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Research Paper

The effect of whitening toothpastes on color change in discolored esthetic restorative CAD/CAM material

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Abstract
Aim. *The aim of this in vitro study was to evaluate the efficacy of toothpastes with whitening properties in the color change of resin nano-ceramic and hybrid CAD/CAM materials after exposure to a coffee solution, through simulated brushing.*
Methods. *In this study, a total of 80 samples were prepared from two different color resin nano-ceramic (Lava Ultimate, 3M ESPE), a hybrid CAD/CAM material (Vita Enamic VITA Zahnfabrik), and a resin based CAD/CAM material (Cerasmart, GC Corporation). The initial color of each sample was measured, and the color difference values (ΔL, Δa, Δb, and ΔE) were calculated after immersing them in distilled water. The color change (ΔE2000) values were then recorded after samples were stored in a coffee solution for 24 hours. Then, the samples were divided into two subgroups (n=10), and subjected to 5000 cycles in a brushing simulator with two different whitening toothpastes (Opalescence and Sensodyne Nourish). The normality of the data was assessed using the Shapiro-Wilk test, and for non-normally distributed delta E values, the Paired two-sample t-test and Wilcoxon test were used to make comparisons.*
Results. *Statistical analysis revealed significant differences (p<0.001, p=0.001) in the color change of the samples brushed with Sensodyne Nourish toothpaste after being stored in coffee solution. However, in the other subgroup where whitening toothpaste was applied, there was no significant difference (p>0.05) observed, despite Lava Ultimate material exhibiting the greatest color change.*
Conclusion. *The toothpastes utilized in the study, each possessing varying degrees of whitening properties, were found to be successful in visibly reducing the coffee induced discoloration and producing a visible whitening effect. Additionally, the resin nano-ceramic materials exhibited the greatest color change compared to other materials used in this study.*
Keywords: *Color change, whitening toothpaste, CAD/CAM material, brushing*

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I. Introduction

With the growing demand for esthetic dentistry, tooth colored restorative materials have become a popular choice in clinical applications. Achieving a color match with healthy dental tissues during restorative procedures and maintaining the color of the restoration over time is crucial for successful and clinically long lasting treatment. Several properties of dental restorations, including color stability, surface gloss, and surface roughness, are essential factors in determining their esthetic performance (1). Nevertheless, ensuring the color stability of ceramic restorations is crucial for meeting the esthetic expectations of patients. This can be accomplished by meticulously choosing the type and composition of ceramic material, as well as implementing appropriate surface treatments (2). CAD-CAM systems have revolutionized the production of inlays, onlays, veneers, and crowns, utilizing prefabricated CAD-CAM blocks made of various materials to create dental restorations. The tooth colored CAD-CAM materials available traditionally include composite resin or silicate ceramics such as lithium disilicate glass ceramic, leucite reinforced or feldspathic ceramic. However, novel composite resin and ceramic components have been introduced to the market, allowing for more diverse options. These materials include Vita Enamic from Vita Zahnfabrik, which includes a feldspathic based ceramic network and a reinforcing polymer network, Lava Ultimate from 3M ESPE, which contains nanoceramic particles bound in a resin matrix, and as an alternative to ceramic blocks, GC composite resin CAD-CAM blocks have been introduced in the form of GC Cerasmart. This innovative material from GC offers a composite resin option for dental restorations manufactured using CAD-CAM technology (3,4). Resin-based materials used in dental restorations possess physical properties that closely resemble those of natural teeth structures. However, the optical properties of all materials can change over time due to aging, which may negatively impact their esthetic outcome (5). The physical and mechanical properties of dental restorations can be adversely affected by patients oral habits and exposure to various clinical procedures (6). Factors that can contribute to this include daily consumption of citric or acidic foods and beverages such as tea, coffee, lemon and carbonated drinks, sudden changes in oral temperature due to hot or cold drinks and food, and the use of various toothpaste during brushing (7,8).

Whitening toothpastes are widely available products that can be used daily without the need for dental supervision, making them a popular choice for many individuals. These toothpastes can help to enhance the esthetic appearance of teeth by gradually reducing extrinsic stains over time. To achieve this whitening effect, many whitening toothpastes contain specific agents such as peroxides, polyphosphates, adsorbent particles, agents with optical properties and most importantly abrasives (9).

The surface color stability of a material can be influenced by its wear resistance, and if a material is deteriorating, it may exhibit color change. To assess the longevity of dental materials, laboratory wear tests such as artificial brushing can be utilized. In this in vitro study, the color change of various chairside CAD-CAM restorative materials were assessed before and after simulated brushing. The study aimed to test the null hypotheses that the type of material and whitening toothpaste after brushing would not have an impact on color stability of the tested dental materials.

II. MATERIAL AND METHODS

Samples preparation

Table 1 represents the materials used and examined in this study. The ceramic dental materials used included A1 and A3 colored resin nanoceramics (Lava Ultimate, 3M ESPE, St Paul, MN, USA), an A1 colored hybrid CAD/CAM material (Vita Enamic VITA Zahnfabrik, Bad Säckingen, Germany), and an A3 colored resin based CAD/CAM material (Cerasmart, GC GC EUROPE, Leuven, Belgium). Using water cooling with a cutter (Micracut 201; Bursa, Turkey), the blocks were sliced into rectangular specimens measuring 12 mm wide and 14 mm long, with thicknesses of 1.2 mm. Following the determination of the optimal sample size for each group, a total of 80 specimens were produced. To ensure consistency in surface quality, both sides of the specimens were polished with 600, 800, 1000 and 1200 grit carbide paper while being cooled with water for a duration of 30 seconds. The specimens were subsequently cleaned and dried with clean towel paper. The universal polishing paste was applied to finish and polish the specimens surface (Universal Polishing Paste, Ivoclar Vivadent, Schaan, Liechtenstein).

Table.1 . Summary of tested materials and toothpaste manufacturers and compositions

Material group	Product	Manufacturer	Composition/Ingredients
Resin nanoceramic block	3M Lava Ultimate	3M ESPE, St Paul, MN, USA	BisGMA, TEGDMA, UDMA, BisEMA 20%, SiO2 (20 nm), ZrO2 (4-11 nm), aggregated ZrO2/SiO2 microcluster 80%
Nanoceramic block	GC CeraSmart	GC EUROPE, Leuven, Belgium	Bis-MEPP, UDMA, DMA 29%, Silica (20 nm), barium glass (300 nm) 71%
Polymer-infifiltrated ceramic-network block	VITA ENAMIC	VITA Zahnfabrik, Bad Säckingen, Germany	UDMA and TEGDMA 14%,Fine-structure feldspar ceramic with aluminum oxide 86%
Whitening toothpasta	Opalecence	Ultradent Products, Inc., USA	Sodium Fluoride 0.25%, w/w,Glycerin,water(Aqua), Silica,Sorbitol Xylitol,lavor(aroma), Poloxamer, Sodium Lauryl Sulfate, Carbomer, (Cl 42090),(Cl 19140), Sodium Benzoate, Sodium Hydroxide, (Cl 77019 Cl 77891), Sucralose, Xanthan Gum
Whitening toothpasta	Sensodyn Nourish	GlaxoSmithKline, London,	Aqua, Sorbitol, Hydrated Silica,

		UK	Glycerin, Potassium Nitrate, Sodium Lauryl Sulfate, Aroma, Xanthan Gum, Cocamidopropyl Betaine, Sodium Saccharin, Titanium Dioxide, Limonene, Benzyl Alcohol, Sodium FLuoride %0.315 w/w (1450m)

Immersion of the samples

Each material group was randomly divided into two groups (n=20) and immersed in coffee solution (Nescafe Gold, Nestle, Switzerland). To prepare the coffee solution, 3.6 grams of coffee were dissolved in 300 mL of distilled boiling water, following the recommended concentration provided by the manufacturer. The solution was stirred for 10 minutes and subsequently filtered through filter paper. After being immersed in the coffee solution for 24 hours, the specimens were rinsed with distilled water for a period of 5 minutes and then gently dried with clean towel paper.

Simulated toothbrushing

Following the immersion into coffee solution, all specimens were divided into subgroups (n=10) and subjected to brushing using an artificial toothbrushing stimulator (DentArGe TB-6.1 , Analitik Medikal, Turkye). Toothbrushing simulation was carried out using a medium toothbrushes (Denta, Banat Medium, Istanbul, Turkey). A 3.5 N load was applied to the specimens during brushing. Each brushing cycle consisted of 5 000 cycles, with a toothpaste slurry and a 1:1 ratio of distilled water and whitening toothpastes Opalescence (Ultradent Products, Inc., USA) and Sensodyne Nourish (GlaxoSmithKline, London, UK) used. This regimen was consistent with the recommendations for twice daily brushing. Toothbrushes and the slurry of the toothpaste was replaced after every cycle was done.

Color measurements

At the begging all the samples underwent initial color measurements (T0) using a spectrophotometer Vita Easyshade (Advance 4.0, Vita Zahnfabrik, Bad Sackingen, Germany) on a white background. Prior to taking measurements, the spectrophotometer was calibrated according to the manufacturer's instructions. Following 24 hours of immersion in the coffee solution, the specimens were rinsed with distilled water and then dried with clean towel paper before color measurement (T1). The spectrophotometer was used as previously described to measure the color of the specimens after being stored in coffee solution. The samples were cleaned before measuring, and their color values were determined using ΔL, Δa, and Δb parameters. The initial ΔL, Δa, and Δb values of the samples were used as a reference point for calculating the color difference resulting from coffee immersion and toothbrushing. The CIEDE2000 formula (ΔE00) was employed to detect staining or whitening values caused by the experimental conditions, and three consecutive measurements were taken in the central areas. The mean values of the ΔL, Δa, and Δb parameters were used. The assessment of color stability in restorative materials is commonly evaluated based on acceptability threshold (AT) and perceptibility threshold (PT) values for color differences. A ΔE00 value equal to or less than the PT indicated an excellent match in color, while a ΔE00 value between the PT and AT was rated as an acceptable match with observable but acceptable color differences (10,11).

Statistical analysis

The statistical analysis was carried out using IBM SPSS V23 software. The normality of the data was tested using the Shapiro-Wilk Test. Generalized linear models were employed to compare the color changes in ΔE00, ΔL, Δa, and Δb based on exposure time and whitening toothpastes effect. For non-normally distributed delta E values, the Paired two-sample t-test and Wilcoxon test were used to make comparisons. The results were reported as mean ± standard deviation, with a significance level of $p < 0.050$.

III. RESULTS

Table 2 represents the average and standard deviation of color for both the two whitening toothpaste variants, as well as the dental restorative materials at the baseline and after the application of the whitening toothpastes. For 24 hours time intervals, dental materials displayed significant variations in color change for all toothpaste investigated. According to the initial color values, the whitening toothpastes caused color changes of different degrees in the resin based CAD/CAM blocks. The Cerasmart and Lava Ultimate exhibited the most significant color change, after brushed with whitening toothpastes (($p=0.001$) ($p<0.001$), respectively). Whereas the Vita Enamic displayed no color change before or after brushing with both whitening toothpastes (p values 0.605, 0.077, respectively). In comparison to all the other materials that were tested, Sensodyne Norish demonstrated the highest degree of whitening efficacy, with the exception of Vita Enamic. Statistical analysis indicated that the observed differences were significant ($p< .05$). The examination of the whitening effect of toothpastes on hybrid CAD/CAM blocks did not show any significant statistical difference (p> .05). Lava Ultimate showed the highest ΔE (3.02, 3.43) values after brushing, followed by Cerasmart (ΔE 2.13) according to statistics results.

Table 2. ΔE00 values (mean and standart deviation) of CAD-CAM blocks after 24 hours of immersion in coffee solution and toothbrushing

Tested groups	Delta E00 before brushing		Delta E00 after brushing		p
	mean ± deviation	Median (min. - max.)	mean ± deviation	Median (min. - max.)	
C1O	2,01 ± 1,10	1,43 (0,98 - 3,82)	2,83 ± 1,59	2,92 (0,93 - 5,96)	0,093**
C1S	**1,18 ± 0,68**	**1,02 (0,56 - 2,47)**	**2,13 ± 0,61**	**1,99 (1,43 - 3,34)**	**0,001***
L1O	**2,00 ± 1,00**	**1,67 (0,82 - 4,07)**	**3,43 ± 1,24**	**3,37 (2,03 - 6,26)**	**<0,001***
L1S	**1,71 ± 0,41**	**1,71 (1,07 - 2,37)**	**3,02 ± 0,61**	**3,07 (2,20 - 4,18)**	**<0,001***
L3O	1,54 ± 0,30	1,55 (1,08 - 1,97)	1,16 ± 0,92	0,78 (0,47 - 3,16)	0,241**
L3S	**2,42 ± 2,37**	**1,71 (0,58 - 8,73)**	**1,18 ± 0,90**	**0,83 (0,47 - 3,16)**	**0,028****
V3O	0,89 ± 0,66	0,73 (0,12 - 2,08)	1,00 ± 0,41	1,16 (0,29 - 1,47)	0,605*
V3S	1,04 ± 0,49	0,89 (0,48 - 1,94)	1,78 ± 0,82	1,76 (0,56 - 2,98)	0,077*

C1O: A1 colored, Cerasmart- Opalecence; C1S: A1 colored, Cerasmart- Sensodyn Nourish; L1O: A1 colored, Lava Ulitmate-Opalecence; L1O: A1 colored, Lava Ultimate- Opalecence; L3O: A3 colored, Lava Ultimate-Opalecence; L3S: A3 colored, Lava Ultimate- Sensodyn Nourish; V3O: A3 colored, Vita Enamic- Opalecence; V3S: A3 colored, Vita Enamic- Sensodyn Nourish
* Paired two-sample t-test, **Wilcoxon test
Significantly different at p<.05.

IV. DISCUSSION

The null hypotheses, which proposed that whitening toothpastes would not have an impact on the color stability of various types of dental CAD/CAM materials under brushing simulation, was partially accepted when the toothpaste exhibited a noticeable whitening effect only on discolored resin based restorative materials. The research was intended to replicate a situation where patients who consume coffee are interested in undergoing a whitening procedure to enhance the visual appearance of their discolored ceramic restorations. The selection of coffee as a colorant was based on two factors: its widespread popularity among individuals and its notable impact on various dental materials. The coffee immersion period was structured so that 24 hour cycle of exposure to coffee replicated one month of staining on the material being tested (12). The samples color was assessed 24 hours after coffee immersion and brushing with the previously mentioned toothpastes. Results suggests that the brushing with whitening effect toothpastes resulted in a notable change of color in resin based CAD/CAM dental materials. Of all the CAD/CAM materials that were examined, Vita Enamic, a hybrid ceramic material that contains a polymer infiltrated ceramic network, exhibited the lowest susceptibility to color change resulting from brushing with whitening toothpaste. Nevertheless, Cerasmart, and Lava Ultimate, a nanoceramic blocks were observed to be the most susceptible to color changes. In this study, the type of resin matrix and filler used in a material were found to be directly linked to its discoloration. While the extent of color change on dental materials may differ based on the duration of exposure to beverages, generally tea, coffee, and red wine have the most substantial impact on causing color changes (13). Alternatively, the chemical composition, size, and type of materials filler particles may have an impact on color change. The resistance of materials to discoloration is influenced by the physicochemical properties of the monomers used in the resin matrix. The water absorption rate of resins containing Bis-GMA is dependent on the concentration of TEGDMA in the material. The presence of the monomer TEGDMA in certain resin composites makes them more prone to absorbing water, leading to increased solubility of the resulting material (14). As a result, the color stability of the composite decreases, since the increase in polymer free volume provides more space for water molecules to penetrate into the polymeric structure (15,16). When a composite material is submerged in water, two processes occur: unbound molecules are rapidly released, and water slowly diffuses into the polymer matrix. The majority of water molecules fill up the free space between the chains and crosslinks, along with the microvoids generated during polymerization (17). Our findings can imply that the observed change in color may be linked to the enhanced water absorption of the tested CAD/CAM materials. According to the study conducted by Shree Roja et al. (2019), the nanoceramic composite displayed the greatest color change, which was attributed to structural distinctions. They reported that the highest color change in nanoceramic composites might be linked to such structural composition (18).

To measure discoloration in dental materials, various instruments can be employed. Spectrophotometers and colorimeters are preferred as they provide objective measurements, thereby eliminating any subjective interpretation of visual color comparisons (19). By utilizing the latest CIEDE2000 formula, the color differences were computed. The formula incorporates three different weighting functions, namely chroma, lightness, and hue. This updated system is considered to be a more accurate reflection of the human eye's ability to detect and accept color changes compared to its predecessors, as supported by existing research studies. Specifically, the term perceptibility is used to describe the smallest color difference that can be detected by the human eye, whereas acceptability refers to the level of color match that is deemed acceptable between a tooth and an adjacent restoration (10). The ΔE00 color differences for the sample pairs were determined by applying the CIEDE2000 color difference formula to the values of T0 and T1. In this study, the parametric factors of the formula were set at ΔE00 value greater than 1.28 units was considered as the perceptibility threshold, whereas a ΔE00 value of 2.25 units or less was regarded as the clinical acceptability threshold. This threshold was based on the results of previous research (20). After undergoing 5000 brushing cycles, the color change resulting from brushing for the Vita Enamic material was not visibly detectable, as the ΔE00 value was below 1.28. On the other hand, the color change for A1 colored Lava Ultimate, was noticeable but still considered acceptable, as the ΔE00 value ranged between 1.28 to 2.24. In contrast, the color changes observed in the Cerasmart and A3 colored Lava Ultimate materials were considered clinically unacceptable, as their ΔE00 values exceeded 2.24.

A wide range of whitening toothpastes are currently available in the market, which are primarily designed to prevent or treat discoloration of teeth. These toothpastes usually contain ingredients such as calcium carbonate, hydrated silica, calcium pyrophosphate, sodium bicarbonate, alumina, fluoride, perlite or dicalcium phosphate dihydrate. These ingredients help to diminish the appearance and intensity of discoloration by eliminating pigmented chromophores and biofilms that contribute to discoloration (21). Toothpaste manufacturers use a range of abrasive systems, but the most commonly employed ones are derived from silica and calcium carbonate. Research has demonstrated that hydrated silica is highly effective at removing stains and cleaning teeth (22,23). Two of the toothpastes in this study contained similar ingredients, with silica and hydrated silica being the primary abrasive used. Therefore, the whitening results for each toothpaste were similar due to this common ingredients. Sensodyne Norish toothpaste contain only one abrasive agent, which is hydrated silica, as a whitening ingredient. However, despite the absence of other whitening agents commonly found in toothpastes, Sensodyne Norish has demonstrated superior whitening effectiveness. This suggests that the contribution of abrasive agents to the overall whitening effect cannot be underestimated. Typically, toothpaste manufacturers only disclose the types of abrasives they use, without providing information on the specific characteristics of these abrasives. For instance, even two toothpastes that utilize silica with similar particle sizes may exhibit different levels of whitening effect when tested. In a recent study by Dursun et al. (2022), the same toothpaste examined in our study, Opalesecence among others was utilized on enamel surface, and the researchers found that all of the whitening toothpastes tested produced a clinically acceptable level of color change. Furthermore, no significant differences were observed between the various groups (24). Another study conducted recently by Yılmaz et al. (2021), investigated the efficacy of whitening toothpastes, conventional toothpastes, and two different whitening agents in restoring the color of coffee stained composite resins. The study findings indicated that there was no statistically significant difference in ΔE values before and after brushing across all groups. The study also suggested that effective tooth brushing practices were more crucial than the type of toothpaste used in achieving effective stain removal (25). Another study conducted by Hashemikamangar et al. (2020), investigated the color change of composite resins following brushing with conventional and whitening toothpastes at the 1, 7, 30, and 90 day respectivly. The results of the study demonstrated that there were no clinically detectable color changes in the composite resins at any of the time points tested (26). Studies assessing color stability may yield inconsistent results due to variations in methodology. Some studies may not employ a polishing protocol on specimen surfaces following restoration. If resin material surfaces are not polished, the inhibition layer may not be removed, leading to the accumulation of extrinsic pigments. In this study, polishing was utilized on specimen surfaces to emulate clinical conditions, ensuring consistency in methodology.

V. CONCLUSION

The results of this study indicate that regular use of any of the tested whitening toothpastes can provide an effective whitening approach. Other factors, such as the presence of whitening agents and the method of use, can also contribute to the effectiveness of a whitening toothpaste. Therefore, it is important for dental professionals to consider various factors when recommending a whitening toothpaste to their patients, including the patient's individual needs, preferences, and oral health status. These findings may be useful in guiding patients in selecting a whitening toothpaste as an option. However, the study is limited in that it was conducted in vitro, a limited number of toothpastes were tested, there were a limited number of specimens, and the evaluation period was short. Consequently, these limitations should be taken into account when interpreting the results. Future studies should investigate the long term effects of whitening toothpastes and assess these outcomes through clinical studies.

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