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ORIGINAL ARTICLE

In vitro comparison of natural tooth-whitening remedies and professional tooth-whitening systems

Randa F. Abidia [a], Ahmed A. El-Hejazi [b,*], Ambreen Azam [c], Shahad Al-Qhatani [d], Khuloud Al-Mugbel [d], Maryam AlSulami [d], Aleshba Saba Khan [e]

[a] *College of Dental Medicine, Qatar University, Qatar*
[b] *College of Dentistry, Restorative Department King Saud University, Riyadh, Kingdom of Saudi Arabia*
[c] *Dental Materials, College of Dentistry, Margalla Institute of Health Sciences Pakistan*
[d] *College of Dentistry, Princess Nourah Bint Abdulrahman University, Riyadh, Kingdom of Saudi Arabia*
[e] *Department of Prosthodontics, Shahida Islam Dental College, Lodhran, Pakistan*

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Abstract *Background:* An increasing number of patients are using natural homemade remedies such as strawberries, banana peels, coconut oil rinse, basil, lemon, activated charcoal, apple cider vinegar, baking soda, and turmeric to obtain whiter teeth. However, studies on these natural whitening products are limited.

Aim: To evaluate the effectiveness of different homemade tooth-whitening agents in vitro.

Materials and methods: Ninety caries-free extracted anterior and premolar teeth were collected, cleaned, and sectioned at the roots. The teeth were mounted in epoxy resin (buccal surface) and stored in 0.2 % thymol solution, and were treated with one of the following six whitening agents: baking soda, activated charcoal, lemon juice, strawberries, Colgate Optic Whitening toothpaste, and Opalescence 20 % home-bleaching system. The enamel shade in each sample was measured four times using a spectrophotometer. Baseline measurements for ΔE and (L*, a*, b*) were obtained, and the second measurement was obtained after 5 days. The third reading was obtained on the 10th day, and the fourth reading was obtained at the 4th week to measure colour stability. One-way analysis of variance and post-hoc Tukey tests were used for statistical analysis.

Results: ΔE measurements showed a significant difference on the 10th day in all groups except

* Corresponding author at: College of Dentistry, RDS department, King Saud University, POBox 60169, Riyadh 11454, Kingdom of Saudi Arabia
E-mail addresses: rabidia@gmail.com (R.F. Abidia), aelhejazi@ksu.edu.sa (A.A. El-Hejazi), aleshba.saba@hotmail.com (A.S. Khan).
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the lemon group (P = 0.164), while all groups showed a statistically significant difference at the 4th week. The mean colour change differed remarkably between the first and fourth readings. The highest change was observed in the lemon group (44.0 ± 2.9), closely followed by the Opalescence 20 % and Colgate Optic Whitening toothpaste groups. The lowest change was observed with strawberries (38.2 ± 4.8). ΔE showed a significant difference in all groups except the turmeric group.

Conclusion: Statistically significant differences were obtained with baking soda, activated charcoal, strawberries, lemon juice, Colgate Optic Whitening toothpaste, and Opalescence 20%. Further studies are required to evaluate the effects of these agents on surface roughness and colour stability.

1. Introduction

The demand for celebrity-like whiter Hollywood smiles has increased recently (Kwon et al., 2015), with the media playing a vital role in raising awareness about ways to improve smiles and inculcate the desire for whiter and brighter smiles (Benahmed et al., 2021). Consequently, tooth whitening or veneering has gained popularity as a dental procedure to improve smiles (Kwon et al., 2015). More than a million Americans opt for tooth-whitening treatment in each year, generating a revenue of nearly 600 million dollars for the dentists providing these treatments (Kwon et al., 2015). The increased demand, social pressure, and desire to look good among people of different financial strata has led to the identification and use of a variety of tooth-whitening methods, ranging from in-office whitening by dentists, the use of dental veneers or over-the-counter products, and cheaper solutions using natural products to attain lighter shade of teeth at home (Kwon et al., 2015; Maciel et al., 2022).

The mode of action of tooth-whitening products is well established (Maciel et al., 2022). The whitening agent causes the pH to become acidic (Babot-Marquillas et al., 2022). The most common active ingredient in bleaching agents is hydrogen peroxide (Babot-Marquillas et al., 2022), which oxidises the double bonds of chromogens to make them lighter (Babot-Marquillas et al., 2022). However, despite its effectiveness in achieving tooth whitening, the use of hydrogen peroxide is associated with some limitations (Senthilkumar and Ramesh, 2021), since it can lead to undesirable changes in the microhardness, surface texture, and composition of enamel (Senthilkumar and Ramesh, 2021). While 35 % hydrogen peroxide is used for in-office bleaching, 15 %-20 % carbamide peroxide is used in bleaching products meant to be applied at home (Senthilkumar and Ramesh, 2021). Although at-home bleaching is relatively milder than in-office whitening, both can cause adverse reactions such as tooth sensitivity, gingival or throat irritation, soft tissue burns, and nausea (Senthilkumar and Ramesh, 2021). These factors have led to the evolution of over-the-counter products with only 3 %-6% hydrogen peroxide for easy, safe, and milder applications; however, the absolute safety of these products remains questionable (Senthilkumar and Ramesh, 2021).

In attempts to further lower the risks and costs of whitening agents, natural products that are easily available at home have been used to lighten the shade of teeth (Senthilkumar and Ramesh, 2021). However, these products are typically used without any scientific proof of their safety or efficiency (Maciel et al., 2022). Strawberry purees, coconut oil, lemon, activated charcoal, apple cider vinegar, baking soda, and banana peel are some examples of natural products that have been used as whitening home remedies (Benahmed et al., 2021; Maciel et al., 2022). Among these, activated charcoal is gaining increasing popularity as an ingredient in oral hygiene products that can also facilitate tooth lightening (Benahmed et al., 2021). Despite the visible changes in colour observed with the use of activated charcoal, evidence supporting its use is limited (Benahmed et al., 2021). The ions in activated charcoal are reported to attach to enamel to remove chromogens, thereby removing stains from teeth (Ghajari et al., 2021). It is also thought to lighten the tooth through mild abrasion of the enamel (Ghajari et al., 2021). Baking soda also causes whitening through an abrasive mechanism and acid-buffering function, causing lightening of acid-based food stains (Li, 2017). The acidic content in strawberries helps lighten the stains by reducing the pH to 3 or 4 (Neha et al., 2022). It works as an oxidising agent for stains, thereby providing a bleaching effect (Benahmed et al., 2021; Neha et al., 2022). Apart from these home-based items, Colgate Optic Whitening toothpaste is commonly available in the market and used for tooth whitening (de Freitas et al., 2021). The market for whitening toothpastes grew by 4 % from the year 2017 to 2021 and generated 3 million US dollars (de Freitas et al., 2021; Anderson et al., 2020). The ease of availability, low cost, and easy usage of toothpastes and other over-the-counter tooth-whitening products have contributed to an increase in their market value (de Freitas et al., 2021).

Although the mode of action and whitening potential of natural products have been addressed in previous studies, their comparative efficacy in tooth whitening needs to be evaluated further. Therefore, the aim of this study was to evaluate the whitening efficacy of six different at-home tooth-whitening methods in vitro. The null hypotheses were that the six methods would show no difference in the level of whitening and that the degree of whitening would not change on the basis of the time after application or the time of colour observation.

2. Materials and methods

2.1. Ethical approval

This in vitro analysis was conducted at the College of Dentistry, Princess Nora Bint Abdul Rahman University, Riyadh, KSA. Ethical approval was obtained from the Research Board Committee, and the assigned approval number was 2017/CDS/INT/09.

2.2. Specimen preparation

Ninety caries-free extracted anterior and premolar teeth were collected. The teeth were cleaned of calculi, debris, and blood by using an ultrasonic scaler (Senthilkumar and Ramesh, 2021). The samples were first stored in a 0.2 % thymol solution. The roots were sectioned, and each sample was mounted in epoxy resin facing the buccal surface of the tooth. After preparation, samples were stored in distilled water at 37 °C for 24 h. The teeth were divided into six groups: baking soda, activated charcoal, turmeric, strawberries, and Colgate Optic Whitening toothpaste as experimental groups and an Opalescence 20 % home-bleaching system as the control group. Each group contained five samples.

2.3. Preparation of paste and application on sample

2.3.1. Group 1: Baking soda

- A mixture of 19 mL of baking soda and approximately 15 mL of distilled water was used to make a fine paste.
- The paste was applied to the samples' buccal/facial surface in the Toothbrush Stimulator (Omron SD Mechatronik; Fig. 1) by using a soft toothbrush.
- The samples were brushed on the buccal surface for 2 min twice daily.
- The samples were rinsed off thoroughly with water.
- The samples were stored in distilled water at 37 °C.

2.3.2. Group 2: Activated charcoal

- Activated charcoal (24 mL) was mixed with 15 mL of regular toothpaste (LACALUT).
- The paste was applied on the samples' buccal/facial surface in the Toothbrush Stimulator (Omron SD Mechatronik) by using a soft toothbrush.
- The samples were brushed on the buccal surface for 2 min twice daily.
- The samples were rinsed off thoroughly with water.
- The samples were stored in distilled water at 37 °C.

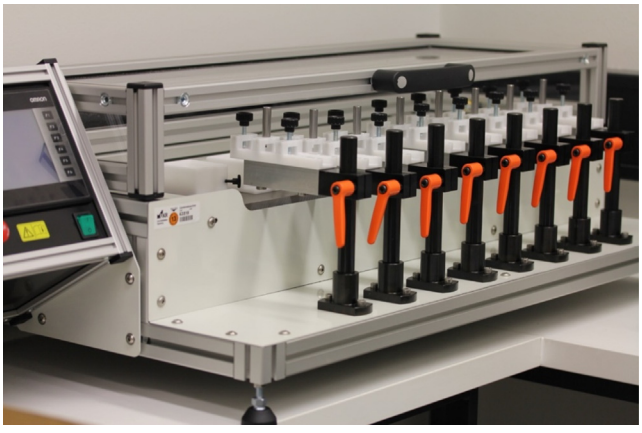

Fig. 1 Toothbrush stimulator (Omron SD Mechatronik).

2.3.3. Group 3: Strawberries

- Three large strawberries were mashed.
- The mashed strawberry was applied on the samples' buccal/facial surface in the Toothbrush Stimulator (Omron SD Mechatronik) by using a soft toothbrush.
- The samples were brushed on the buccal surface for 2 min twice daily.
- The samples were rinsed off thoroughly with water.
- The samples were stored in distilled water at 37 °C.

2.3.4. Group 4: Lemon juice

- Lemon juice (39 mL) was extracted.
- The juice was applied on the samples' buccal/facial surface in the Toothbrush Stimulator (Omron SD Mechatronik) by using a soft toothbrush.
- The samples were brushed on the buccal surface for 2 min twice daily.
- The samples were rinsed off thoroughly with water.
- The samples were stored in distilled water at 37 °C.

2.3.5. Group 5: Colgate Optic whitening toothpaste

- The toothpaste was applied on the samples' buccal/facial surface in the Toothbrush Stimulator (Omron SD Mechatronik) by using a soft toothbrush.
- The samples were brushed on the buccal surface for 2 min twice daily.
- The samples were rinsed off thoroughly with water.
- The samples were stored in distilled water at 37 °C.

2.3.6. Group 6: Opalescence 20 % home-bleaching system (control group)

- The bleaching gel was applied for 2 h per day for 5 days according to the manufacturer's instructions.
- The samples were rinsed off thoroughly with water.
- The samples were stored in distilled water at 37 °C.

2.4. Measurement of whitening

The enamel shade of each sample was measured using a spectrophotometer (LabScan XE) before the application of the whitening agents baseline measurement first (L*, *a, *b) then Four readings were obtained for each sample as follows:

- The first reading was at 24 h baseline measurement for (L*, *a, *b) (ΔE 1)
- The second reading was obtained after 5 days of application (ΔE 2)
- The third reading was obtained after 10 days of application (ΔE 3)
- The fourth reading was obtained after 4 weeks to measure colour stability (ΔE 3)

A toothbrush stimulator (Omron SD Mechatronik) was used for brushing samples in all groups. The brushing time for each sample was twice daily for 2 min for 10 days. The brushing movement pattern was linear, with a travel length of 10 mm and a speed of 10 mm/s.

2.5. Statistical analysis

The results were analysed using one-way analysis of variance. The analysis was performed to evaluate the whitening effects in the six groups vs ti me, while the present data were evaluated using descriptive analysis. Post-hoc multiple comparisons were performed using Tukey's test. Specialised software (SPSS version 19, IL, USA) was used for this analysis. The significance level for each test was set at 5 %.

3. Results

Colour comparisons between the different homemade tooth-whitening methods showed a range of values in spectrophotometric analyses. The CIE L*a*b* system was used to calculate the mean L*, a *, and b *values for each material. The equation $\Delta E = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)2]^{1/2}$ was used to measure the total colour change (ΔE). Table 1 shows the changes in groups across different readings. The ΔE showed a significant difference on the 10th day in all groups except the lemon group (P = 0.164). However, at the fourth week, all groups showed a statistically significant difference (Table 1).

The means and standard deviation values of ΔE for each group are presented in Table 2. A remarkable difference was observed in the mean colour change between the first and fourth readings. The highest change was observed in group 4 (lemon juice; 44.0 ± 2.9), closely followed by Opalescence 20 % and Colgate Optic White paste. The lowest change was observed with strawberries (38.2 ± 4.8) (Table 2).

In assessments based on the Munsell colour system, baking soda, activated charcoal, strawberries, and Colgate Optic Whitening toothpaste showed colour changes from yellow to red. The colour in the lemon group changed from green to blue, while that with the Opalescence 20 % home-bleaching system changed from yellow to green (Table 3). As shown in Table 3, all groups displayed notable high values.

4. Discussion

With the increasing awareness of aesthetics and methods to improve it, various tooth-whitening products and natural ingredients are being discovered and gaining popularity among dentists and the general population (AlShehri et al., 2022). Among home-bleaching methods, over-the-counter products and home remedies are becoming increasingly popular because of their low cost and easy availability (AlShehri et al., 2022). Chemical means to whiten teeth involve direct contact of relatively strong chemicals with tooth enamel, which raises concerns about damage to the enamel surface (AlShehri et al., 2022; Goyal et al., 2021). The surface characteristics of enamel are modified by the application of chemicals, which may result in loss of calcium and demineralisation at the micro level (AlShehri et al., 2022; Wijetunga et al., 2021).

Enamel is the white-coloured outer layer of the tooth crown and dentin is the second underlying layer, which is

Table 1 Comparison of ΔE values among groups.

Group		N		Tukey's multiple-comparison test			
			ANOVA P-value	ΔE 1	ΔE 2	ΔE 3	ΔE 4
Baking soda	**ΔE 1**	**15**	0.000*	1			
	ΔE 2	**15**		0.000	1		
	ΔE 3	**15**		0.000	0.000	1	
	ΔE 4	**15**		0.000	0.000	0.000	1
Activated charcoal	**ΔE1**	**15**	0.000*	1			
	ΔE2	**15**		0.000	1		
	ΔE3	**15**		0.000	0.002	1	
	ΔE4	**15**		0.000	0.000	0.000	1
Strawberries	**ΔE1**	**15**	0.000*	1			
	ΔE2	**15**		0.000	1		
	ΔE3	**15**		0.000	0.001	1	
	ΔE4	**15**		0.000	0.000	0.000	1
Turmeric	**ΔE1**	**15**	0.000*	1			
	ΔE2	**15**		0.000	1		
	ΔE3	**15**		0.000	0.164	1	
	ΔE4	**15**		0.000	0.000	0.000	1
Colgate Optic Whitening toothpaste	**ΔE1**	**15**	0.000*	1			
	ΔE2	**15**		0.000	1		
	ΔE3	**15**		0.000	0.001	1	
	ΔE4	**15**		0.000	0.000	0.000	1
Opalescence 20 %	**ΔE1**	**15**	0.000*	1			
	ΔE2	**15**		0.000	1		
	ΔE3	**15**		0.000	0.000	1	
	ΔE4	**15**		0.000	0.000	0.000	1

*Significant difference at P < 0.05.

Table 2 Mean and standard deviation values of ΔE.

Group		N	Mean	P-value
Baking soda	**ΔE 1**	**15**	7.7 (5.1)	
	ΔE 2	**15**	23.7 (2.9)	0.000
	ΔE 3	**15**	27.9 (3.4)	
	ΔE 4	**15**	39.3 (4.2)	0.000
Activated charcoal	**ΔE1**	**15**	4.9 (2.6)	
	ΔE2	**15**	24.9 (2.4)	0.002
	ΔE3	**15**	28.7 (4.8)	
	ΔE4	**15**	40.3 (3.7)	0.000
Strawberries	**ΔE1**	**15**	6.7 (2.7)	
	ΔE2	**15**	23.5 (2.2)	0.001
	ΔE3	**15**	30.7 (5.7)	
	ΔE4	**15**	38.2 (4.8)	0.000
Turmeric	**ΔE1**	**15**	4.9 (2.7)	
	ΔE2	**15**	29.1 (3.6)	0.164
	ΔE3	**15**	30.7 (4.4)	
	ΔE4	**15**	44 (2.9)	0.000
Colgate Optic Whitening toothpaste	**ΔE1**	**15**	4.3 (2.3)	
	ΔE2	**15**	25.6 (2.7)	0.001
	ΔE3	**15**	28.8 (2.6)	
	ΔE4	**15**	42.3 (4.4)	0.000
Opalescence 20 %	**ΔE1**	**15**	3.9 (2.1)	
	ΔE2	**15**	27.2 (1.6)	0.000
	ΔE3	**15**	30.3 (1.8)	
	ΔE4	**15**	43.3 (1.9)	0.000

Table 3 Mean Δa*, Δb*, ΔL* values in the first and the fourth readings (after 4 weeks).

	1st reading at 24 h			**4th reading after 1 month**		
	Δb*	**Δa***	**ΔL***	**Δb***	**Δa***	**ΔL***
Baking soda	6,33	−0,37	22,66	−0,44	0,18	39,27
Activated charcoal	6,82	−0,46	23,72	−1,96	0,53	39,96
Strawberries	3,86	0,29	23,23	−2,46	1,44	37,93
Turmeric	8,3	−1,91	27,84	−4,89	0,34	43,57
Colgate Optic Whitening toothpaste	3,93	−0,95	25,21	−3,10	1,45	42,0
Opalescence 20 %	1,48	−0,48	27,03	−4,79	−0,13	42,97

yellow-to-yellowish brown in colour (Benahmed et al., 2021). Worn-off enamel tends to show the yellow shade of dentin, and whitening agents are of little to no use in such cases (Benahmed et al., 2021). Whitening agents mostly reduce the pH of enamel, and prolonged exposure may cause wearing off of the enamel and make it more prone to decay (Carvalho et al., 2017). Enamel-bleaching methods can be categorised as mechanical, physical, and chemical methods (Benahmed et al., 2021). Mechanical methods involve rubbing of paste or powder; physical methods involve the use of laser light, infrared light, ultrasound, etc.; and chemical bleaching is based on the interactions between chemicals and tooth substances (Benahmed et al., 2021). Among all three methods, chemical bleaching, especially with natural ingredients, is considered to be relatively longer-lasting and less damaging to teeth (Benahmed et al., 2021).

In this study, the effects of four home remedies for tooth whitening were tested along with an over-the-counter toothpaste and an at-home bleaching system. Activated charcoal is one of the most commonly used agents and is also added to different toothpastes (Ghajari et al., 2021). It functions by attaching to the tooth surface and binding to colouring agents or stains (Ghajari et al., 2021). Thus, upon removal, it removes the stains and causes mild abrasion, resulting in whitening (Ghajari et al., 2021). Baking soda has also been used as an abrasive in various dentifrices (Li, 2017). Because of its low abrasive potential, and it is less damaging to the teeth (Li, 2017). Strawberries have acidic contents that function as redox reagents and facilitate bleaching (Neha et al., 2022). Lemons are highly acidic and tend to reduce the pH to 2 or 3, which causes demineralisation and results in a whiter appearance of teeth (Amelia et al., 2022). Whitening toothpastes such as Colgate Optic White contain hydrogen peroxide, which shows erosive potential along with some abrasive functions due to the presence of other ingredients (Yilmaz et al., 2021; Rostamzadeh et al., 2021). Opalescence 20 % contains carbamide peroxide, a bleaching agent (Féliz-Matos et al., 2014) that is decomposed to hydrogen peroxide, which bleaches teeth by oxidising pigments (Amelia et al., 2022; Féliz-Matos et al., 2014). It also contains fluoride, which increases the microhardness of the tooth by penetrating the pores created by bleaching (Féliz-Matos et al., 2014).

Significant differences in tooth whitening were observed among the methods; therefore, the first null hypothesis was rejected. All groups except the lemon group showed a significant difference in whitening at the 10th day, while a significant difference was observed in all groups after 4 weeks; the time-dependent difference in whitening meant that the second null hypothesis was also rejected. The highest change in whitening was observed in group 4 (lemon), closely followed by the Opalescence 20 % bleaching system and then Colgate Optic White paste. The maximal colour change in the lemon group could be attributed to the etching effect of lemon juice, which results in a white-frosted appearance (Amelia et al., 2022; Syawalia et al., 2020). However, the lemon juice-induced demineralisation that results from the loss of hydroxyapatite crystals and makes enamel porous requires time (Amelia et al., 2022; Syawalia et al., 2020). This may explain why the results for the lemon group were non-significant at 10 days and significant after four weeks. As the application time increased from the first day to the fourth week, the shade showed a progressive improvement. These results are consistent with those reported by Amelia et al. and Syawalia NP et al. (Amelia et al., 2022; Syawalia et al., 2020). In contrast, another study reported that lemon juice and bicarbonate mixtures showed less whitening than whitening toothpaste (bin Obaid et al., 2021). This may be attributable to the addition of bicarbonate to lemon juice, whereas the present study used only lemon juice. Bicarbonate is alkaline in nature, so it may have neutralised some of the tooth-whitening effects of lemon juice.

The next groups showing the most significant change in colour were Opalescence 20 % and Colgate Optic White. These results are similar to those of other studies in which whitening pastes or agents showed higher whitening efficiency than natural ingredients (Kwon et al., 2015; Maciel et al., 2022; de Freitas et al., 2021; bin Obaid et al., 2021; Franco et al., 2020). This may be because professional whitening agents combine the effects of chemicals with abrasion, thus increasing stain removal and shade improvement (AlShehri et al., 2022). These agents also contain fluoride, which further helps increase the microhardness of teeth, thereby improving the overall results (AlShehri et al., 2022). The next in line in terms of colour improvement were activated charcoal and baking soda. In the present study, a significant change in colour was observed in these two groups as well. This result is in contrast to the findings of another study that reported a minimal whitening effect with charcoal (Franco et al., 2020). These difference in results may be attributable to the different modes of shade evaluation. The present study used a spectrophotometer for analysis, whereas the study by Franco et al. used the VITA classical shade guide for colour evaluation (Franco et al., 2020). Other studies reported similar results to the present study, showing good whitening efficacy of baking soda and charcoal (Maciel et al., 2022; Senthilkumar and Ramesh, 2021; Li, 2017; de Freitas et al., 2021; bin Obaid et al., 2021; Buelo et al., 2016; Değer and Müjdeci, 2020). These effects can be attributed to the abrasive effect of charcoal. Baking soda also has an abrasive effect, but it is less than that of charcoal; thus, activated charcoal showed slightly higher whitening efficacy than baking soda.

The strawberry group showed the least change in colour, although the change was significant. This result is in accordance with the results of other studies, which showed that strawberries have low whitening efficacy (Kwon et al., 2015; Senthilkumar and Ramesh, 2021; Neha et al., 2022). This may be due to the fact that the mild acidic content (ellagic and malic acid) in strawberry leads to light bleaching and causes no alteration to tooth morphology (Neha et al., 2022).

4.1. Limitations

Extracted teeth were used to observe the effects of whitening agents under environments different from those encountered in the oral cavity (Kwon et al., 2015). Lemons, if used on teeth in the oral cavity, promote staining since they increase the microporosity of the enamel surface (Syawalia et al., 2020). Another limitation was that we did not have adequate knowledge about the size of the particles and the percentage of each toothpaste ingredient because the manufacturers did not clearly disclose the compositions; therefore, absolute comparisons were not possible (Rostamzadeh et al., 2021). Additional research is required to determine the effects of these agents on tooth morphology in terms of microhardness and surface roughness. These findings will facilitate identification of agents that can improve tooth colour while maintaining the integrity of the enamel structure.

5. Conclusions

Within the limitations of the study, we concluded that the effects of over-the-counter whitening toothpaste were almost similar to those of home-bleaching agents (opalescence) or lemons. Activated charcoal and baking soda also showed significant whitening effects. Strawberries had the mildest but most significant whitening effects on the teeth.

Conflict of interest

Authors have no conflict of interest relevant to this article.

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