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EFFECT OF SILICON OXIDE COMPLEX REMINERALIZATION MATERIAL ON TOOTH COLOUR

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ABSTRACT

Objectives: The study aimed to evaluate whitening efficacy of silicon oxide complex on teeth and to observe the silicon oxide complex layer on enamel following application of hydrodynamic shear forces. *Materials and methods:* 60 premolar teeth from orthodontic patients were selected and distributed into three groups. First two group were treated with silicon oxide complex (Dentcoat P™, Germany) preparations of 100% and 50% by volume. The third group is a positive control group treated using whitening toothpaste (Colgate® Optic White™, New York). L*a*b* measurement was recorded at the following time points t1, without any treatment; t2, immediately after treatment; and t3, 24h after application of hydrodynamic shear forces to mimic mechanical loading. The colour difference between all timepoints and baseline was calculated and expressed as ΔE. One randomly selected tooth from the silicon oxide group (100% per volume) and one tooth from the control group were examined using Scanning Electron Microscope (SEM) (Hitachi SU 5000, Japan). *Results:* Color differences, ΔE of teeth tested with 100% concentration of silicon oxide complex was significant, compared to teeth tested with whitening toothpaste (8.62±1.34 SE, Sig 0.000) indicating excellent retention of material despite the application of hydrodynamic shear forces. SEM images of the teeth revealed a smoother surface of enamel with diminished pores and surface roughness for 100% volume of silicon oxide complex as compared to the control group. *Conclusion:*

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Silicon oxide complex-based materials can adhere to the enamel surface of teeth and contribute to tooth whitening.

This clinical importance of this article is that it highlights the brightening effect of silicon oxide that may warrant further research interest for their use to improve tooth colour in an adjunctive manner with conventional bleaching.

Keywords: Silicon oxide, tooth whitening, enamel protection, tooth colour

INTRODUCTION

The perceived tooth colour is the interplay between intrinsic colour that is associated with the light scattering ability of enamel and dentine and extrinsic colour formed by staining at the surface or subsurface of the teeth. Tooth colour is an important parameter of aesthetics, and it has been reported that up to 34% of adults in the US and over 50% of adults in the UK are dissatisfied with the colour of their teeth or consider them to have some form of discolouration [1].

However commonly used oxidizing agents such as sodium hypochlorite, sodium perborate, hydrogen peroxide, or carbamide peroxide, may have harmful effects on microhardness, elastic modulus and surface roughness of teeth. Still, the reports on these are conflicting. It has been observed that coating of enamel with hydroxyapatite and remineralization processes can cause an increase in diffuse reflection of light, leading to optical effect of whiteness [2]. Silicon oxide or silicon hydroxide may contain one or more additional elements such as Ca, P, Na, K, Al, B, N, Mg, Ti, or F in various formulations that can whiten teeth when a suitable amount contacts the tooth due to remineralization of the enamel resulting in a shade reduction [3].

Silicon oxide complex (Dentcoat P™, Germany) was introduced to the market for protective enamel coating. In addition to this, bioactive tooth-whitening is among one of the reported applications. The material consists of 2 cartridges containing pure alcohol and colloidal silicon dioxide that when combined forms silica crystals. The whitening process is attributed to reactive oxygen that is slowly released by the cleaving of the lattice-oxygen from the newly formed crystals through a process of hydrolysis. At the same time, the crystals are bonded to the hydroxyapatite with covalent bonds. The whitening process causes the oxidation of unsaturated double bonds and a reduction of chromogenic metal oxides [4].

Despite these claims, the whitening potential of the bioactive liquid material consisting of silicon oxide complex has not been adequately explored. This study aimed to evaluate the whitening efficacy of silicon oxide complex on extracted premolar teeth and to observe the stability of the silicon oxide complex bonding to enamel following application of hydrodynamic shear forces.

MATERIALS AND METHODS

This study was conducted with the ethical standards of the responsible committee on human experimentation in accordance with the Helsinki Declaration of 1975. The study protocol was approved by the Ethics Committee of University Teknologi MARA, Shah Alam Selangor, Malaysia reference number: 600-RMI (5/1/6).

Treatment Preparations

The (Dentcoat P™, Germany) kit was provided as two syringes consisting of ethanol and colloidal silicon dioxide complex in ethanol. The concentration or dosage-dependence of the whitening effect of silicon oxide complex was tested using two preparations containing 100% and 50% volume. The 50% volume of silicon oxide complex was prepared by reducing the colloidal silicon dioxide complex by the ratio of 0.5:1.0 to the ethanol solution to reduce the final bioavailability of silicon oxide during application on teeth. Commercial whitening toothpaste (Colgate Optic White) served as a positive control treatment.

Study Design

15 orthodontic patients planned for extraction of four premolar teeth were selected. In total, 40 premolar teeth were randomly selected and divided into 2 groups treated using 100% volume and 50% volume of silicon oxide complex and 20 premolar teeth served as control and treated using the whitening toothpaste according to the following criteria:

Inclusion criteria:

- Permanent teeth

Exclusion criteria:

- Caries
- Severe staining (example tetracycline staining)
- Teeth with shades brighter than A3

Before treatment, each tooth was cleaned using a polishing cup attached to slow-speed handpiece running at 40,000 rpm for 1 minute and left to dry before testing with the two different preparations of silicon oxide complex. In each treatment group, the material was applied for 30 seconds the labial/buccal surfaces of teeth using an applicator for three times at the interval of 2 minutes according to the manufacturer's instruction. The suspension was left for 10 minutes to allow undisturbed interaction between the material and the enamel surfaces. The positive control group using Colgate Optic White was treated similarly. Following treatment, the teeth were extracted and stored in mineral water for 24 hours at 37ºC.

Following storage, the stability of the interaction between the applied material and the enamel surface was tested by using hydrodynamic shear forces, produced by a sonic toothbrush (Oral B Vitality™ Precision Clean, United States). The toothbrush operated at 20,000 pulsations and 7,600 oscillations per minute and was applied to all teeth for 30 seconds. Both toothbrush and tested tooth were mounted on silicon indexes kept at a fixed distance to ensure reproducible conditions. The durability of the silicon complex based material on the enamel surfaces against the hydrodynamic shear forces was observed with the SEM images.

Assessment of Tooth Colour

Tooth colour was measured using a dental spectrophotometer (Easyshade Vita, Germany) and calibrated using the built-in ceramic calibration reference block. A silicon attachment to the tip of the spectrophotometer was fabricated and used to produce a repeatable measurement for each extracted tooth. The L*a*b* values of the treated and control teeth were recorded for the following time points t1, without any treatment; t2, immediately after treatment; and t3, 24 h after application of hydrodynamic shear forces. Three measurements were obtained after each test stage, and the mean of the three measurements was subjected to further analysis. The colour difference, ΔE between each group and baseline was calculated using the following formula:

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)}$$

Observation of Enamel Using SEM

Following application of the hydrodynamic shear forces, one randomly selected tooth from the silicon oxide group (100% volume) and one tooth from control group were examined using scanning electron microscope (SEM). The effects of enamel surface before and after the application of silicon oxide complex were visualised.

Statistical Analysis

The colour changes between treatment groups and baseline were evaluated using one-way ANOVA and the Bonferroni post hoc test was used to identify homogenous subgroups at a significance level of *p* less than 0.05. The calculations were performed with the statistical software package SPSS 23.

RESULTS

Colour Assessment

The average colour changes (ΔE) following application of the various treatments were calculated relative to the baseline values. One-way ANOVA was performed to analyze the differences in mean colour changes. Test of homogeneity of variances (Table 1) was performed with resultant p-values of 0.194 and 0.000. As the p-value was more than 0.05, equality of variances is assumed, and Bonferroni adjustment was used to identify differences between the groups.

Mean colour changes of all treatment groups were significantly different following application of test substance and following hydrodynamic shear stress application via the sonic toothbrush (Table 2). Colour changes were observed following the application of the two different concentration of silicon oxide complex material. The range of ΔE value for 100% volume group between t1 and t2 intervals was 1.60 – 7.96 and range of ΔE value for

50% volume group was 0.33 – 5.44 indicating that the 50% volume showed lesser colour changes. The mean difference for ΔE at t1-t2 time intervals for both 100% and 50% volume when compared to control were not statistically significant (Table 3). At the t2-t3 intervals following 24 hours and the application of hydrodynamic shear forces, the range ΔE for 100% volume group was 1.8-25.24, and the range of ΔE value for 50% volume group was 0.70-10.30. The mean difference for ΔE t2-t3 intervals for the 100% volume when compared with the control group was significant (8.62 ± 1.34 SE, Sig 0.000) as when compared with the 50% volume group (8.52 ± 1.34 SE, Sig 0.000) as seen in Table 3.

Table 1. Test of homogeneity of variances

	Levene statistics	df 1	df 2	Sig.
t1-t2	1.691	2	57	0.194
t2-t3	15.000	2	57	0.000

Table 2. Comparison of differences in mean between and within groups at t1-t2 and t2-t3 intervals using the ANOVA test

Weight gain	Sum of squares	df	Mean square	F	Sig.
t1-t2 Between Groups	58.527	2	29.263	6.068	0.004*
Within Groups	274.877	57	4.822		
Total	333.404	59			
t2-t3 Between Groups	979.818	2	489.909	27.318	0.000*
Within Groups	1022.228	57	17.934		
Total	2002.046	59			

Table 3. Multiple comparisons between the groups using Bonferroni (Post Hoc test)

Dependent Variable	(I) volume	(J) volume	Mean Difference (I-J)	Std. Error	Sig.
t1-t2	100%	50%	2.41550	.69444	.003*
		Control	1.09150	.69444	.365
	50%	100%	-2.41550	.69444	.003*
		Control	-1.32400	.69444	.185
	Control	100%	-1.09150	.69444	.365
		50%	1.32400	.69444	.185
t2-t3	100%	50%	8.52300	1.33917	.000*
		Control	8.62100	1.33917	.000*
	50%	100%	-8.52300	1.33917	.000*
		Control	.09800	1.33917	1.000
	Control	100%	-8.62100	1.33917	.000*
		50%	-.09800	1.33917	1.000

* The mean difference is significant at the 0.05 level.

Field-Emission Scanning Electron Microscopy (SEM)

Representative SEM images of enamel surfaces of the control group that was treated with whitening toothpaste and test group with 100% volume of silicon oxide following loading

with hydrodynamic shear forces are displayed in Figures 1 and 2. On the enamel surface of the control tooth, surface roughness, enamel pores and superficial irregularities are visible. The aprismatic surface layer can also be observed. Compared to the control tooth, the enamel surface layer treated with 100% volume silicon oxide is smoother with less visible enamel pores and surface roughness.

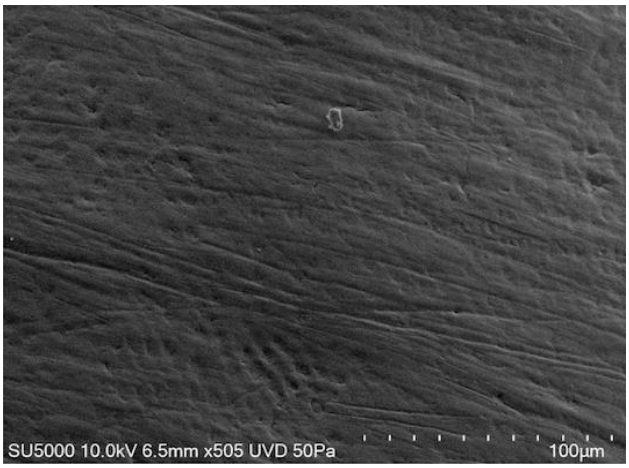

Figure 1. Electron micrographs of the enamel surface treated with whitening toothpaste after hydrodynamic shear loading at x1000 magnifications.

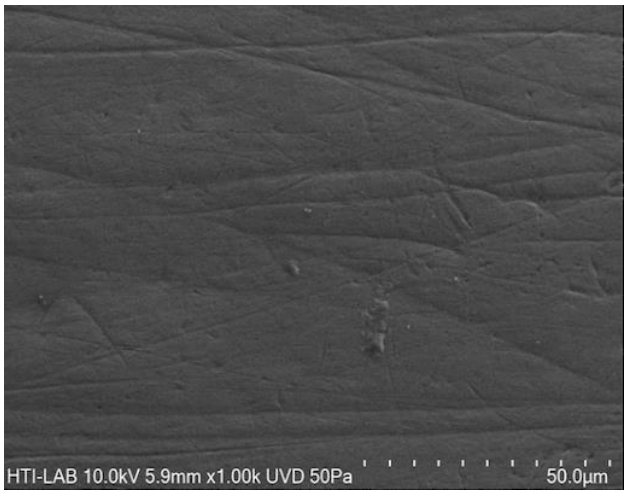

Figure 2. Electron micrographs of the enamel surface treated with 100% volume silicon oxide after hydrodynamic shear loading at x1000 magnifications.

DISCUSSION

The market is flooded with whitening products, most of which contain peroxides as the bleaching agent. Although these peroxide-based materials effectively whiten teeth, on occasion, they may cause irreversible damage to the surface of teeth or tissue irritation.[5], [6]

Porosity, depressions, surface erosion, increased depth of enamel grooves, removal of the aprismatic layer and loss of interprismatic substance, were some of the reported microtrographic changes that occurred following tooth bleaching and laser activated tooth bleaching [7]. In addition to this, direct contact with high concentration of peroxide-based materials with the tissues can cause severe irritation and tissue burns [8].

Other non-peroxide whitening agents have been described in the literature for the whitening of vital teeth. An example of this is the use of hydroxyapatite (HAP) instead of oxidizing chemicals. Deposition of HAP that is concentration dependent attaches to the enamel through a process of remineralization and diffuses reflection of light from the tooth surface, resulting in a brighter appearance of the tooth [9]. Similarly, in this study, it was observed under the SEM that the applied silicon oxide complex forms a layer that covers the enamel prisms resulting in a smoother and denser surface of enamel with fewer enamel pores and grooves when compared to the control group.

The indication of silicon oxide complex or liquid bio-glass is for repair and protection of the enamel. Other indication includes brightening of teeth. The material mechanically and chemically adheres to enamel following application, and thus is not readily removed by tooth brushing. The thickened enamel surface covered with aligned Si-Fluorapatite in its structure contributes to the brightening of the enamel and increases its opacity level [4].

Several methods are available for measuring the colour of teeth and the colour changes that takes place during tooth whitening procedures. In this study, colour differences or efficacy due to the whitening effect were quantified with a spectrophotometer. It has been reported that Easyshade only produced repeatable results in 50% of the measurements in a clinical study [10]. However, it has also been concluded that Easyshade is one of the most reliable colour measuring devices on the market, in both in-vitro and in-vivo measurements [11]. Reproducible results may be obtained when the probe tip of the spectrophotometer is placed on the same site of the tooth during each measurement. In our study, all the teeth were indexed in silicon blocks with depression made corresponding to the diameter of the spectrophotometer tip to allow for 90° contact between the tip and the buccal surface of the extracted tooth during shade measurement. All measurements were made against a neutral grey background.

The Commission International de 1'eclairage (CIE), or International Commission on Illumination, defined a colour space as three axes L*, a* and b*. The L* value is a measure of the lightness of an object and is quantified on a scale such that a perfect black has an L* value of zero and an ideal reflecting diffuser an L* value of 100. The a* value is a measure of redness (positive a*) or greenness (negative a*). The b* value is a measure of yellowness (positive b*) or blueness (negative b*). The a* and b* co-ordinates approach zero for neutral colours (white, greys) and increase in magnitude for more saturated or intense colours [12].

In this study, it appears that immediately following application of 50% and 100% concentration of silicon oxide complex on the tested teeth, the limited interaction within the short duration did not result in a significant change in the colour of these teeth compared to the control group. However, following 24 hours, colour changes (ΔE) of the teeth tested with 100% concentration of silicon oxide material was significantly higher when compared to the control. The explanation for this could be that the slow hydrolysis of the silicon dioxide compound and uptake into the enamel reduce the subsurface chromogenic ions and contribute to teeth whitening in addition to the enamel coating of the enamel layer that alters its surface reflectance. Hydrodynamic shear forces were applied to the tooth surface of the control and

test groups to test the stability of the colour changes (ΔE) by trying to reduce the amount of attached material on the enamel surface. The results revealed that the colour changes at t3 were significant following the application of the hydrodynamic shear forces indicating the stability of the bond of the silicon oxide complex on the enamel.

Artificial saliva or fluoride products have been used between or after treatments to simulate the clinical situation more closely. It has also been reported that the less deionized mineral water could prevent HAP particles in suspension from dissolving before they reacted with the enamel surface [13]. To avoid interference with the potential remineralisation compounds, artificial saliva was not used as the storage solution instead mineral water was used as a storage solution.

Also, the durability of the effect of this silicon complex-based material on enamel surfaces was evaluated using a sonic toothbrush that operated at 20,000 pulsations and 7,600 oscillations per minute. The effectiveness of sonic toothbrush systems to generate the fluid dynamic shear forces has been addressed by several studies [14], [15]. Future clinical studies should evaluate the durability of these materials on the enamel surfaces following shear forces generated from the lip and cheeks and also the effects of food.

CONCLUSION

In conclusion, silicon oxide complex tested exhibited whitening effects of the enamel surface by variable degrees reflected by increase in ΔE and showed excellent durability against the hydrodynamic shear forces. SEM investigation demonstrated a smoother and denser enamel surface. The present data demonstrated that the silicon oxide complex containing material is an attractive biomimetic agent for improvement of tooth colour.

ETHICAL COMPLIANCE

The authors declare no potential conflict of interest concerning the authorship and publication of this article. This study was funded by Exploratory Research Grant, Ministry of Higher Education Malaysia. Informed consent was obtained from each individual participant involved in this study. This study was conducted with the ethical standards of the responsible committee on human experimentation in accordance with the Helsinki Declaration of 1975. The study protocol was approved by the Ethics Committee of University Teknologi MARA, Shah Alam Selangor, Malaysia reference number: 600-RMI (5/1/6).

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