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The Efficacy of 3 Bleaching Methods on Stained Polymer-Based CAD/CAM Materials

Rua Babaier [a*], *Julfikar Haider* [b,c], *Rasha A. Alamoush* [d], *Nick Silikas* [c]

[a] *Department of Prosthetic Dental Sciences, College of Dentistry, King Saud University, Saudi Arabia*
[b] *Department of Engineering, Manchester Metropolitan University, Manchester, UK*
[c] *Biomaterials Science, Division of Dentistry, School of Medical Sciences, University of Manchester, Manchester, UK*
[d] *Department of Fixed and Removable Prosthodontics, School of Dentistry, University of Jordan, Jordan*

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ABSTRACT

Introduction and aims: This study aimed to investigate the efficacy of 3 bleaching methods on stained polymer-based CAD/CAM blocks in terms of surface roughness, hardness stability, discolouration reduction and susceptibility to re-staining following bleaching.
Methods: Two-mm-thick slabs (N = 128) were prepared from CeraSmart (CS), Grandio Blocs (GB), Vita Enamic (VE), and direct resin composite GrandioSO (RC). Coffee-stained specimens (n = 8) were subdivided into bleaching (BL) groups: in-office bleaching (OB), home bleaching (HB), whitening mouthwash (MW), and a control group with 14-day storage in water (CL). Measurements of roughness (Ra), Vickers hardness (HV), and colour parameters (ΔE_{00}, ΔL^*, Δb^*) were taken before and after BL. Then, all the bleached specimens were re-stained to determine their stain susceptibility. Repeated measures of ANOVA, Pearson's χ^2 test, and multiple post hoc tests were performed ($\alpha = 0.05$).
Results: HB was more effective in whitening in terms of achieving minimal residual colour (-0.87 to 0.7) and greater resistance to re-staining (0.41 to 0.89). MW resulted in an increased lightness (ΔL^*) of all materials (1.96 - 2.30). However, MW increased the roughness of VE (0.8 μm) and RC (0.4 μm), compared to their baseline measurements (0.057 μm and 0.087 μm, respectively, $p = 0.003$). All the BL treatments resulted in a greater hardness reduction (14.4% to 18.1%) in the RC than in the other materials.
Conclusion: The investigated polymer-based materials and modes of bleaching treatment influenced the bleaching efficacy. For CAD/CAM blocks, in-office bleaching and whitening mouthwash reduced the discolouration but adversely affected their roughness and hardness compared to home bleaching. Home bleaching proved to be the least susceptible to re-staining.
Clinical relevance: Knowing how a specific bleaching product affects the colour, roughness and hardness and consequent susceptibility to staining of 4 studied polymer-based materials that represent pre-existing restorations would impact the consideration of bleaching treatment.

Introduction

Sustainability, which may encompass the long-term maintenance of restorations to reduce their replacement rate and, consequently, material and chemical waste, is becoming increasingly important in the field of dentistry.[1] One of the most frequent reasons for replacing direct resin composite restorations is staining,[2] which could be caused by a combination of intrinsic and extrinsic factors. Although the surface characteristics of the material are significant for attracting food residues; hence stains, the composition and microstructure of the material could be highly influential.[3] However, CAD/CAM technology produces stronger homogenous blocks of polymer-based composites due to improved and controlled high temperature – high pressure methodology of polymerisation techniques.[4,5]

There are 2 forms of CAD/CAM polymer-based composites: filler dispersed resin and polymer-infiltrated ceramic network (PICN) blocks.[6] Although advancements in chemical and microstructural compositions have significantly influenced physical and mechanical properties,[7] research indicates that these materials may not be inherently resistant to

* Corresponding author. Department of Prosthetic Dental Sciences, College of Dentistry, King Saud University, Saudi Arabia.
E-mail address: rbabaier@ksu.edu.sa (R. Babaier).
Rua Babaier: http://orcid.org/0000-0001-9565-8275
Julfikar Haider: http://orcid.org/0000-0001-7010-8285
Rasha A. Alamoush: http://orcid.org/0000-0002-5031-5081
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stains.[8-10] Therefore, bleaching is one of the initial minimally invasive treatments used to reduce the discolouration of existing restorations.[11]

Whitening works differently based on the formulation, which might involve chemical agents, mechanical abrasives, or a combination of both.[12] Conventional bleaching systems containing hydrogen peroxide and carbamide peroxide have been applied under clinical supervision to bleach or enhance the colour of pre-stained restorative materials.[11,13] Recently, over-the-counter (OTC) products such as whitening toothpastes.[14,15] and mouthwashes[16,17] have been increasingly advertised. However, these products raise a greater concern since they are used more frequently without supervision, and their side effects are less recognised.[16,18] The application of bleaching treatment to natural teeth has been associated with several adverse effects, such as cytotoxicity,[19] dentin hypersensitivity, and increased roughness.[20,21] In addition, the integrity of pre-existing resin composites is compromised by factors such as pH level, abrasiveness and chemical agents.[22]

Regardless of the bleaching method used, it should not interfere with the surface or the integrity of the teeth or any existing restorations. The efficacy of bleaching systems can be determined by monitoring several surface and optical parameters following ISO standards.[23] Most research relates the efficiency of a bleaching treatment to its ability to reduce colour change relative to the initial measurement, i.e., minimal residual colour.[24-26] However, only a few studies extended their investigation to include changes in surface roughness[27,28] and hardness[16,29] and their potential influences on the retention of stains[30] and the release of ions.[31,32] Therefore, this study aimed to compare the efficacy of 3 bleaching treatments (BL) on stained resin-based CAD/CAM blocks and one direct resin composite (control) using multiple parameters. The bleaching treatment groups included were in-office bleaching, home bleaching, whitening mouthwash, and water storage (control) groups. The CIE parameters for colour include ΔE_{00} after staining S1, after bleaching S2, after re-staining S3, increases in lightness ΔL^*, and decreases in yellowness Δb^*. The surface properties include changes in surface topography, roughness (Ra) and Vickers hardness (HV).

1. The null hypotheses were as follows: There were no differences in the surface properties (Ra and HV) measured at baseline, after staining, and after each bleaching treatment for each material.
2. There were no differences in colour change (ΔE_{00}) measured after staining (S1), after each bleaching treatment (S2), and after re-staining (S3) for each material.
3. There were no differences in the measured surface and optical parameters (residual colour ΔE_{00}, ΔL^* and Δb^*) among the bleaching groups for each material.

Materials and methods

Study design

Specimens were prepared from 3 commercially available polymer-based CAD/CAM blocks (2 resin composites and one polymer-infiltrated ceramic-PICN) and one direct resin composite (Table 1).

The study included 3 subsequent stages, as illustrated in Figure 1:

i. Accelerated staining: storage of all the specimens in coffee at 37°C for 14 days.
ii. Bleaching treatment (BL) the specimens were divided into 4 groups: in-office bleaching (OB), home bleaching (HB), whitening mouthwash (MW), and control (CL), where specimens were stored in distilled water for 14 days, refer to Table 1 for the products used and the protocol applied.
iii. Stain susceptibility after bleaching: specimens from each BL group were stored in coffee at 37°C for 3 days.

To investigate the effectiveness of BL on the 4 materials, changes in roughness, Vickers hardness, colour parameters, and surface topography were established for the 3 treatment groups in comparison to baseline measurements.

Specimen preparation and treatment groups

Thirty-two specimens were prepared from each material into 2-mm-thick plates. Each CAD/CAM block was sectioned using a low-speed diamond saw (IsoMet 1000 precision saw) under water cooling. Direct resin composite specimens were made from a nanohybrid type and prepared in a preformed Teflon mould with a plate-shaped opening in dimensions nearly matching those of the CAD/CAM specimens (14.5 mm × 14.5 mm × 2 mm). The Teflon mould was placed on a glass slide and filled with resin composite paste. Then, the specimen was covered with another glass slide and manually pressed to obtain a flat surface, after which any excess extruded material was removed.[11] The plates were polymerised for 20 seconds in the centre and at each corner on the top and bottom surfaces with an LED light-curing unit (Elipar S10, 3M ESPE). The mean irradiance was 1200 mW/m^2, as verified by a Marc resin calibrator (Marc-LC: Blue-light Analytics Inc.).

The surfaces of the plate specimens were polished using a MetaServ 250 single grinder-polisher (Buehler) with CarbiMet grit P1000, followed by MICROCUT^{â} silicon carbide grinding paper grits P2500 and P4000.[33] Using a digital calliper, specimens with thicknesses within a tolerance of ± 0.2 mm were included in the study.

After polishing, all specimens were ultrasonically cleaned in distilled water for 10 min (L & R Ultrasonics, Kearny). The surface opposite the polished one was marked and stored in separately labelled containers. Baseline measurements (roughness, Vickers hardness, and colour) were obtained after 24 h of storage in water at 37°C. The accelerated staining solution was made of 2 g of coffee powder (Nescafé Classic, Nestlé) dissolved in 200 ml of boiled water. Each container was filled with 3 ml of coffee solution at 37°C and was changed every 2 days with a fresh solution. After 14 days of storage in coffee, the colour changes of all stained specimens were measured (ΔE_{00}*S1) and then, the specimens were subdivided into 4 BL groups (N = 128, n = 8), as described in the *study design* section.

Table 1 – The investigated polymer-based aesthetic materials and the bleaching agents used in this study, their manufacturer information including application methods.

Material	Code	Brand name and shade	Composition		Manufacturer lot no.
			Filler content (wt. %)	Resin matrix	
Dispersed filler-resin composite blocks	**CS**	CeraSmart A2 HT	71% silica nanoparticles (20 nm) and barium glass (300 nm).	29% Bis-MEPP, UDMA, DMA	GC dental products, Europe 151209
	GB	Grandio blocs A2 HT	86% nanohybrid fillers (1 μm), silicon dioxide nanoparticles (20 to 40 nm).	14% UDMA, DMA	VOCO GmbH, Germany 2122435
Polymer-infiltrated ceramic network (PICN)	**VE**	Vita Enamic 2M2-HT	86% feldspar ceramic porous structure	14% UDMA, TEGDMA	VITA Zahnfabrik, Germany 55310
Direct resin composite (control)	**RC**	GrandioSO A2	89% silicon dioxide nanoparticles (20 to 40 nm), glass ceramic filler (1 μm).	Bis-GMA, Bis-EMA, TEGDMA	VOCO, Germany 91170

Bleaching treatment	**Code**	**Brand and manufacturer**	**Composition and experimental method of application**	**Manufacturer**
In-office bleaching	**OB**	Opalescence Boost In-office Whitening 40%	40% hydrogen peroxide. A 1-mm thick gel applied to the top surface of the specimen for 1 h, followed by rinsing and air-drying.	UltraDent, USA
Home bleaching	**HB**	Opalescence Whitening gel 10%,	10% carbamide peroxide. A 1-mm layer applied on the top surface of each specimen for 8 hours per day for 14 days. In-between sessions, the specimens were rinsed and stored in water at 37°C.	UltraDent, USA
Whitening mouthwash	**MW**	Colgate Max White Expert Whitening Mouthwash	Aqua, glycerin, sorbitol, propylene glycol, tetrapotassium pyrophosphate, tetrasodium pyrophosphate, zinc citrate, sodium saccharin, sodium fluoride 0.05% (225 ppm F). Each specimen was stored in 3 mL of mouthwash for a total of 4 min equivalent to daily rinse for 14 d.	Colgate, UK
Water storage	**CL**	Storage in distilled water	Stained specimens were stored in distilled water for 14 d at 37°C in the incubator.	

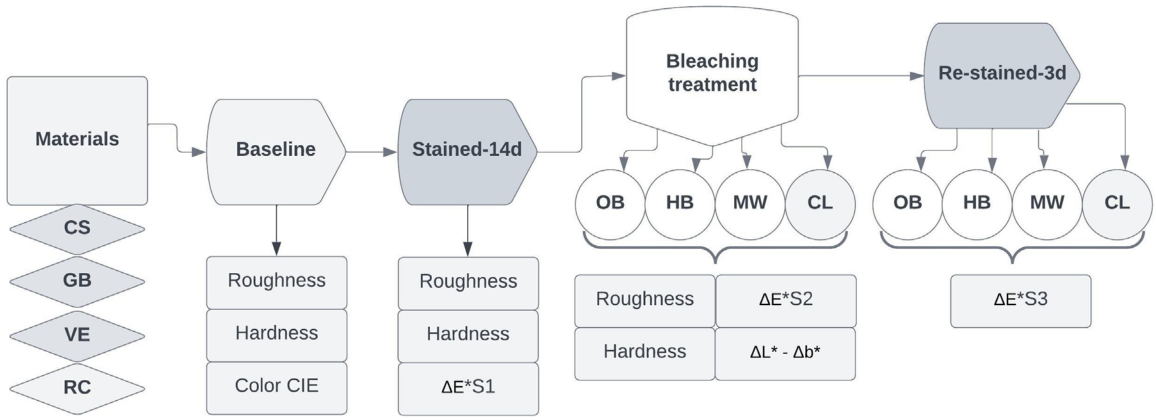

Fig. 1 – Study flowchart and bleaching treatment (BL) groups: in-office bleaching (OB), home bleaching (HB), whitening mouthwash (MW), and a control group with 14-day storage in water (CL). Note that colour change (ΔE00) was determined at 3 time intervals.

After bleaching treatment, the Ra, HV and colour (ΔE_{00}*S2) were immediately measured. Then, specimens from each BL group were stored flat at 37°C in separate labelled containers filled with coffee. The colour measurements were repeated after 3 days of storage (ΔE_{00}*S3). Further optical parameters were determined such as the increase in lightness, reduction of yellowness, and the residual colour after bleaching, which are all defined in Table 2. Prior to each measurement session, the specimens were washed under running tap water and patted dry with absorbing paper.

Roughness

Surface profiles of 5 material specimens were measured repeatedly at baseline, post-14-day staining, and post-bleaching using a non-contact surface profilometer (Talysurf CLI 1000, Taylor Hobson Precision). The confocal point gauge range used was CLA-400 μm with a bi-directional measurement and a sampling rate of 500 Hz. Each specimen was positioned on the centre of the platform, and the parameters were set to scan 1 mm^2 with a resolution of 1001 points and a speed of 500 μm/s. The mean of 3 successive scans was taken at the specimen centre with a 3 mm spacing.

Roughness was analyzed using TalyMap software (Ametek Taylor Hobson Precision, Leicester, England) after applying a Gaussian filter with a cut-off distance set at 0.25 mm. Two-dimensional profiles were extracted to obtain the arithmetical mean of roughness (Ra), as defined by ISO 25178/2017.[34] A 2D altitude parameter (Ra) was used for comparative analysis with other studies.[27,35]

Vickers hardness

The hardness of 3 material specimens was measured repeatedly at baseline, post-14-day staining, and post-bleaching using a micro-hardness instrument (FM-700, Kawasaki, Japan). The mean of 5 Vickers indentations was obtained after the load application of 500 gf at 23 ± 1°C for 15 s at separate locations on the specimen surface. The reductions in hardness percentages were determined by comparing the baseline measurements with the measurements taken after staining and bleaching treatments, using equations (1) and (2) accordingly.

$$\text{Hardness decrease after staining } (\%) = \left(\frac{HV_{baseline} - HV_{staining}}{HV_{baseline}}\right) \quad (1)$$

$$\text{Hardness decrease after bleaching } (\%) = \left(\frac{HV_{baseline} - HV_{bleaching}}{HV_{baseline}}\right) \quad (2)$$

Table 2 – Parameters used for estimating the bleaching efficacy of polymer-based composites investigated in this study.

Parameters	Criteria for successful bleaching
Roughness (Ra)	Ra < 0.2 μm.[34,38]
Hardness (HV)	Hardness loss < 10% after bleaching.[23]
ΔL*	Lightness increased by a factor of 2 after bleaching.[23,37]
Δb*	Yellowness reduced by a factor of 2 after bleaching.[23,37]
Residual colour after bleaching - CIE ΔE_{00}	S2 − S1 = 0. A difference close to zero between specimens stained (S1) and bleached (S2) indicates effective bleaching. A negative value suggests over bleaching.[11,39,40]
CIE ΔE_{00}*(S3)	S3 = 0. Minimum colour difference indicates greater stain resistance.[23]
Clinical interpretation of colour difference	ΔE_{00} > 0.81 represents a perceivable difference based on 50:50% perceptibility colour threshold (PT) ΔE_{00} > 1.88 represents an unacceptable difference based on 50:50% acceptability colour threshold (AT).[37,41]

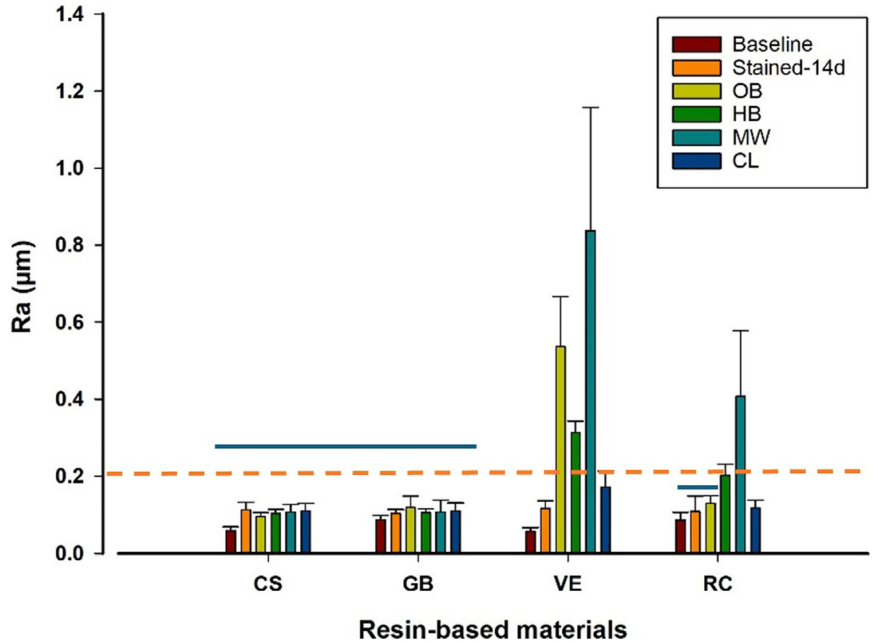

Fig. 2 – Roughness Ra (μm) of the material specimens at baseline, post-staining, and post-bleaching treatment (OB, HB, MW, and CL). The horizontal dashed line marks the clinically accepted maximum, and the solid lines indicate no statistical significance.

Scanning electron microscopy (SEM)

One specimen from each material and BL treatment group (OB, HB, MW, and CL) was selected for SEM imaging to observe any changes in the surface topography after bleaching. Prior to gold sputtering, the specimens were allowed to dry for 24 hours at room temperature. Images were obtained in backscattered electron mode at 15 kV and 1000 × magnification (SEM, JSM-6610 LV, JEOL Co., Tokyo, Japan).

Colour parameters

Colour measurements were obtained by one operator using a reflective spectrophotometer with a 6 mm-diameter aperture (LabScan XE, HunterLab, USA). For each specimen, the CIE colour coordinates relative to the standard illuminant D_{65} were recorded against a standardised black background.

The colour change was calculated from the differences in the L*a*b coordinates following eqn (3) and expressed as CIEΔE_{00}, where $\Delta L'$, $\Delta C'$, and $\Delta H'$ represent the lightness, chroma, and hue, respectively.[36]

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)^2\left(\frac{\Delta H'}{K_H S_H}\right)^2\right]^{1/2} \quad (3)$$

S_L, S_C, and S_H are weighting functions that adjust the total colour difference for variations in the location of the colour difference pair in the L′, a′, and b′ coordinates. K_L, K_C, and K_H are the correction terms for the experimental conditions. R_T is a rotation function that accounts for the interaction between chroma and hue differences in the blue region. Using ΔE_{00}, colour variation was interpreted based on two clinically relevant thresholds: 50:50% perceptibility (0.81) and 50:50% acceptability (1.77–1.88).[36,37] In summary, the effectiveness of each bleaching treatment was estimated using multiple surface and optical parameters, as defined in Table 2.

Statistical analysis

The data (means and standard deviations) were analyzed using SPSS (Version 25.0, IBM) for surface roughness, Vickers hardness, and colour change. The distribution normality and homogeneity of variance of the data were investigated by Shapiro-Wilk and Levene's tests, respectively. For Ra and HV, two-way ANOVA, one-way ANOVA, and Games-Howell post hoc tests were applied to determine any significant differences between the materials and treatment groups at $p \leq .05$. Dunnett's post hoc tests were used for comparing each group to the baseline at $p \leq .05$.

To investigate any significant differences in the colour (ΔE_{00}), residual colour, Δ^*L, and Δ^*b between treatment stages for each material, repeated measures of ANOVA and Greenhouse-Geisser post hoc tests were used at $p \leq .05$. A Pearson's χ^2 test was used to determine the effectiveness of each bleaching method (ΔL^* and Δb^*) at $p \leq .05$.

Using G′power software (V. 3.1.3; Heinrich Hein University, Germany), repeated measures of ANOVA having a power of 91% and an effect size of 0.21 were used to detect differences in colour, with a sample size of n = 8 per material in each BL treatment group and 3 readings from each sample ($p \leq .05$).

Similarly, the sample size was confirmed by a previous study[9] ($p \le .05$).

Results

Tables A1-A5 are presented in the appendix.

Changes in roughness

The results are presented in Table A1 and Figure 2.

The arithmetic means of height (Ra) ranged from 0.057 to 0.088 μm at baseline. Although the Ra of the stained materials did not significantly differ from each other ($p = .541$), this was not the case after bleaching. VE and RC exhibited significantly rougher surfaces post-bleaching, especially in the MW groups (0.837 μm and 0.407 μm, respectively). The surfaces of VE specimens were the most affected by bleaching products, revealing increased roughness in the sequence HB < OB < MW ($p = .000$). In contrast, RCs had rougher surfaces in the following order: HB < MW ($p = .00$). Notably, CS and GB exhibited relative stability after bleaching and did not exceed 0.2 μm.

Changes in hardness

The results are presented in Table A2, and the percentage of hardness reduction is illustrated in Figure 3.

The materials varied widely in their resistance to Vickers indentations, ranging from 82.4 to 362 at baseline ($p = .000$). All stained materials softened ($p = .00$), but RC and VE had significantly greater reductions in HV than did CS and GB.

After bleaching, the hardness varied between the BL groups and materials. All the bleached CAD/CAM materials showed less than a 10% reduction in hardness, irrespective of the bleaching mode (except for GB). In contrast, the hardness of the bleached direct resin composite considerably decreased, ranging between 14.4% and 18.1%.

OB treatment caused the most softening in all materials (except for GB material), followed by HB and MW treatments. All specimens in the CL group continued to soften after 14 days of water storage, but the RC specimens exhibited significantly the greatest HV reductions.

Microscopic imaging

All the bleached materials showed surface changes overall (Figure 4). The VE and RC specimens showed relatively more frequent voids and pitted surfaces due to filler particle detachment. For HB and MW, the RC specimens showed rougher surfaces than did the other groups, consistent with their roughness measurements.

Changes in colour and efficacy of bleaching

Table A3 presents the variations in colour at each treatment stage, and the parameters used for estimating the bleaching efficacy are shown in Table A4 and Figure 5.

After storing the specimens in coffee for 14 days, all material specimens showed discolouration significantly exceeding the 50:50% PT threshold of 0.81 ($p = .001$). The VE specimens showed the highest discolouration (2.92, $p = .00$), exceeding the 50:50% AT threshold of 1.88.

After bleaching, all materials were significantly affected by each bleaching group ($p = .000$), except for RC in CL group. However, VE had the greatest residual colour after bleaching (0.67–1.31), with HB and MW being more effective at

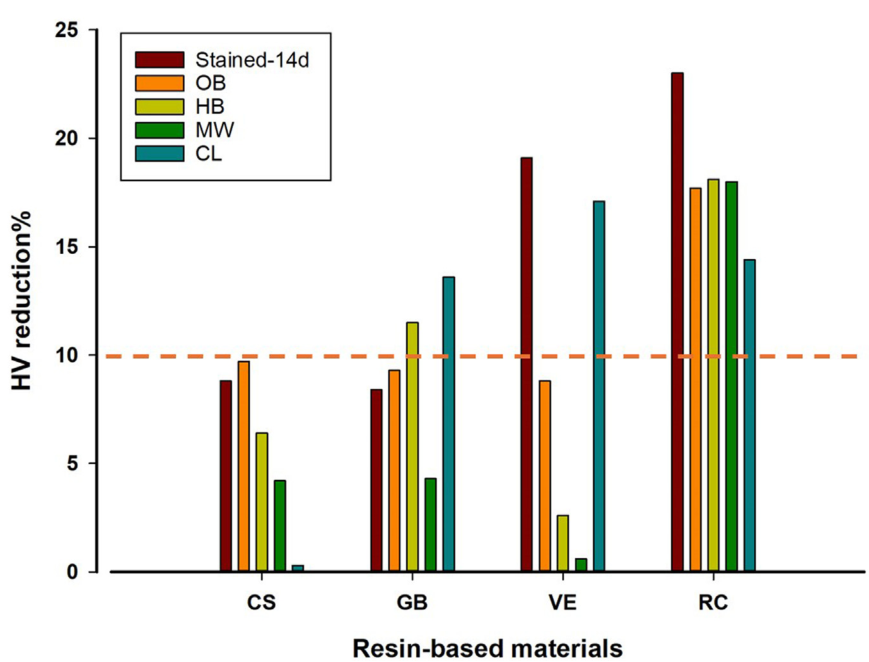

Fig. 3 – Percentage of hardness reduction from baseline for specimens (CS, GB, VE, and RC) after 14-day staining, followed by bleaching treatment (OB, HB, MW, and CL). The horizontal dashed line indicates the maximum acceptable limit for HV reduction after bleaching (10%).

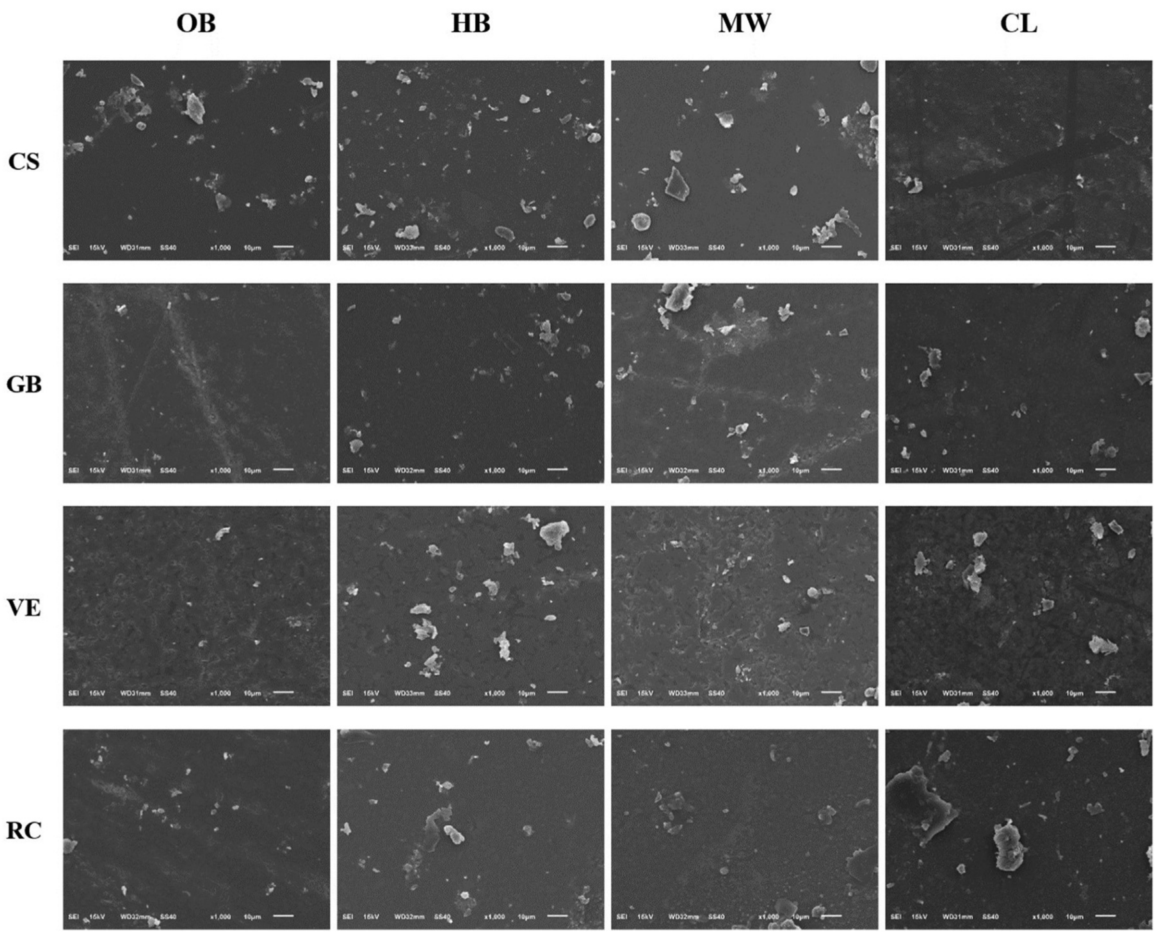

Fig. 4 – Representative SEM images (1000 ×) of specimens (rows: CS, GB, VE, RC) from each bleaching treatment group (columns: OB, HB, MW, CL). VE and RC specimens show rougher surfaces in MW compared to CS and GB.

whitening VE than OB and CL (Figure 5,C). The resin composites (CS, GB, and RC) were overbleached using whitening mouthwash; however, storing these stained resin composite specimens in water for 14 days was sufficient to reduce their discolouration. All the bleached resin composite specimens had a residual ΔE_{00} lower than both the 50:50% PT and AT colour thresholds (Figure 5,C).

All specimens showed a reduction in b* of less than 2 units, with the HB group exhibiting the greatest difference, ranging from 0.96 to 1.85. According to the lightness increase measurements, MW was the most effective method for lightening all stained specimens in descending order: CS = 79.2% > RC = 58.3% > GB = 54.2% > VE = 41.7% (Pearson's χ^2, $p = .004$). HB increased the lightness of VE by 20.8%, CS by 8.3%, and RC by 8.3% but did not affect GB. Interestingly, water storage was effective in numerically increasing the lightness (ΔL*) in CS and RC (62.5% and 20.8%, respectively) and decreasing the b* (yellowness) of VE by 29.2% (Pearson-χ^2, $p = .003$), as shown in Figures 5A and B).

Figure 5D shows that all materials had favourably greater stain resistance after HB than after the other treatments ($p = .000$), with CS, GB, and VE having ΔE*S3 values well below the 50:50% PT limit. Bleached VE appeared to be the most resistant to staining among the materials in the OB group. Although CS and RC were overbleached, their resistance to staining was lower than that of the other materials. However, storing unbleached specimens in water resulted in more staining in CS and VE, exceeding the 50:50% AT limit. In contrast, GB was more resistant to staining than the other materials in the CL group.

Discussion

This study aimed to determine the effectiveness of 3 bleaching procedures on stained polymer-based restorative materials by investigating various surface and optical parameters. Table A5 (Appendix) summarises the results, indicating notable differences in the surface and optical properties of the materials following bleaching procedures. All null hypotheses were rejected.

Overall, CAD/CAM dispersed-filler resin composites (CS and GB) reacted more positively to bleaching treatment than did PICN (VE) and direct resin composite (RC). In-office bleaching exhibited the greatest amount of residual colour and softness, whereas home bleaching presented promising bleaching outcomes. Whitening mouthwash resulted in lighter shades but rougher material surfaces, subsequently leading to more stains. Storing all stained specimens in water for 14 days (CL) reduced their discolouration, except for VE.

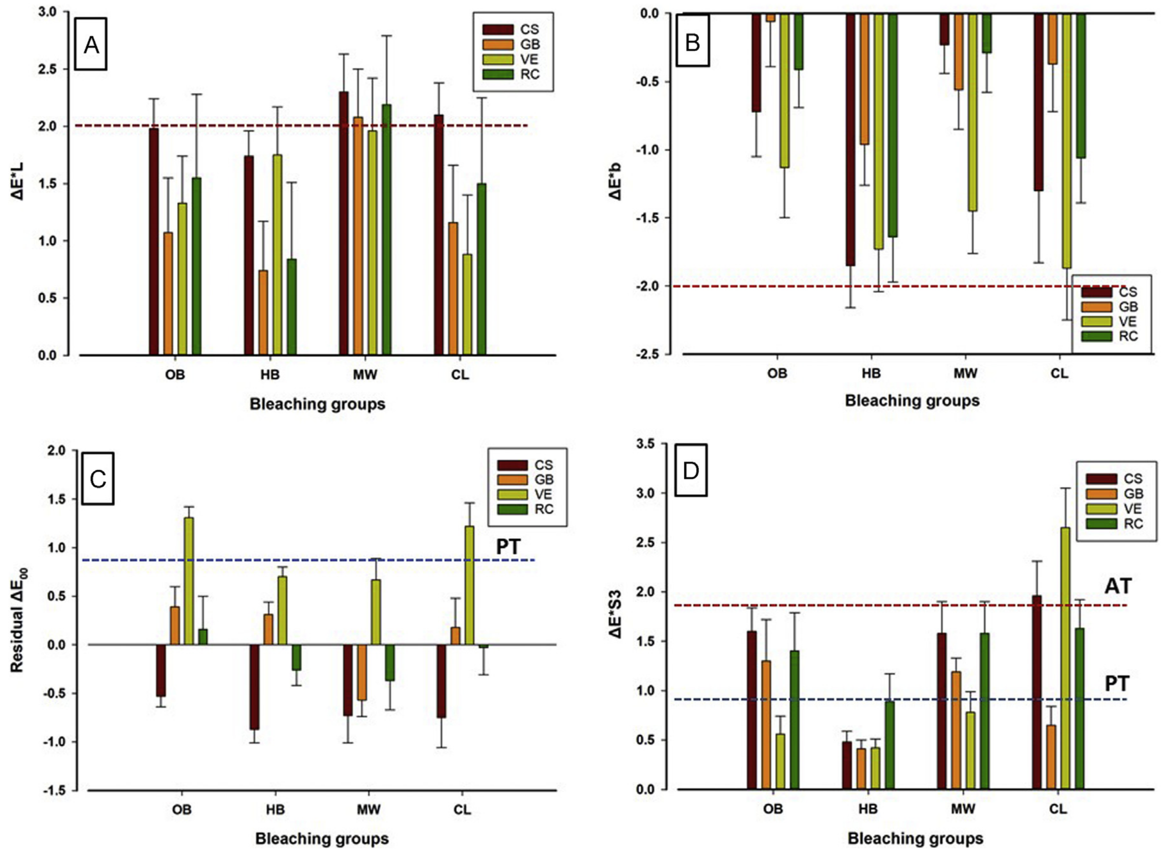

Fig. 5 – Efficacy of bleaching treatments on resin-based CAD/CAM materials expressed by (A) lightness (ΔL*), (B) yellowness (Δb*), (C) residual colour (ΔE00), and (d) their susceptibility to staining after bleaching (ΔE*S3). Reference lines are included in the graphs as dotted lines indicate the factor of 2 in (A) and (B) and the 50:50% perceptibility (PT) and acceptability (AT) colour thresholds in (C) and (D).

The long-term success of a restorative material could be ensured by maintaining favourable aging behaviour, which includes colour stability, physical integrity, and mechanical performance.[42,43] The composition and polymerisation techniques of polymer-based composites impact their degree of crosslinking and, hence, their optical and surface stability.[44,45] Multiple studies have investigated the effect of different filler particle technologies and polymer contents on the polishability[46,47] and susceptibility to staining[9,39,48] of resin composites.

Similarly, SEM images (Figure 4) revealed structural differences among the materials, influencing their response to bleaching in terms of changes in roughness and hardness. Similarly, VE exhibited greater roughness (0.109–0.837 μm) than CS and GB, possibly due to increased water sorption[43] and polymer degradation at a different rate from that of the ceramic structures after storage in coffee, in line with similar studies.[33,49] This was also seen in VE's increased susceptibility to coffee staining before and after bleaching compared to that of CS and GB. In contrast, another study showed that VE had similar colour stability to ceramics, with greater resistance to staining over 120 days.[9] In this study, one day of restaining would be sufficient but the bleached specimens were stored in coffee for 3 days to show the distinctive differences between the study groups.

This research used a direct resin composite (RC) that consists of relatively larger filler particles than other composites. Thus, their staining and bleaching behaviours were less favourable, possibly because of the uneven degradation of the polymer resin and the partial exposure of the large filler particles, resulting in rougher, softer, and more stain-prone surfaces.[33,49] In addition, compared with UDMA-based resin composites, RC has a greater affinity for liquids and, hence, colorants in coffee due to its content of Bis-GMA and TEGDMA.[50] GB shared the filler technology of RC but exhibited similar behaviour to that of CS during staining and bleaching. The excellent results of CS and GB may stem from their compact microstructure and the high-temperature, high-pressure polymerisation process employed in CAD/CAM technology.

After bleaching, the hardness of the RC decreased in all study groups by a significantly greater percentage, varying from 14.3% to 18.1%. The 2 resin composite blocks behaved differently after home bleaching, with GB exhibiting a greater reduction in hardness than CS. However, all bleaching treatments for the CAD/CAM blocks (CS, GB, and VE) resulted in a hardness reduction percentage of less than 10%, which is considered acceptable according to the ISO standards. A study showed that the hardness of VE was significantly reduced but only after a second and third sessions of in-office bleaching.[51] Another study showed that the hardness and surface topography of polished and non-polished VE were negatively affected after bleaching.[52] Further studies might be directed towards the frequency of the treatment applications and potential consequences.

The CIE2000 colour formula was applied in this study due to its improved fit of data and better ability to distinguish minor colour differences compared to the CIELAB formula.[36,53] The whiteness index is one way to reflect the effect of bleaching.[23,27] However, the perceptibility and acceptability thresholds could be applied to both measure and understand colour changes during staining and bleaching.[37] However, it should be noted that these thresholds are lower than the previously established thresholds for the CIELAB formula, which accepted up to 3.48 (AT) and 1.74 (PT) of the colour difference.[37]

Any colour changes greater than 1.8 were considered clinically unacceptable following the coffee staining process (S1). When the residual ΔE_{00} was near zero, bleaching was deemed effective, indicating that all the stain was removed. The investigation showed that MW was highly successful, and all bleaching treatments caused excessive whitening of CS, at least in numerical terms of residual colour ΔE00, ΔL^* and Δb^*. Although the residual ΔE_{00} decreased after bleaching, noticeable bleaching effects were observed only when the colour difference exceeded 0.8. VE had the greatest residual colour after bleaching but showed increased resistance to re-staining, perhaps due to being heavily stained after the initial exposure to coffee.

Increased lightness and decreased yellowness are additional recommended parameters for determining the efficacy of bleaching.[23] MW was more successful in increasing the lightness of all studied materials, with a difference in L^* ranging from 1.96 ± 0.5 to 2.30 ± 0.3. None of the bleaching treatments reduced the yellowness by 2 units or more. HB was the most effective treatment for reducing yellowness compared to the other bleaching treatments, with a reduction range of 0.96 ± 0.3–1.85 ± 0.3.

Several in vitro studies have investigated different whitening products and revealed that hydrogen peroxide (HP) is the most frequently used active bleaching agent. Using 40% HP in OB showed clinically observed whitening results on CAD/CAM resin composites, as previously documented.[11,13] Conveniently, this investigation applied 40% HP gel for 1 hour, which is the longest recommended in-office application period. This was done following similar previous studies to maximise the bleaching effect.[11,54] The findings showed that OB slightly increased the lightness of the resin composites rather than reducing their yellowness. However, OB was not as effective at bleaching the stained VE in terms of residual colour, roughness, and hardness. The effect of OB treatment on the surface properties of VE showed conflicting results from no significant effect on rougher and softer surfaces.[51,55]

An HB gel containing 10% carbamide peroxide (CP) was applied for 14 days, falling within the range of HB gels that typically contain between 5% and 35% CP.[56] The CAD/CAM resin composites (CS and GB) showed better bleaching results (colour change, roughness and hardness) than did PICN, which is in line with previous research on HB.[57] A double-blind clinical trial on vital teeth showed faster whitening results with a higher concentration of CP (17% versus 10%), yet comparable results were achieved after a week of daily use.[58] After 2 weeks, the bleached shade regressed. Other clinical trials involving HB (16% CP) reported prolonged colour stability over 6-month[42] and 42-month follow-up periods.[59] However, 2 *in vitro* studies showed contrasting whitening results when examining the effect of HB (10% CP) on direct resin composites.[26] A study on HB (15% CP) revealed that ceramics and PICN had better whitening results and colour retention than CAD/CAM resin nanocomposite (Lava Ultimate, LU), despite all the bleached materials showing greater roughness.[60]

The whitening mouthwash (MW) used in this study contains pyrophosphates and zinc citrate as bleaching agents; however, other MW products with bleaching effects contain low concentrations of HP, CP, or sodium chloride.[56] The specimens were immersed in MW for 4 minutes and rinsed approximately daily over 14 days, following the manufacturer's recommendations. The short application time and the expectedly lower concentration of bleaching ingredients limit its effectiveness. However, the MW is an OTC product that can be used without professional supervision for extended periods.[61,62] Several studies[16,28,35] have shown some adverse effects of whitening MW on CAD/CAM aesthetic materials, highlighting the importance of product safety. In their work, the whitening MW was more effective at reducing the discolouration of PICN than the resin nanocomposite (LU). However, the bleached PICN surface suffered greater deterioration in gloss, roughness, and hardness than did the LU surface. Similar to the findings of this study, although MW lightened the colour of the polymer-based composites, it resulted in rougher surfaces, which subsequently compromised their stain resistance. However, although VE and RC had a greater decrease in hardness, the final value was still comparable to GB and significantly greater than CS. Consequently, VE and RC would exhibit comparable clinical performance to the other materials. After taking all the factors into account, the MW did not promote bleaching effectively compared to other professionally applied treatments. Therefore, the results in this study might be influenced by the selection of bleaching treatments and the pre-existing restorative materials.

Conclusion

The findings of this study confirm that 4 polymer-based restorative materials were less susceptible to re-staining after home bleaching (10% carbamide peroxide), compared to in-office bleaching (40% hydrogen peroxide) and an OTC whitening mouthwash. Compared with direct resin composites (RC) and polymer-infiltrated ceramics (VE), CAD/CAM resin composites (CS and GB) had relatively more favourable results after 3 bleaching treatments in terms of hardness, roughness, and colour changes. The investigated whitening mouthwash successfully lightened the stained materials but it resulted in rougher and softer surfaces. Therefore, the effectiveness of a bleaching treatment could be dictated by its mechanism of action, its impact on the surface, and the optical characteristics of the studied polymer-based restorative materials.

Conflict of interest

None disclosed.

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Author contributions

Rua Babaier: Conceptualisation, Methodology, Investigation, Formal analysis, Resources, Writing—Original draft. *Julfikar Haider:* Visualisation, Writing—review and editing. *Rasha Alamoush:* Methodology, Writing—review and editing. *Nick Silikas:* Resources, Writing—review and editing, Supervision.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.identj.2024.09.038.

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