes in the two studies indicated that Dionysopoulos et al., (2020) reported the difference in the whitening effect of the charcoal toothpaste compared to that of the non-whitening toothpaste as 'may not be clearly perceivable by the human eye', which in essence is a subjective visual assessment by the human eye. However, the study by Rashid et al., (2022), observed that following a brushing period of 21 days, no positive changes in tooth lightness, chroma, or hue were observed, although a 'significant reduction in lightness' was noted in the charcoal group. This observation would suggest that whilst charcoal-containing toothpastes may have clinically significant whitening effects as described in these two studies, to the human eye, they are ineffective tooth-whitening agents when used in toothpastes. This observation regarding charcoal toothpastes is supported by a literature review conducted by Brooks, et al., (2017), where it was concluded that there was 'insufficient clinical and laboratory data' to determine the effectiveness charcoal-based products claim to produce.

Type of Toothpaste	Toothpaste	Ingredients	Active Agent
Whitening Charcoal	Premium Nature Charcoal Toothpaste	Calcium carbonate, purified water, sodium bicarbonate, vegetable glycerin, hydrated silica, xylitol, cocos nucifera oil, carrageenan, sodium cocoyl glutamate, mentha piperita oil, mentha viridis leaf oil, pimpinella anisum seed extract, gaultheria procumbens leaf oil, stevia	Activated charcoal

Table 3: Ingredients of charcoal toothpaste used in the study by Rashid et al., (2022) Source: (Davids Natural Toothpaste, n.d.)

Blue Covarine

Also known as CI 74160, or copper phthalocyanine, blue covarine is a synthetic blue pigment used as a colourant in toothpastes. Blue covarine works by being deposited and retained onto the pellicle over the tooth surfaces, resulting in a perceived shift in colour from yellow to blue (Dantas et al., 2015). This

perception of a colour shift ultimately achieves an illusion of higher luminosity and whiteness, without the need for harsh abrasives which risk increasing enamel surface roughness and thinning the teeth over time. A study by Dantas et al., (2015) compared blue covarine toothpaste to bleaching treatments, measuring whiteness by reflectance spectrophotometer (Vita EasyShade® – Vident, Brea, CA, USA). Studies by Gerlach et al., (2000) and Gerlach et al., (2002) determined that the yellow-blue colour axis (Δb*) was the most important factor in evaluating of tooth whitening products, which is exactly what blue covarine claims to achieve. The results of the study by Dantas et al., (2015) demonstrated no evidence of a bleaching effect by the blue covarine toothpaste, although these investigators noted that due to the pigment's whitening mechanism, the pigment may have been unjustly assessed. For example, blue covarine works by adherence to the pellicle covering teeth rather than intrinsically bleaching the enamel or altering the tooth per se, the methodology used in the study would not have been compatible with this whitening method, and as such failed to demonstrate any whitening effect. For example, a reflectance spectrophotometer would normally measure the colour of the body of enamel and dentine, ignoring any surface changes and as such was unable to record any optical differences initiated by blue covarine ingredient within the toothpaste. This observation was recognised as a flaw by Dantas et al., (2015), but was not subsequently corrected by these investigators to improve a more accurate method of measuring tooth colour.

Other studies by Ashcroft et al., (2008) and Joiner et al., (2008) used a more suitable method of measurement, opting for a colorimeter which would be able to fairly assess the whitening capacity of blue covarine-containing toothpastes. A further study by Collins et al., (2008) decided to evaluate whiteness using digital methods and by analysis of the International Commission of Illumination whiteness index (CIELAB) and tooth whiteness index (WIO). This methodology provides an unbiased, objective measure of whiteness. Studies using both colorimeter and digital methods reported significant results as reported by Ashcroft et al., (2008) and Joiner et al., (2008). Collins et al., (2008) also reported 'a statistically significant reduction in tooth yellowness' immediately following brushing with a blue covarine toothpaste. Although this result was encouraging, the study did not consider any effects of the long-term evaluation of a blue covarine toothpaste, which would be more clinically relevant to twice daily brushing by the consumer. Joiner et al., (2008) reported that following measurements with a colorimeter, a blue covarine toothpaste provided a significantly greater shift in the yellow-blue colour axis (Δb*) compared to a water control. The blue covarine toothpaste was reported to have a mean Vita Shade change of 1.18, and an increase in the WIO whiteness index. However, in this study, salivary pellicle-coated extracted human teeth were treated with blue covarine for only 30 seconds, then rinsed with water and immediately assessed with a colorimeter. This study however, also failed to evaluate the long-term use or exposure to blue covarine, as specimens were only exposed for 30 seconds, whereas in practice, it is recommended to brush for two minutes, twice daily (Public Health England, 2021), and as such does not represent using the toothpaste in the oral environment. It was also evident that the optical whitening effect was strongest immediately after brushing due to the deposition onto the pellicle, but there was no mention of the longevity of the whitening effect. In humans, a constant salivary flow, as well as abrasion from foods masticated throughout the day would remove the blue covarine from the tooth surfaces, reducing the perception of whiteness achieved by blue covarine-containing toothpastes. There does not however appear to be any effort to investigate this effect. It can therefore be concluded that although the immediate whitening effect was significant, the longer-term efficacy may be questioned and as such further investigation is required to determine true efficacy of this ingredient as a whitening agent in toothpastes.

Oliveira et al., (2016) attempted to resolve this issue, by measuring the efficacy of blue covarine-containing toothpaste after both one and seven days, to measure the cumulative use of the toothpastes using a colorimeter. This study was conducted on heavily stained specimens, stained by fruit juices, teas, and wine to evaluate the efficacy of blue covarine in combatting these stains. Although all stained specimens experienced a whitening effect due to the blue covarine toothpaste after one and seven days, it was determined that the effectiveness of blue covarine was insufficient to overcome severe discolouration, even though it was observed to contribute to the whitening effect. The most effective whitening effect occurred in the group stained by black tea, presumably due to the superior abrasive nature of hydrated silica, which was an ingredient in all blue covarine toothpastes evaluated in this literature review. It is therefore reasonable to assume that the blue covarine ingredient per se did not improve the perception of tooth whiteness, but rather a combination of the pigment and an abrasive to remove any adherent extrinsic stains.

Ultimately this study concluded that although the blue covarine toothpaste reduced discolouration, it failed to significantly whiten the teeth when compared to a traditional abrasive toothpaste (Oliveira et al., 2016).

Peroxide

Peroxides are also used in a professional context by dentists to whiten teeth intrinsically, and as such over-the-counter toothpastes and products include peroxide albeit at a lower concentration. Two of the most used peroxides are hydrogen peroxide and carbamide peroxide. Hydrogen peroxide is a recognised bleaching compound, often used in dental practices at concentrations as high as 40%, this is regulated for use in toothpastes and sold at a lower concentration for at-home use. Hydrogen peroxide works by removing both intrinsic and extrinsic stains. The removal of extrinsic stains helps reduce yellowness caused by food and drink (e.g. tea) stains and plaque, whereas intrinsic bleaching attempts to correct the natural yellow colour of dentine. The other peroxide commonly used is carbamide peroxide, which breaks down into hydrogen peroxide and urea. Following the breakdown, hydrogen peroxide acts to whiten the teeth as previously described above (Colgate, n.d.).

Despite these claims of bleaching and whitening teeth, Raoufi and Birkhed, (2010) reported that peroxide toothpastes have no significant whitening effect, although participants did experience a subjective improvement in tooth colour. This study was conducted in humans over twelve weeks, with only the tooth colour of the front four teeth in both the maxilla and the mandible being examined at zero, four, eight and twelve weeks using 1) a Vita Easyshade digital spectrophotometer and 2) a Degudent shade pilot alongside self-assessment by the study. Although the study reported that there were no significant whitening benefits, it was noted at week four that the ‘average tooth colour was somewhat improved” despite no further changes in tooth colour by the end of the twelve-week study. This observation was also associated with significant improvements in both the plaque and gingival indices over the course of the study which may, however, be due to the participants learning to brush properly, or the influence of the Hawthorne effect and/or placebo effect. It is therefore important to acknowledge that reinforcement of oral hygiene practices, such as improvement in tooth brushing technique, may also contributed to the whitening effect rather than the use of the hydrogen peroxide toothpaste per se during a controlled clinical study.

The same conclusion appears to have been reported in other studies since there were improvements in both lighting and yellowness values, however the whitening effect remained insignificant. It has been theorised that this was due to the lack of stability of peroxide compounds in aqueous environments, as these constituents can be rapidly diluted and broken down by saliva, thereby rendering them ineffective and as such, the oxidising effect would be insufficient to produce the desired whitening effect (Agostinho Simionato et al., 2023).

A contradicting result was reported by Putt et al., (2009) who examined the effects of a peroxide-containing toothpaste by measuring whiteness with both a chromometer and the Vita shade guide. The study reported that following a month of simulated brushing, the peroxide toothpaste achieved a 2-shade improvement using the Vita shade guide, compared to only a half-shade improvement which was achieved by a non-peroxide containing toothpaste. The study concluded that any further whiteness could be achieved with the extended use of the peroxide toothpaste. The study did however use artificial saliva, which may not have degraded the peroxide in the same manner that was described in the study by Agostinho Simionato et al., (2023). It is also important to note that in the study by Putt et al., (2009), it was not a toothpaste formula containing peroxide, but rather a standard fluoride toothpaste mixed in a 1:1 ratio with peroxide gel, possibly leading to an overall higher amount of peroxide in the mouth which may have allowed the whitening effect to be significant.

A recent systematic review and meta-analysis paper by Jamwal et al. (2022) evaluated the in vitro effects of whitening toothpastes on surface roughness and reduced micro-hardness and concluded that while tooth colour can be improved these toothpastes (including peroxide) can impact on the mineral content of teeth due to the increased surface roughness and reduction in microhardness.

Discussion

The purpose of this literature review was to consider the available whitening agents in over-the counter (OTC) toothpastes and determine the effectiveness of these whitening agents in Improving the natural colour of the teeth. However, it became apparent that there was a wide variety of available products with different whitening ingredients as well as different abrasives included in the toothpaste formulations. Evaluation of these whitening products was also difficult due to the different methodologies and assessment methods used to evaluate the products particularly in the in vitro environment.

Of the studies reviewed, several investigators cited the same comparative study by Vaz et al., (2019), which investigated the whitening effects of charcoal, blue covarine, hydrogen peroxide and microbead abrasives. Most studies, however, appear to evaluate the whitening effect immediately following brushing or after a relatively short period of time, such as one month as described by Putt et al., (2009). It was also evident that when reviewing these studies there was a variety of different whitening methods, and as such there does not appear to be a consistent methodology used by the investigators. Although charcoal toothpastes appear to show mixed whitening results, these toothpastes cause surface roughness due to the abrasive nature of charcoal (Zamudio-Santiago et al., 2023). Despite blue covarine showing positive results immediately after brushing, it was unable to combat severe staining (Oliveira et al., 2016). Peroxide also showed limited effectiveness due to the rapid degradation by salivary enzymes (Agostinho Simionato et al., 2023).

It is also important to note that studies often compared branded toothpastes, which would contain other ingredients which may also have had a whitening effect, meaning that the whitening ingredient under investigation may not have been the only ingredient demonstrating whitening effects. In future studies, toothpastes being investigated should have a standard set of ingredients, only adding the desired whitening agent to ensure a relevant control is achieved, thereby reducing any bias which could be introduced by other ingredients.

Most studies reviewed recorded possible adverse effects of whitening toothpastes, such as abrasive damage to tooth surface and gingival tissues (Epple et al 2019). For example, the prolonged use of an abrasive toothpaste, particularly one with a high radioactive dentin abrasion (RDA) value, could lead to loss of tooth tissue potentially leading to more yellowing as dentine is exposed as well as dentine sensitivity or gingival recession due to 'over-zealous toothbrushing'. Jamwal et al. (2022) in a systematic review and meta-analysis paper also reported on the effects of whitening toothpastes on surface roughness and reduced micro-hardness. It was evident from this paper that some whitening toothpastes may impact on the mineral content of the tooth and effect both surface roughness of the enamel and reduce microhardness although the evidence from the seven included studies was contradictory.

Possibly due to the different compositions (such as the abrasive used with different particle size etc) of the toothpastes and the different methodologies used to assess tooth whiteness. It is evident from the reviewed studies that whitening toothpastes have an aesthetic benefit, although further research should be undertaken to evaluate the effect on the mineral content (e.g., increased surface roughness and reduced microhardness).

Although laboratory evaluation is relevant to determine the effects of the whitening products on the mineral content of the tooth as indicated above, it is also essential to evaluate these products in well controlled randomised clinical trials (RCTs) over a period of at least one-three months, ensuring regular time points (intervals) to evaluate both the short-term and long-term whitening effects as well safety evaluation to determine the most effective whitening agent commonly used in over-the-counter products.

There are other toothpastes with different whitening methods on the market, which were not included in this literature review, e.g., toothpastes such as toothpastes containing alternative abrasives such as sodium bicarbonate, silica and microbeads, and these products should also be investigated to evaluate their effectiveness.

Conclusion

Although studies appear to show some evidence that tooth whitening products improve tooth colour there is a requirement to determine which are the most effective in tooth whitening and less damaging to both the soft and hard tissues. Further studies are therefore required to compare these whitening agents in well

controlled comparative clinical studies using standardized methodology over extended periods of time.

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