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COLOR STAINABILITY OF GRAPHENE-REINFORCED PMMA COMPARED TO CAD/CAM PMMA IN DIFFERENT pH MEDIA

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ABSTRACT

Statement of problem: CAD/CAM PMMA needs to improve its color stability as used for long-term provisional restoration.

Purpose: To evaluate the nanographene-reinforced PMMA surface roughness after thermocycling and color stainability after immersion in coffee and ginger (two different pH media) to frequently used pre-polymerized PMMA.

Methods: Sixty CAD/CAM interim materials discs were divided into two groups (n=30): PMMA (P) and graphene-reinforced PMMA (G). All specimens were polished according to the manufacturer's instructions, followed by artificial accelerated aging. Surface roughness (Ra) was analyzed using a non-contact profilometer. Then, both tested groups were immersed in 3 different pH media (coffee, ginger, and distilled water) (n=10) for 3 and 7 days. The color difference (ΔE) was assessed. All data were statistically analyzed.

Results: Thermocycling did not significantly change mean Ra (P-value = 0.172, Effect size = 0.150) between tested materials. After 3 days of coffee or ginger immersion, group (P) showed a significant decrease in mean ΔE compared to group (G). The two materials were not statistically different after distilled water immersion. After 7 days of coffee immersion, group (P) showed a significant rise in mean ΔE compared to group (G). After ginger immersion, the two materials did not differ significantly. After distilled water immersion, group (P) showed a significant reduction in mean ΔE compared to group (G). However, both materials showed unacceptable color change clinically (ΔE > 3.3).

Conclusion: Nanographene-reinforced PMMA had no significant improvement regarding surface roughness after thermocycling and color stainability after immersion in different pH media compared with frequently used CAD/CAM PMMA.

KEYWORDS: Nanographene, CAD/CAM PMMA, graphene-reinforced PMMA, color stainability, and surface roughness.

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INTRODUCTION

Polymethyl methacrylate (PMMA) is frequently utilized in manufacturing dental prosthetic restorations owing to its biocompatibility, easiness of manufacturing, and cost-effectiveness.[1,2] Nonetheless, conventionally processed PMMA possesses intrinsic weaknesses.[3] Advancements in computer-aided design and computer-aided manufacturing (CAD/CAM) have led to the emergence of pre-polymerized PMMA discs as an alternative. Although pre-polymerized PMMA shares a similar chemical composition with standard PMMA, it demonstrates superior mechanical properties resulting from high-temperature and high-pressure processing.[4] CAD/CAM technology facilitates the subtractive manufacturing of composite resins suitable for the creation of permanent prostheses.

Prior research has demonstrated the application of several strengthening agents to enhance the PMMA's mechanical properties.[5] Nanotechnology has permitted the incorporation of graphene in PMMA to recently formulated a novel nanographene-reinforced prepolymerized PMMA (G-CAM; Graphenano Dental, Valencia, Spain) for application in permanent prosthetics.[6] Although there are reports on the properties of PMMA reinforced with nanographene, there is a deficiency of studies that directly compare this material with other available comparable alternatives.[7-9]

Surface roughness and stainability are critical attributes for visually pleasing restorative materials.[10-12] A 0.2 mm surface roughness has been established clinically as the maximum permissible amount for bacterial plaque deposition.[3,4,11] The incorporation of nanoparticles might influence the surface roughness of resins, particularly considering the vulnerability of resin-based materials to thermal variations and moisture absorption. Additionally, acidic staining solutions adversely affect the long-term stain resistance of intermediate materials by infiltrating their matrix and compromising their integrity.[10,11] However, the effect of beverage-induced alterations in intraoral temperature on the surface roughness and stainability of nanographene-reinforced CAD/CAM PMMA has not been well investigated.

This investigation aimed to evaluate the surface roughness of graphene-reinforced PMMA resin and CAD/CAM PMMA interim material before and after thermocycling, as well as to assess the color difference of these materials following immersion in various staining pH media for different durations. The null hypotheses posited that graphene-reinforced PMMA resin would exhibit reduced surface roughness during thermocycling and enhanced color stability after exposure to various pH media over any storage duration, as compared to PMMA resin.

MATERIALS AND METHODS

Sepcimens preparation

This power analysis employed surface roughness (Ra) as the principal outcome measure. According to the findings of Tasın S et al.,[13] and utilizing an alpha (α) level of 5% and a beta (β) level of 0.8 (Power = 80%), the effect size (d) was determined to be 1.86, necessitating a minimum estimated sample size of 7 specimens per group that was increased to 10 specimens. The sample size computation was conducted utilizing a sample size calculation software (G*Power; Version 3.1.9.2, HHUD, Germany).

A virtual disc plate (10×2 mm) was designed using a software program (Dental CAD 3.1 Rijeka; Exocad, GmbH, Darmstadt, Germany). Sixty milled specimens were produced utilizing a 5-axis milling machine (DWX-52D Plus; Roland DGA Corporation, Japan) from CAD/CAM PMMA blocks (PMMA DISK, shade: A2; Yamahachi Dental MFG., Aichi Pref., Japan) (n=30) and CAD/

CAM graphene-reinforced PMMA (G-CAM, shade: A2; Graphenano Dental, Valencia, Spain) (n=30) according to the saved design.

The disc's surfaces were subjected to polishing as recommended by the manufacturers.[14] Then, they were subjected to cleaning with a steam cleaner (Wasi-Steam 2; Wassermann Dental-Maschinen, Hamburg, Germany), after that undergoing ultrasonic cleaning in distilled water (Sonorex Super; Bandelin, Berlin, Germany) for 5 minutes and air dried.[14]

Surface Roughness Analysis Before Thermocycling

A non-contact optical technique was applied to examine the surface topography of all discs quantitatively.[15] A USB digital microscope adjusted at 90× magnification (Scope Capture Digital Microscope; Guangdong, China) equipped with a built-in 3 MP resolution camera (U500X Capture Digital Microscope; Guangdong, China). This camera was utilized to take 20 images for each specimen. Eight tunable LED lights for illumination were utilized, featuring a color rendering index near 95%. The photos were recorded and subsequently cropped and examined in 3 dimensions (3D) utilizing software (WSxM,v5.0 Develop 4.1; Nanotec Electronica S.L., Madrid, Spain) to generate 10 × 10 μm 3D images (Fig. 1 A and B). The system calibration converted pixels into absolute real-world units (μm) to assess the average heights (Ra), regarded as a reliable surface roughness index.[16]

Thermocycling

The discs were subjected to accelerated artificial aging (Thermocycler TC4, SD Mechatronik GmBH, Feldkirchen-Westerham, Germany®), cycling in distilled water at 5°C and 55°C for 5,000 cycles, with each temperature maintained for 30 seconds and a 10-second transfer time between baths, in accordance with ISO/TR 11405:1994 simulating 6 months of clinical service.[17]

Surface Roughness Analysis After Thermocycling

After thermocycling, the surface topography of all discs was assessed, as mentioned before (Fig. 1 C and D).

Baseline Color Assessment

Based on immersion in two distinct pH staining media and distilled water for the storage procedure, the specimens of each group were subsequently divided into 3 subgroups (n=10). A Reflective Spectrophotometer (Model RM200QC; X-Rite, Neu-Isenburg, Germany) was used to assess the quantitative baseline color parameters of each specimen in accordance with the CIE L*a*b* color space relative to the Commission Internationale de l'Eclairage (CIE) standard illuminant D65, where L* indicates lightness (0-100), a* represents the red/green axis, and b* denotes the yellow/blue axis using a white background (CIE L*= 88.81, a*= -4.98, b*= 6.09). The specimens were centrally located within the measurement port, which was adjusted to a 4 mm diameter. Each specimen was undergone for 3 measurements after the spectrophotometer calibration prior to each measurement, and then the average was recorded.

Staining

All staining solutions were prepared according to the manufacturer's instructions. For Turkish coffee, 10-12 g of coffee (Dark roasted plain; Abu Auf, Cairo, Egypt) was added to 100 mL of boiled water. While, 2 g of ginger (Royal Herbs, Giza, Egypt) was added to 100 mL of boiled water. Then, each coffee and ginger solution was agitated every 5 minutes for 10 seconds until they reached room temperature, after which they were filtered through filter paper. Distilled water (Health Aqua, Alexandria, Egypt) of 100 mL served as the control group.

Specimens were individually immersed in sealed vials containing 5 ml of each immersion media and maintained in an incubator (Model 431/V; CBM,

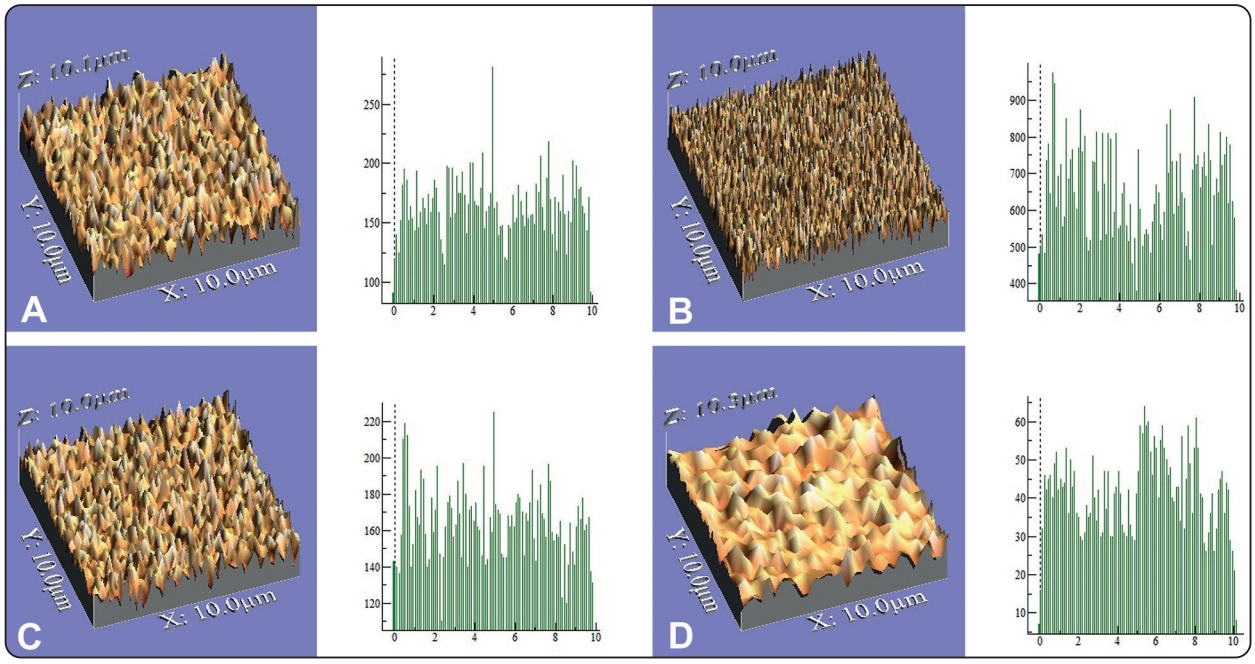

Fig. (1) 3D image and histogram for the disc surface of CAD/CAM PMMA (A and C) and graphene-reinforced PMMA (B and D) before and after thermocycling, respectively.

Torre Picenardi, Italy) at 37ºC in a dark atmosphere for 3 and 7 days, which correspond to 3 and 7 months of clinical usage.[18] The solutions were refreshed daily to prevent bacterial or yeast contamination, and they were replaced every two days throughout the test.[19] To diminish particle sedimentation in the staining solutions, the solutions were agitated bi-daily. At the end of the immersion period, specimens were rinsed with distilled water for 5 min and then rubbed with gauze, followed by tissue paper prior to the color reassessment.

Color Change (ΔE) Assessment

The color of each specimen was assessed after the various staining protocols outlined for baseline measurements. The color difference (ΔE) was determined using the subsequent formula: ΔE = [(L* post-staining – L* baseline)] 2 + (a* post-staining – a* baseline) 2 + (b* after staining - b* baseline 2)$^{1/2}$.

Statistical Analysis

Numerical data had a normal (parametric) distribution as they were assessed by examining the data distribution and utilizing normality tests (Kolmogorov-Smirnov and Shapiro-Wilk tests). Data were expressed as mean values and standard deviations (SD). Repeated assessments ANOVA test was employed to examine the influence of material type, thermocycling, and their interactions on the mean (Ra). It was utilized to examine the influence of material type, immersion medium, duration, and their interactions on the average color change (ΔE). Bonferroni's post-hoc test was employed for pairwise comparisons when the ANOVA test yielded significant results. The significance threshold was established at $P < 0.05$. Statistical analysis was conducted using statistics software (IBM SPSS Statistics for Windows, Version 23.0, IBM Corporation, NY, USA).

RESULTS

Surface roughness (μm)

The findings indicated that the type of material, independent of thermocycling, did not have a statistically significant impact on the mean Ra (P-value = 0.172, Effect size = 0.150). Thermocycling, irrespective of the material type, demonstrated a statistically significant impact on the mean Ra (P-value = 0.035, Effect size = 0.320). However, the lack of statistically significant impact in the interaction between the variables on the mean Ra (P-value = 0.309, Effect size = 0.086) indicates that they are independent of one another, as shown in Table 1.

After thermocycling, Group (P) showed no statistically significant change in mean Ra (P-value = 0.371, Effect size = 0.067). At the same time, Group (G) revealed a statistically significant decrease in mean Ra (P-value = 0.0320.309, Effect size = 0.330) as shown in Table 2.

Color change (ΔE)

The findings indicated that the type of material (independent of the immersion medium and duration) significantly influenced the mean ΔE, with a P-value <0.001 and an effect size of 0.546. Group (P) exhibited a statistically significant reduction in mean ΔE compared to Group (G).

The immersion medium, irrespective of the material type and duration, demonstrated a statistically significant impact on the mean ΔE (P-value <0.001, Effect size = 0.956). Pair-wise comparisons indicated that coffee exhibited the highest mean ΔE, which was statistically significant. The mean value for ginger was notably lower and statistically significant. Distilled water exhibited the statistically significant lowest mean ΔE.

The duration, irrespective of the material type and immersion medium, significantly influenced the mean ΔE, with a P-value <0.001 and an effect size of 0.890. There was a statistically significant increase in mean ΔE after seven days, regardless of the type of material and immersion medium.

The relationship among the variables demonstrated a statistically significant impact on the mean ΔE (P-value <0.001, Effect size = 0.966). The statistical significance of the interaction between the variables indicates that they are dependent on one another, as shown in Table 3.

Regarding the effect of different interactions of variables on ΔE, following 3 days of immersion in coffee or ginger, Group (P) exhibited a statistically significant reduction in mean ΔE compared to Group (G). Following immersion in distilled water, no statistically significant difference was seen between the two materials. Following 7 days of immersion in coffee, Group (P) exhibited a statistically significant increase in mean ΔE compared to Group (G). Following immersion in ginger, no statistically significant difference was observed between the two materials. Following immersion in distilled water, Group (P) exhibited a statistically significant reduction in mean ΔE compared to Group (G), as shown in Table 4.

In Group (P), immersion in coffee or ginger resulted in a statistically significant rise in mean ΔE after 7 days. In contrast, immersion in distilled water led to a statistically significant drop in mean ΔE. Group (G) exhibited a statistically significant reduction in mean ΔE following immersion in coffee after 7 days. No statistically significant change in mean ΔE was noted after 7 days of immersion in ginger. However, a statistically significant increase in mean ΔE occurred after 7 days of immersion in distilled water, as shown in Table 4.

TABLE (1) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for main effects of the two variables on Ra (μm).

Source of variation		Mean (μm)	SD	Type III Sum of Squares	df	Mean Square	F-value	P-value	Effect size (Partial eta squared)
Material type	**Group (P)**	0.2513	0.02	0.001	1	0.001	2.112	0.172	0.150
	Group (G)	0.2604	0.0251						
Thermocycling	**Before**	0.2661	0.0184	0.003	1	0.003	5.647	0.035*	0.320
	After	0.2455	0.0222						
Material type x Thermocycling interaction			0.001		1	0.001	1.129	0.309	0.086

df: degrees of freedom = (n-1), *: Significant at P ≤ 0.05.

TABLE (2) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between Ra (μm) with different interactions of variables.

Thermocycling	Group (P)		Group (G)		P-value	Effect size (Partial eta squared)
	Mean(μm)	SD	Mean(μm)	SD		
Before thermocycling	0.257	0.0152	0.2753	0.0175	0.058	0.267
After thermocycling	0.2455	0.0231	0.2454	0.0231	0.993	0.0001
P-value	0.371		0.032*			
Effect size (Partial eta squared)	0.067		0.330			

****: Significant at P ≤ 0.05.***

TABLE (3) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for main effects of the three variables on ΔE.

Source of variation		Mean	SD	Type III Sum of Squares	df	Mean Square	F-value	P-value	Effect size (Partial eta squared)
Material type	**Group (P)**	10.04	8.36	209.054	1	209.054	43.314	<0.001*	0.546
	Group (G)	13.19	7.83						
Immersion medium	**Coffee**	19.14 ^{A}	6.81	3752.708	2	1876.354	388.766	<0.001*	0.956
	Ginger	12.79 ^{B}	4.48						
	Distilled Water	2.9 ^{C}	1.3						
Time	**3 days**	10.15	7.87	180.074	1	180.074	290.839	<0.001*	0.890
	7 days	13.08	8.37						
Material type x immersion medium x time interaction			629.539		2	314.770	508.387	<0.001*	0.966

df: degrees of freedom = (n-1), *: Significant at P ≤ 0.05 and different superscripts indicate statistically significant difference between immersion media.

TABLE (4) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between ΔE with different interactions of variables.

Time	Immersion medium	Group (P)		Group (G)		P-value	Effect size (Partial eta squared)
		Mean	SD	Mean	SD		
3 days	**Coffee**	9.78 ^{A}	0.72	23.95 ^{A}	3.48	<0.001*	0.880
	Ginger	5.45 ^{B}	0.31	15.84 ^{B}	1.63	<0.001*	0.798
	Distilled Water	3.44 ^{C}	0.63	2.45 ^{C}	0.35	0.263	0.035
	P-value	<0.001*		<0.001*			
	Effect size (Partial eta squared)	0.607		0.945			
7 days	**Coffee**	25.62 ^{A}	1.32	17.24 ^{A}	3.44	<0.001*	0.709
	Ginger	14.71 ^{B}	0.63	15.18 ^{B}	1.61	0.603	0.008
	Distilled Water	1.22 ^{C}	0.21	4.5 ^{C}	0.45	0.001*	0.272
	P-value	<0.001*		<0.001*			
	Effect size (Partial eta squared)	0.954		0.867			

3 Vs. 7 days		P-value	Effect size (Partial eta squared)	P-value	Effect size (Partial eta squared)
	Coffee	<0.001*	0.975	<0.001*	0.876
	Ginger	<0.001*	0.931	0.125	0.064
	Distilled Water	<0.001*	0.434	<0.001*	0.398

: Significant at P ≤ 0.05, Different superscripts in the same column indicate statistically significant difference between immersion media.

DISCUSSION

Recently, prefabricated, pre-polymerized PMMA blocks for the CAD/CAM technology have been introduced.[11] These blocks are produced under optimal controlled conditions, utilized for temporary fixed dental prostheses, and exibit superior qualities compared to autopolymerizing temporary materials.[20,21]

The combined use of graphene-linked materials and polymers yields composites with enhanced mechanical properties. The improvements are notably evident even with a restricted quantity of filler incorporated into the polymer matrix. The use of graphene and carbon fillers has been shown to significantly boost the flexural strength of PMMA polymers, resulting in notable improvements in their physico-mechanical properties.[22, 23]

Current literature posits that darker materials exhibit greater color stability than lighter materials.[24-26] Mutlu-Sagesen et al. conducted research on color, revealing a correlation between the provisional materials and composites hue, and color alteration, with lighter materials exhibiting greater color change.[27] Consequently, the A2 shade was selected as the primary shade for the manufactured specimens. Moreover, A2 is a favored shade among prosthodontists.

Furthermore, earlier publications have proven that the specimen surface's smoothness and thickness influence the material's color stability;

thus, in the current investigation, the provisional restorative material thickness was standardized to 2 mm in accordance with prior research.[28-31] Nevertheless, Costa and Lima reported that the specimens' thickness had no significance.[32]

The surface roughness of dental materials subjected to oral conditions influences color change; therefore, a smooth and glossy surface is preferred.[33] In this study, samples underwent conventional polishing procedures and were maintained in distilled water at 37°C for 24 hours prior to immersion in solutions to eliminate residual monomer.[27]

Color stability is essential for the long-term provisional restorations' aesthetics utilized in lengthy prosthetic rehabilitation, which may be required for 6 months or longer.[1] In this investigation, samples were immersed in various pH media solutions for one week to replicate one year of beverage intake, with the oral cavity exposed to the beverages for 30 minutes daily.[34] This strategy does not accurately represent clinical reality. Nevertheless, a comparable procedure for assessing the color stability of interim restorations was utilized in prior investigations and deemed sufficient.[35,36]

The color difference was quantified using a spectrophotometer to possibly mitigate mistakes compared to a colorimeter and other visual methods.[37,38] The Commission International de L'Eclairage (CIE L*a*b*) uniform color scale is advantageous due to its organization in a nearly uniform 3D color space.[38,39] This system characterizes color based on human perception and quantifies it using 3 spatial coordinates. In the system, the L* value denotes lightness–darkness, the* value indicates the red-green color coordinate and the b* value signifies the blue–yellow position. Color change (ΔE*) is a mathematical computation that quantifies the direction and size of the disparity between two points in a 3D color space.[36] The ΔE* value assesses the perceived color change in materials resulting from a certain technique or elapsed time. A ΔE* value of 1 unit corresponds to a color variation that is discernible to approximately 50% of viewers under controlled settings.[39,41] ΔE* values ranging from 0 to 2 indicate imperceptible color differences, while values between 2 and 3 imply barely discernible color differences.[42] ΔE* values of 3.3 or higher are visually discernible and deemed clinically inappropriate by 50% of qualified observers.[39] Consequently, considering the ΔE* value to evaluate the color change has more impact than the L, a, and b values one by one.[29]

Commonly ingested beverages, including cola, tea, coffee, and red wine, are typically utilized in research investigating the color stability of restorative dental materials.[39] Consequently, the solutions utilized in the study were formulated for everyday application.[43]

The initial null hypothesis was dismissed. All materials exhibited acceptable and statistically insignificant Ra both before and following thermocycling. Moreover, thermocycling did not significantly impact the Ra values of PMMA materials. Nonetheless, G-PMMA exhibited reduced surface roughness upon thermocycling, which may be due to high micro-hardness by adding graphene nanoparticles to the matrix. However, differences in surface roughness and hardness depend on the method of fabrication and surface treatments.[44,45]

The incorporation of nanoparticles into the PMMA matrix did not markedly influence the surface roughness of PMMA in comparison to CAD/CAM PMMA. Consequently, the evaluated materials seem to exhibit resistance to prolonged exposure, as 5000 cycles equate to 6 months of intraoral use.[12,46] The mean Ra levels for each group above the plaque accumulation threshold of 0.2 mm, although they remained below the clinically undesirable threshold of 10 mm.[47] Consistent with the findings of the current work, Ionescu et al. and others showed that prepolymerized PMMA and G-PMMA exhibited comparable Ra values, irrespective of aging.[9,48]

It was indicated that alterations in color are affected by increased surface roughness, which facilitates stain infiltration.[9] Conversely, other research has demonstrated no association between surface imperfections and color alterations in restorative materials.[49] This aligns with the current study.

The length of time is crucial for the color stability of temporary restorative solutions. Reports indicated that an increase in dipping time resulted in much higher color variations.[50,51] Concerning Group (P), immersion in coffee or ginger resulted in a statistically significant rise in mean ΔE, whereas immersion in distilled water showed no significant change after seven days. This aligns with the findings of Lauvahutanon et al., who assessed the ΔE values of CAD/CAM blocks following immersion in coffee and water.[52] No significant color alteration was noted in the specimens immersed in water. However, those in coffee exhibited an elevated ΔE. Research indicated a significant color alteration in temporary materials caused by coffee.[9,53] The discoloration caused by coffee results from the adsorption and absorption of pigment particles. [9,53] The primary cause of discoloration in coffee solutions is tannic acid.[54] Coffee includes tannins, a type of polyphenol that dissolves in water. Tannins are a subclass of phenolic chemicals that induce an undesirable yellowish staining on teeth. Consuming just one cup of coffee daily might lead to discoloration. The impact of coffee pH may be linked to the resin's vulnerability to chemical erosion of the resin matrix caused by low pH, leading to the hydrolytic disintegration of filler particles and chemical deterioration, which may contribute to their discoloration.[54]

Moreover, low pH levels of the colorant immersion media can weaken the resin matrix, potentially leading to chemical erosion. This deterioration may lead to increased water absorption and subsequent discoloration.[55] Furthermore, the acidification of coffee generates high-molecular-weight, brown-hued nitrogenous chemicals known as melanoidins, which are chiefly accountable for coloring.[56]

The ginger extract comprises dark brown oleo-resin oil and several essential oils, predominantly green in color. The phenol component in ginger, when interacting with resin, could cause alterations in color stability. Phenol interacts with resin, resulting in H^+ ions from phenol binding to $CH3O^-$, which is liberated from the ester resin group, while the benzene moiety in phenol associates with the RCO group of esters. This ion exchange process weakens the binding of acrylic resin, resulting in a physical change in the polymer, including a change in color.[57,58] The alteration in color is also attributable to the phenol concentration, which can deteriorate polymers through water absorption.

Furthermore, in both examined materials, a statistically significant elevation in mean ΔE was observed following seven days of immersion in distilled water. The diffusion of resin into water significantly influences the properties and dimensions of polymers. Water absorbed by resin infiltrates the polymethyl methacrylate matrix, subsequently occupying a position between the polymer chains and disrupting their structure. The disrupted polymer chain facilitates mobility, hence weakening the chain link and resulting in the release of pigments from the acrylic resin. Weak bonds compromise the integrity of the polymer chain, altering its physical properties and resulting in color degradation and diminished aesthetic appeal of the resin.[59]

Group (G) exhibited a statistically significant reduction in mean ΔE following immersion in coffee after seven days. The inclusion of tannic acid might function as a crosslinker with graphene, perhaps enhancing the material's resistance to degradation as tannic acid onto graphene oxide

surface led to improved solubility/dispersibility in organic solvents, higher thermal resistance, and better antibacterial activity.[60]

The present investigation, akin to previous research, observed minimal color alteration in the PMMA specimens immersed in distilled water.[61,62] This condition arised because there were no substances that might induce discoloration in materials, and the pH of distilled water did not result in surface roughness due to its neutrality. Graphene-reinforced PMMA exhibited more color variations at pH 7 compared to alkaline and acidic pH environments.

In all groups, the mean ΔE values were greatest for coffee, followed by ginger and distilled water. These findings align with researches that evaluated the stainability of interim materials [63,64]

In the present investigation, after three days, PMMA exhibited a significant reduction in ΔE compared to G-PMMA in both coffee and ginger solutions. This may be attributable to acrylic-based products possessing a homogenous structure. The ability to adsorb and absorb solutions directly influences the color stability of homogenous PMMA-based materials. Despite the tested PMMA containing 98% PMMA[65], the manufacturer of G-PMMA, has not revealed its chemical composition. The increased vulnerability of G-PMMA to discoloration may be linked to its chemical composition, which may be more heterogeneous than that of PMMA. Consequently, further investigations into the chemical composition of the examined materials are required to substantiate this idea. Nonetheless, variations in chemical composition, such as particle size and distribution, monomer polarity, degree of cross-linking, initiator system, and pigment permanence, may influence material staining.

This interpretation contradicts the findings of Çakmak et al.,[9], who observed no color change and statistically insignificant lower ΔE values for G-CAM relative to PMMA following coffee thermocycling. However, a study examining the chemical composition of G-CAM is essential to validate this notion, as the G-CAM producer has not revealed its composition.

After 7 days, PMMA exhibited a much greater ΔE than G-PMMA in coffee. This may result from the continuous deterioration of PMMA when exposed to coffee. In contrast, the crosslinking of tannic acid with graphene in G-PMMA, might result in reduced color change compared to PMMA.

Numerous studies have indicated varying thresholds of color difference values, crossing 3.7, at which the human eye can perceive color shift.[29] In this investigation, a hue shift (ΔE*) exceeding 3.3 was deemed visually discernible and clinically undesirable. The results corroborated prior studies.[29,66]

The concentration of solutions utilized as everyday beverages varies significantly based on the type of cuisine and personal choice. Consequently, the concentrations employed in this investigation yield merely a broad approximation. Furthermore, no artificial saliva was utilized to replicate the oral environment in this investigation. Additionally, the included specimens possessed a planar surface. In clinical environments, several anatomical characteristics, such as grooves and pits, may exist, complicating the polishing process. At the same time, provisional restorations will have an uneven morphology with both convex and concave surfaces. Consequently, additional research is required to assess temporary prosthodontic restorations in vivo.

CONCLUSION

Nanographene-reinforced PMMA had no significant improvement regarding surface roughness after thermocycling and color stainability after immersion in different pH media compared with frequently used CAD/CAM PMMA.

REFERENCES

1. Guler AU, Yilmaz F, Kulunk T, Guler E, Kurt S. Effects of different drinks on stainability of resin composite provisional restorative materials. The Journal of prosthetic dentistry. 2005 Aug 1;94(2):118-24.
2. Sham AS, Chu FC, Chai J, Chow TW. Color stability of provisional prosthodontic materials. The Journal of prosthetic dentistry. 2004 May 1;91(5):447-52.
3. Ayuso-Montero R, Martinez-Gomis J, Lujan-Climent M, Salsench J, Peraire M. Influence of matrix type on surface roughness of three resins for provisional crowns and fixed partial dentures. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2009 Feb;18(2):141-4.
4. Rayyan MM, Aboushelib M, Sayed NM, Ibrahim A, Jimbo R. Comparison of interim restorations fabricated by CAD/CAM with those fabricated manually. The Journal of prosthetic dentistry. 2015 Sep 1;114(3):414-9.
5. Ali Sabri B, Satgunam M, Abreeza NM, N. Abed A. A review on enhancements of PMMA denture base material with different nano-fillers. Cogent Engineering. 2021 Jan 1;8(1):1875968.
6. The Graphenano Dental website. https://www.graphenano-dental.com/descargas-documentos/catalogo-gcam_en.pdf. Accessed September 5, 2022. https://www.graphenano-dental.com/descargas-documentos/catalogo-gcam_en.pdf
7. Agarwalla SV, Malhotra R, Rosa V. Translucency, hardness and strength parameters of PMMA resin containing graphene-like material for CAD/CAM restorations. Journal of the mechanical behavior of biomedical materials. 2019 Dec 1;100:103388.
8. Ciocan LT, Ghitman J, Vasilescu VG, Iovu H. Mechanical properties of polymer-based blanks for machined dental restorations. Materials. 2021 Nov 29;14(23):7293.
9. Çakmak G, Herren KV, Donmez MB, Kahveci Ç, Schimmel M, Yilmaz B. Effect of coffee thermocycling on the surface roughness and stainability of nanographene-reinforced polymethyl methacrylate used for fixed definitive prostheses. The Journal of Prosthetic Dentistry. 2023 Mar 1;129(3):507-e1.
10. Al Sunbul H, Silikas N, Watts DC. Surface and bulk properties of dental resin-composites after solvent storage. Dental Materials. 2016 Aug 1;32(8):987-97.
11. Dayan C, Guven MC, Gencel B, Bural C. A comparison of the color stability of conventional and CAD/CAM polymethyl methacrylate denture base materials. Acta Stomatologica Croatica. 2019 Jun;53(2):158.
12. Acar O, Yilmaz B, Altintas SH, Chandrasekaran I, Johnston WM. Color stainability of CAD/CAM and nanocomposite resin materials. The Journal of prosthetic dentistry. 2016 Jan 1;115(1):71-5.
13. Taşın S, Ismatullaev A, Usumez A. Comparison of surface roughness and color stainability of 3-dimensionally printed interim prosthodontic material with conventionally fabricated and CAD-CAM milled materials. The Journal of Prosthetic Dentistry. 2022 Nov 1;128(5):1094-101.
14. Tichy A, Simkova M, Schweiger J, Bradna P, Güth JF. Release of bisphenol A from milled and 3D-printed dental polycarbonate materials. Materials. 2021 Oct 7; 14(19): 5868.
15. Hassan SA, Beleidy M, El-Din YA. Biocompatibility and surface roughness of different sustainable dental composite blocks: comprehensive in vitro study. ACS omega. 2022 Sep 15;7(38):34258-67.
16. Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. Journal of Materials Science: Materials in Medicine. 2007 Jan;18:155-63.
17. Ziada A, Beleidy M. Effect of artificially accelerated ageing and different mouth rinses on color stability of veneered PEEK crowns. Egyptian Dental Journal. 2021 Jan 1;67(1-January (Fixed Prosthodontics, Removable Prosthodontics and Dental Materials)):497-507.
18. Shiozawa M, Takahashi H, Asakawa Y, Iwasaki N. Color stability of adhesive resin cements after immersion in coffee. Clinical oral investigations. 2015 Mar;19:309-17.
19. Al-Shami AM, Alshami MA, Al-Kholani AI, Al-Sayaghi AA. Color Stability of Nanohybrid and Microhybrid Composites in Common Yemeni Immersion Media Including Qishr, Coffee, and Qat: A Laboratory-Based Study.
20. Stawarczyk B, Ender A, Trottmann A, Özcan M, Fischer J, Hämmerle CH. Load-bearing capacity of CAD/CAM milled polymeric three-unit fixed dental prostheses: effect of aging regimens. Clinical oral investigations. 2012 Dec;16:1669-77.
21. Banerjee R, Banerjee S, Prabhudesai PS, Bhide SV. Influence of the processing technique on the flexural fatigue strength of denture base resins: An: in vitro: investigation. Indian Journal of Dental Research. 2010 Jul 1;21(3):391-5.

22. Ghosh M, Shetty S. Effect of addition of graphene and carbon nanotubes on flexural strength of polymethylmethacrylate-a comparative in-vitro study. J Evol Med Dent Sci. 2020 May 4;9:1494-9.

23. Swami P, Sanyal P, Guru R, Kore A. Comparative evaluation of multiwall carbon nanotubes and graphene on the impact strength and flexural strength of auto polymerized acrylic resin. Int J Curr Res. 2018;10:66262-70.

24. Uchida H, Vaidyanathan J, Viswanadhan T, Vaidyanathan TK. Color stability of dental composites as a function of shade. The Journal of prosthetic dentistry. 1998 Apr 1;79(4):372-7.

25. Eldiwany M, Friedl KH, Powers JM. Color stability of light-cured and post-cured composites. American Journal of Dentistry. 1995 Aug 1;8(4):179-81.

26. Mutlu-Sagesen L, Ergün G, ÖZKAN Y, Semiz M. Color stability of a dental composite after immersion in various media. Dental materials journal. 2005;24(3):382-90.

27. Mutlu-Sagesen L, Ergün G, Özkan Y, Bek B. Color stability of different denture teeth materials: an in vitro study. Journal of oral science. 2001;43(3):193-205.

28. Rutkunas V, Sabaliauskas V, Mizutani H. Effects of different food colorants and polishing techniques on color stability of provisional prosthetic materials. Dental materials journal. 2010;29(2):167-76.

29. Bayindir F, Kürklü D, Yanikoğlu ND. The effect of staining solutions on the color stability of provisional prosthodontic materials. Journal of dentistry. 2012 Dec 1;40:e41-6.

30. TURĞUT S, Bagis B, AYDOĞAN AYAZ EL, Ulusoy K, ALTINTAŞ S, KORKMAZ F, Bagis N. Discoloration of provisional restorations after oral rinses. International journal of medical sciences. 2013;10(11).

31. Koishi Y, Tanoue N, Matsumura H, Atsuta M. Colour reproducibility of a photo-activated prosthetic composite with different thicknesses. Journal of oral rehabilitation. 2001 Sep;28(9):799-804.

32. da Fonsêca Costa ÍA, Lima EM. Effect of colorant solutions on the color stability of provisional prosthetic materials. Brazilian Journal of Oral Sciences. 2018 Jun 5;17:e18153-.

33. Atabay C, Tunçdemir MT. Geleneksel Türk içeceklerinde bekletilen laminate geçici restorasyon materyallerinin renk stabilitelerinin karşılaştırılması. 7tepe Klinik Dergisi. 2019;15(2):166-70.

34. Barbosa GF, Cardoso MB. Effects of carbonated beverages on resin composite stability. Am J Dent. 2018 Dec 1;31(6):313-6.

35. Givens Jr EJ, Neiva G, Yaman P, Dennison JB. Marginal adaptation and color stability of four provisional materials. Journal of prosthodontics. 2008 Feb;17(2):97-101.

36. Elagra MI, Rayyan MR, Alhomaidhi MM, Alanaziy AA, Alnefaie MO. Color stability and marginal integrity of interim crowns: An in vitro study. European journal of dentistry. 2017 Jul;11(03):330-4.

37. Brewer JD, Wee A, Seghi R. Advances in color matching. Dental Clinics. 2004 Apr 1;48(2):341-58.

38. Okubo SR, Kanawati A, Richards MW, Childressd S. Evaluation of visual and instrument shade matching. The Journal of prosthetic dentistry. 1998 Dec 1;80(6):642-8.

39. Gross MD, Moser JB. A colorimetric study of coffee and tea staining of four composite resins. Journal of Oral Rehabilitation. 1977 Oct;4(4):311-22.

40. Singh SV, Aggarwal P. Effect of tea, coffee and turmeric solutions on the colour of denture base acrylic resin: An in vitro study. The Journal of Indian Prosthodontic Society. 2012 Sep;12(3):149-53

41. Seghi RR, Gritz MD, Kim J. Colorimetric changes in composites resulting from visible-light-initiated polymerization. Dental Materials. 1990 Apr 1;6(2):133-7.

42. Kuehni RG, Marcus RT. An experiment in visual scaling of small color differences. Color Research & Application. 1979 Jun;4(2):83-91.

43. Park JK, Kim TH, Ko CC, Garcia-Godoy F, Kim HI, Kwon YH. Effect of staining solutions on discoloration of resin nanocomposites. American journal of dentistry. 2010 Feb;23(1):39.

44. Jones CS, Billington RW, Pearson GJ. The in vivo perception of roughness of restorations. British dental journal. 2004 Jan;196(1):42-5.

45. Amaya-Pajares SP, Ritter AV, Vera Resendiz C, Henson BR, Culp L, Donovan TE. Effect of finishing and polishing on the surface roughness of four ceramic materials after occlusal adjustment. Journal of Esthetic and Restorative Dentistry. 2016 Nov 12;28(6):382-96.

46. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. Journal of dentistry. 1999 Feb 1;27(2):89-99.

47. Kaplan BA, Goldstein GR, Vijayaraghavan TV, Nelson IK. The effect of three polishing systems on the surface roughness of four hybrid composites: a profilometric and scanning electron microscopy study. The Journal of prosthetic dentistry. 1996 Jul 1;76(1):34-8.

48. Ionescu AC, Brambilla E, Pires PM, López-Castellano A, Alambiaga-Caravaca AM, Lenardi C, Sauro S. Physical-chemical and microbiological performances of graphene-doped PMMA for CAD/CAM applications before and after accelerated aging protocols. Dental Materials. 2022 Sep 1;38(9):1470-81.

49. Tantanuch S, Kukiattrakoon B, Peerasukprasert T, Chanmanee N, Chaisomboonphun P, Rodklai A. Surface roughness and erosion of nanohybrid and nanofilled resin composites after immersion in red and white wine. Journal of Conservative Dentistry and Endodontics. 2016 Jan 1;19(1):51-5.

50. Yildiz E, Karaarslan ES, Simsek M, Ozsevik AS, Usumez A. Color stability and surface roughness of polished anterior restorative materials. Dental materials journal. 2015 Oct 2;34(5):629-39.

51. Kotnarin N, Nagaviroj N, Kanchanavasita W. The effect of staining solutions on the color stability of the provisional restorative materials. Mahidol Dent. J. 2018;38:309-18.

52. Lauvahutanon S, Shiozawa M, Takahashi H, Iwasaki N, Oki M, Finger WJ, Arksornnukit M. Discoloration of various CAD/CAM blocks after immersion in coffee. Restorative dentistry & endodontics. 2017 Feb 1;42(1):9-18.

53. Almohareb T, Alkatheeri MS, Vohra F, Alrahlah A. Influence of experimental staining on the color stability of indirect computer-aided design/computer-aided manufacturing dental provisional materials. European journal of dentistry. 2018 Apr;12(02):269-74.

54. Ergün G, Mutlu-Sagesen L, ÖZKAN Y, Demirel E. In vitro color stability of provisional crown and bridge restoration materials. Dental materials journal. 2005;24(3):342-50.

55. Hersek N, Uzun G, Yildiz P. Color stability of denture base acrylic resins in three food colorants. The Journal of prosthetic dentistry. 1999 Apr 1;81(4):375-9.

56. Kumari RV, Nagaraj H, Siddaraju K, Poluri RK. Evaluation of the effect of surface polishing, oral beverages and food colorants on color stability and surface roughness of nanocomposite resins. Journal of international oral health: JIOH. 2015 Jul;7(7):63.

57. Baglar S, Keskin E, Orun T, Es A. Discoloration Effects of Traditional Turkish Beverages on different Composite Restoratives. The journal of contemporary dental practice. 2017 Feb 1;18(2):83-93.

58. Nunes FM, Coimbra MA. Melanoidins from coffee infusions. Fractionation, chemical characterization, and effect of the degree of roast. Journal of Agricultural and Food Chemistry. 2007 May 16;55(10):3967-77.

59. Sari VD, Ningsih DS, Soraya NE. Pengaruh konsentrasi ekstrak kayu manis (Cinnamomum burmanii) terhadap kekasaran permukaan resin akrilik heat cured. Journal of Syiah Kuala Dentistry Society. 2016 Nov 2;1(2):130-6.

60. Hanifa M, Saputera D, Wijayanti TF. Perbandingan ekstrak jahe putih kecil 70% dan alkaline peroxide terhadap nilai perubahan warna basis akrilik. Dentin. 2018 Apr 9;2(1).

61. Sainz-Urruela C, Vera-López S, San Andres MP, Díez-Pascual AM. Surface functionalization of graphene oxide with tannic acid: Covalent vs non-covalent approaches. Journal of Molecular Liquids. 2022 Jul 1;357:119104.

62. Sepúlveda-Navarro WF, Arana-Correa BE, Ferreira Borges CP, Habib Jorge J, Urban VM, Campanha NH. Color stability of resins and nylon as denture base material in beverages. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2011 Dec;20(8):632-8.

63. Erdemir U, Kaner AO, Eren MM, Ozan G, Yıldız E. Color stability of bulk-fill composites immersed in different drinks. Color Research & Application. 2018 Oct;43(5):785-93.

64. Bitencourt SB, Kanda RY, de Freitas Jorge C, Barão VA, Sukotjo C, Wee AG, Goiato MC, Pesqueira AA. Long-term stainability of interim prosthetic materials in acidic/staining solutions. Journal of Esthetic and Restorative Dentistry. 2020 Jan;32(1):73-80.

65. Köroğlu A, Sahin O, Dede DÖ, Yilmaz B. Effect of different surface treatment methods on the surface roughness and color stability of interim prosthodontic materials. The Journal of prosthetic dentistry. 2016 Apr 1;115(4):447-55.

66. Yılmaz D, Sabatini GP, Kahveci Ç, Yoon HI, Yilmaz B, Çakmak G, Dönmez MB. Effect of material thickness and coffee thermocycling on the color stability and translucency of additively and subtractively manufactured resin-based materials for definitive restorations. Int. J. Prosthodont. 2024 Feb 21;37:143-50.