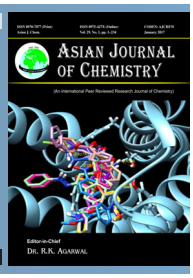
Asian Journal of Chemistry; Vol. 29, No. 4 (2017), 763-770

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2017.20239



Physico-Chemical Analysis of Effect of In-Office Tooth Bleaching Agent on Three Esthetic Composite Resin Restorations (*in vitro* Study)

AMEER HAMDI AL-AMEEDEE

Faculty of Dentistry, University of Babylon, Babylon, Hilla, Iraq

Corresponding author: E-mail: ameeralameedee@gmail.com

Received: 16 August 2016; *Accepted*: 16 January 2017; *Published online*: 31 January 2017; AJC-18240

In the present study, the physical and chemical analysis effects of the in-office bleaching gel (H_2O_2 25 %) on three contemporary restorative composite resins were evaluated by scanning electron microscope (SEM), atomic force microscope (AFM), energy dispersive X-ray spectroscopy (EDAX), Fourier transform infrared spectrometer (FTIR) and Vickers micro hardness taster (HVS). Out of all the tested composite resins in comparison with two follow-up examinations (before bleaching and after one week of bleaching). A total of 300 discus composite resins; Beautifil II, a nano hybrid composite resin (Giomer); IPS Empress Direct, a nano hybrid composite resin (Ceromer); and the Ceram-x-mono, a nano ceramic micro hybrid composite resin (Ormocer); (n = 100 for each group), were selected for an measurements evaluation of before (n = 50 for each group) and after one week of bleaching treatment (n = 50 for each group) by micro hardness tester measurements and chemical analysis using SEM, AFM, EDAX images and FTIR (n = 10 for each test). The Vickers's hardness revealed a significant increase in micro hardness of the Beautifil II and IPS Empress Direct; also the SEM, AFM, EDAX images and FTIR revealed a great diversity in ultrastructure. The results obtained served to validate that the methods employed in this study and were useful in examining and analyzing the physical and chemical changes of bleaching on the composite resins. It was also found that the changes of the arrangement of filler and chemical composition on the composite resins caused by the effect of bleaching had an effect on the chemical and physical properties. Further studies are needed in search of clinical applications that optimally match the differing properties of these materials.

Keywords: SEM, EDAX, AFM, FTIR, Vickers hardness tester, Beautifil II, IPS Empress Direct, Ceram-x-mono, Bleaching materials.

INTRODUCTION

Bleaching teeth treatments are deemed acceptable among the population with increases in the production of new types of bleaching systems. In addition, there are increased numbers of patients with composite resin restorations placed in their teeth. As all composite resins undergo chemical and physical properties change with their increasing use as bleaching agents [1,2], the goal of dental restoration is to conserve sound tooth structure during the preparation and restorative phases. On the development of restorative materials for adhesive procedures, the introduction of composite resins to the dental profession by Bowen has since generated much discussion from clinicians, researchers and manufacturers [3].

Composite resins are acceptable restorative materials for the management of fracture or dental caries in the anterior teeth [4,5]. The recent resin-based materials have shown increasing quality and longevity [6]. The dental composite is made up of four major components: an organic polymer matrix, inorganic filler particles, a coupling agent and an initiator-accelerator system. The resin forms the matrix of the composite material and the coupling agent binds the individual filler particles together. The most used monomer is bisphenol-A-glycidyl methacrylate (Bis-GMA) diluted either with triethyleneglycol-dimethacrylate (TEGDMA) or with di-urethane methacrylate (DUMA) [5,7].

To enhance strength, stiffness, reduce dimensional changes and improve handling, fillers are added to the polymeric part of the composite. Recently, most of the dental resin has been filled with silicate particles based on oxides of barium, aluminum, strontium, or zirconium and zinc [8].

The highest mechanical properties could be obtained by using high concentrations of filler particles of varied sizes into the resin [8-10]. Different classifications according to the average size of the filler particles have been placed [3,8] and they found there was no superiority of any specific filler as every type of filler revealed advantages and disadvantages during clinical application [5,11]. They revealed that one of the most important causes of reinforcing composites was a suitable bond between the fillers and the resin matrix.

The dental resin microstructure and properties were studied extensively [4,9,12]. They used a scanning electron microscope successfully for evaluating the filler particles' numbers, shapes and sizes. The null hypothesis of present study for the effects of in-office bleaching will have no effect on the three resin composites.

EXPERIMENTAL

Three hundred disc-shaped composite resin specimens were prepared from three types of resin composites; group one was prepared using Beautifil II, group two was prepared using IPS Empress Direct and group three was prepared using Ceram-x-mono composite restoration according to the manufacturer's instructions (n = 100 for each group). For each fabricated disc, a notch was marked on the untreated surface in order to distinguish the bleached tested surface. 5 mm diameter and 2 mm thick discs were fabricated using a custom-made Teflon mold. The shade (A1) was standardized for all restorative materials to eliminate this variable and was inserted as one increment into the Teflon mold; covered by a Mylar strip followed by a microscopic glass plate, then 200 g of pressure was applied for 45 s to expel excess material from the mold and to reduce voids [13]. This technique ensures equal pressure and creates a flat surface on all the specimens being fabricated; light polymerization was performed for 40 s at the top surface of specimens for each disc to simulate the clinical condition, using a halogen light of 350 mW/cm^2. The distance between the light tip and the specimen surfaces was standardized by touching the glass slide (1.2 mm thickness). Then the specimens were polished using Sof-Lex system polishing discs with a slow-speed hand piece, rotating in one direction, followed by a 30-second ultrasonic cleaner. All the specimens were stored in distilled water at 37 °C using environmental water bath for one week before bleaching application to ensure complete polymerization [14,15].

Bleaching procedures: The bleaching was performed using Zoom Bleaching kite (25 % HP). After applying a layer of gel (approximately 2 mm thick) to the disc surface (for one hundred fifty disc-shaped composite resin specimens were prepared from three types of resin composites all groups), the zoom light source was applied for four bleaching sessions of 15 min each. After that the gel was removed with a plastic spatula and sterile gauze, then all the disc specimens were cleaned under running water for 1 min and later stored in distilled water for 1 week at 37 °C [15-17].

All groups specimens remain in distilled water at 37 °C using an environmental water bath till the time of measurement, the measuring technique was made for each group separately. Measurement baseline time follow ups for before bleaching treatment for one hundred fifty disc-shaped composite resin specimens were prepared from three types of resin composites all groups and after one week of for each specimen. The mean and standard deviation of each group were calculated [18,19].

The lighter colour indicates raised areas of the specimen surface. The topography picture and diagram curve for the center area of the disc specimen were converted to arithmetic data for the surface roughness value (Sa) to compare with other specimen groups [7,20-23].

Although the arithmetic average of the roughness profile (Ra) is commonly used for surface roughness, the arithmetic average of the three-dimensional roughness profile (Sa) was recorded for bleaching time follow ups of other one hundred fifty disc-shaped composite resin specimens were prepared from three types of resin composites for all parameters were recorded.

Scanning electron microscope (SEM): The measurements were recorded before (n = 10 for each group) and after 1 week of bleaching time intervals for the groups of the study by using scanning electron microscope (Seron technologies, Seron AIS2100C). The resins blocks of 2 × 5 mm were prepared as described before and the specimens were placed on carbon stubs. The samples were coated with carbon for 5 s [20].

Vickers micro hardness (HVS): The measurements were recorded before (n = 10 for each group) and after 1 week of bleaching time intervals for the groups of the study by using a Vickers micro hardness tester (Bijing TIME High Technology Ltd. Italy). A 100 g load and 20 s dwell time were applied at room temperature to the bleach surface specimens disc. The diagonal length impressions were measured and the hardness number (H) was calculated according to a standard formula (H = 1.854 P/d2), where (P) represents the indentation load and (d) indicates the diagonal length impression for each disc specimen, five indentations were made on the bleach treated top surface, not closer than 1 mm to the adjacent indentations or the margins of the specimen [20-22].

Fourier transform infrared spectrometer (FTIR): The measurements were recorded before (n = 10 for each group) and after 1 week of bleaching time intervals for the groups of the study by using FTIR (UV-1800, Spectrophotometer, Shimadzu, Corporation, Kyoto, Japan).

Energy dispersive X-ray spectroscopy (EDAX): From the specimen discs (measurements were recorded before (n = 10 for each group) and after 1 week of bleaching time intervals for the groups of the study), resin powders were prepared, then placed on carbon stubs to analyze using energy dispersive X-ray spectroscopy (EDAX Seron technologies, AIS2100C). The information was obtained after 300 s of measurement. An area of approximately 20 × 15 µm was selected for 2D analysis, which included both the resin matrix and filler particles. Relative values were obtained after 300 s of measurement.

Atomic force microscope (AFM): The surface roughness of the disc specimen (the measurements were recorded before (n = 10 for each group) and after 1 week of bleaching time intervals for the groups of the study) was evaluated using an atomic force microscope (Agilent 5420).

The surface dimensions of the different disc specimens were scanned in different directions: 1 × 1 µm to 10 × 10 µm (x, y) and 4 µm (z). The collected images were processed with software including plane fitting and x-y flattening and two-dimensional (2D) and three-dimensional (3D) images were captured [21]. The Sa measurements were recorded before and after 1 week of bleaching time intervals for the groups of the study [7,24,25].

Statistical analysis: Data were collected, tabulated and statistically analyzed. A master chart was prepared in MS Excel sheet used for tables, diagrams and analyzed using Statistical Package for Social Sciences (SPSS 20, IBM).

Inferential statistics: (1) One-way ANOVA (F-test) was used to compare between mean values of more than two groups. (2) Least Significant Differences test (LSD) was used for multiple comparisons between the groups.

Probability levels of more than 0.05 were regarded as statistically non-significant, while levels less than or equal to 0.05 were considered as a significant. $p < 0.05$ significant; $p < 0.01$ high significant; $p > 0.05$ non-significant.

RESULTS AND DISCUSSION

In the present study, the measurements were recorded before (n = 10 for each group) and after 1 week of bleaching time intervals for the groups.

Scanning electron microscope: SEM micrographs (Fig. 1) revealed that all the composites showed surface alterations in their supercial surface after bleaching. Micrographs of the restorative composite resins observed with the SEM micrographs shown with a backscattered electron signal provided an adequate contrast between the resin matrix and fillers. The shapes and sizes of the filler particles were different among the composites. The appearance of the Beautifil II and IPS Empress Direct groups presented a greater amount of filler particles alike where their superficially bigger filler particles were observed with the inclusion of a few nanoparticles. For the Ceram-x-mono group the SEM micrographs showed that they were alike with their homogeneously smaller filler particles. After 1 week of bleaching for the Ceram-x-mono group, the backscattered micrograph showed a view which was the most similar appearance of the Beautifil II and IPS Empress Direct groups. In surface texture among these composite resin groups, it is interesting to note that Beautifil II presented the most complex ultrastructure, whereby large filler particles were observed in a SEM micrograph. For the Ceram-x-mono group the SEM micrographs showed that they were alike where their homogeneously smaller filler particles were shown because these composite resins were filled with nanoparticles; there were, nonetheless, some micro particles [26]. These particles seemed to be organic filler particles including smaller nanoparticles of inorganic fillers, for IPS Empress Direct, it contained some apparent nano filler complexes [3].

Surface microhardness (VHN) analysis: The mean values of Vickers hardness are shown in Table-1. It must be mentioned that in all cases, size of the indentations were larger than the filler particles. As such, the score recorded was the average value of both the resin matrix and filler. Large differences in microhardness before bleaching and after 1 week of bleaching were observed among the composites. The results were a statistically significant increase in mean value in the Beautifil II and IPS Empress Direct groups (66.12 ± 2.94 VHN and 63.86 ± 2.75), respectively, whereas Ceram-x-mono showed no statistically significant mean value effect (56.44 ± 3.9 VHN).

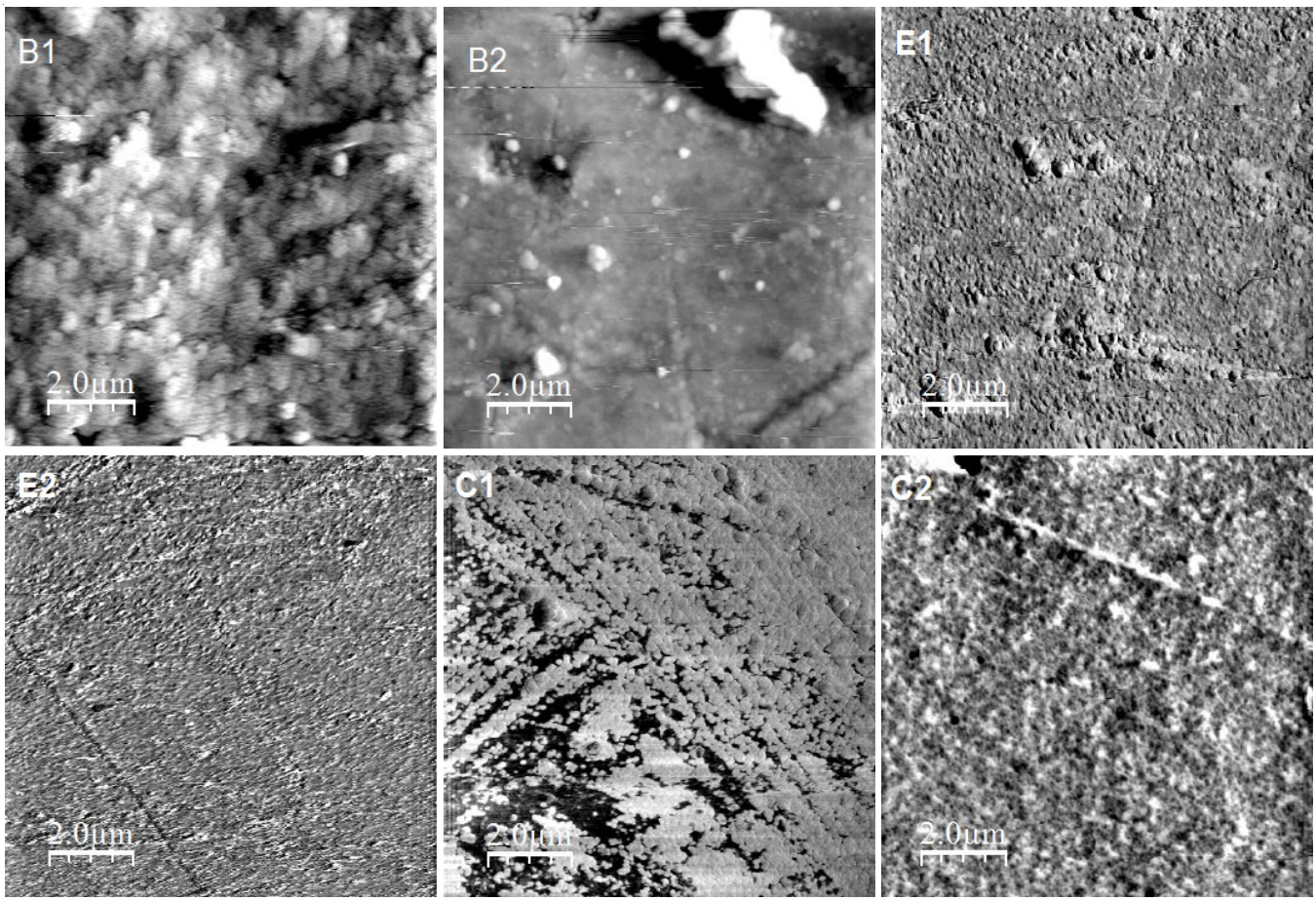


Fig. 1. SEM images of the restorative composite resins: (B1) Beautifil II; (E1) IPS Empress direct and (C1) Ceram-x-mono demonstrated the surface roughness before bleaching and after 1 week of bleaching (B2, E2, C2) at magnification 2.0 µm

TABLE-1
DESCRIPTIVE STATISTICAL STUDY OF SURFACE MICRO HARDNESS VALUES (VHN) IN Kg/mm^2 OF ALL GROUPS (n = 10)

		T_0	T_1
Beautifil II group	Mean	53.0394	66.12
	SD	3.822	2.94
IPS Empress Direct group	Mean	50.355	63.86
	SD	4.576	2.75
Ceram-x-mono group	Mean	58.595	56.44
	SD	4.443	3.9

*The mean difference is significant at the 0.05 level. Different latter in same row = significant differences. Different number in same Colum = significant differences. T_0 = Before expose to H_2O_2 (bleaching), T_1 = 1 week after expose to H_2O_2 (bleaching).

A statistical analysis of the data using an ANOVA test between the groups before bleaching showed that there was significant difference between the surface micro hardness of these groups ($p < 0.05$). It also showed a highly significant difference between the surface micro hardness ($p < 0.01$) for 1 week after bleaching (Table-2).

TABLE-2
ANOVA RESULTS OF THE EFFECT OF TIME ON SURFACE MICRO HARDNESS MEAN VALUES OF ALL GROUPS

	Statistical test	T_0	T_1
Between groups B & E & C	F-test	9.586	17.21
	P-value	P < 0.05*	P < 0.01**

*The mean difference is significant at the 0.05 level. **The mean difference is high significant at the 0.01 level. B = Beautifil II group, E = IPS Empress Direct group, C = Ceram-x-mono group. T_0 = Before expose to H_2O_2 (bleaching), T_1 = 1 week after expose to H_2O_2 (bleaching).

Table-1 showed that time and bleaching had a statistically significant effect on the surface microhardness of the IPS Empress Direct group ($P < 0.01$) and a significant effect on the Beautifil II group ($P < 0.05$), while there was no statistically significant effect on the surface micro hardness of the Ceram-x-mono group at 1 week after the bleaching follow up times ($p = 0.584$).

The results obtained with the Beautifil II composite restorations were highly significant. The decrease in surface roughness values observed with this composite might have been due to the fact that its surface was composed of S-PRG glass ionomer particles. Moreover, the oxidizing effect of bleaching through the ($O^{\bullet}$) and ($OH^{\bullet}$) free radicals may erode the Beautifil II matrix of glass ionomer particles and S-PRG fillers, which would result in surface wash off with the exposure of the cores to silica. Consequently, the significant decreases in surface roughness with the exposure time to bleaching may result in an additional oxidizing effect on the matrix, leading to water uptake by the glass ionomer with complete or partial debonding of the silica, thus causing a reduction in surface roughness. Following this, the water uptake would result in the formation of spheroidal bodies which have an eggshell-like appearance on the surface. Similarly, Kuhn and Wilson [27] explained the mechanism of such erosion but using a different composite material matrix, where they reported that the dissolution of glass ionomer includes a three-step surface wash off, diffusion in the solid state and surface corrosion. These results agreed with Jefferson *et al.* [28], who examined the effect of peroxide-containing products on glass ionomer and reported that the matrix of the specimens showed surface wash off and erosion with longer exposure of the cores to Hassan-Aly *et al.* [29].

In addition, the highly significant decreases in surface roughness observed with both the Beautifil II and IPS Empress Direct composite resins might be explained by the fact that their resin matrix is composed of di-urethane methacrylate (DUMA) and bisphenol-A-glycidyl methacrylate (Bis-GMA), which results in harder matrices. However, it was not supported by Takahashi *et al.* [30], who used the Z250 resin matrix with a different bleaching material applied for a different duration. In their study, the soft phase of surface was easily abraded by bleaching di-urethane methacrylate (DUMA) and bisphenol-A-glycidyl methacrylate (Bis-GMA), which contained in the Z250 resin and form fewer double bonds, which results in a slightly softer matrix, which in turn leads to the debonding of the filler from the resin resulting in a rough surface.

Moreover, this roughening can result in the erosion of the matrix and the consequent debonding of the resin-filler interfaces would lead to the dislodgement and elution of the fillers. Thus, the smaller the size of the bleached particles, the smoother the surface will be obtained, which was the case with both the Beautifil II and IPS Empress Direct composite resins. Indeed, it is known that small fillers enhance the packing of particles, producing a composite with smaller inter-particle spacing, which coincides with the results of Moraes *et al.* [25] and Hassan-Aly *et al.* [29].

In addition, the modulus of elasticity of the materials used in restorations with lower modulus of elasticity tend to bend more like a tooth structure when subjected to a masticatory load and may flex and be retained [31,32]. Our study concurs with the previous findings. Our study revealed increases in smoothness and hardness only in the Beautifil II and IPS Empress Direct composite resin restorations. The increase in surface hardness are associated with an unaffected hardness of core (the deep subsurface of a resin restoration), these results explain the absence of cracking during surface roughness measurements and surface micro-hardness tests (Table-1) and will eventually have an increasing impact force (preventing fracturing of the restoration during mastication). These aspects are obvious evidence for the absence of cracking during surface hardness tests and surface roughness micrographs.

FTIR: The results for the Beautifil l group showed a slight shift in the intensity and peak position of the carbonyl group (C=O), which has an absorbance in the range of 1730 in Beautifil II before bleaching group (B1) and converted or shifted to 1724, as seen in Beautifil II after 1 week of bleaching group (B2). Also we have another peak in the FTIR spectroscopy results but these peaks will not change after 1 week after the bleaching treatment. The most important peak hydroxyl group has an absorbance between 3448-3400 cm^{-1} and this peak will remain the same because the main reaction is:

$$H_2O_2 \longrightarrow 2OH$$

$$OH + \text{Beautifil II (B1)} \longrightarrow \text{[Beautifil II]-OH (B2-OH) [Binary product]}$$

In addition, the IPS Empress Direct group results showed a slight shift in the intensity of the carbonyl group (C=O), which has an absorbance in the range of 1732 for the IPS Empress Direct group before bleaching treatment (E1) and converted or shifted to 1722, 1 week after bleaching treatment. Also, we have another peak in the spectra, but this peak will not change. The most important peak hydroxyl group has an absorbance between 3500-3400 cm^{-1} and this peak will remain the same because the main reaction is:

$$H_2O_2 \longrightarrow 2OH^{\bullet}$$

$$OH^{\bullet} + \text{IPS Empress Direct (E1)} \longrightarrow \text{IPS Empress Direct-OH (E2-OH) [Binary product]}$$

While the results of the Ceram-x-mono group (C) showed a slight shift in the intensity of the carbonyl group (C=O), which has an absorbance in the range of 1728 cm^{-1} before bleaching treatment (C1) and converted or shifted to 1730 cm^{-1} one week after bleaching treatment (C2). Another peak in FTIR spectroscopy also appeared, but this peak will not change. The main important peak hydroxyl group (OH) has an absorbance of between 3448-3400 cm^{-1} and this peak remain the same because of the main reaction is:

$$H_2O_2 \longrightarrow 2OH^{\bullet}$$

$$OH^{\bullet} + \text{Ceram-x-mono (C1)} \longrightarrow \text{Ceram-x-mono-OH (C2-OH) [Binary product]}$$

According to Rastelli *et al*. [24] other factors can influence the direct composite resins such as the light source used, power density, wavelength, irradiation time, light-tip size, photo-activation method, distribution, quantity of inorganic fillers, the type and quantity of the photo initiator and the colour also strongly affect the direct composite resins.

The percentage of unreacted carbon-carbon double bonds (C=C) was determined from the ratio of absorbance intensities of aliphatic C=C (peak at 1637 cm^{-1}) against the internal reference aromatic C=C (peak at 1610 cm^{-1}) before and after the curing of the specimens.

EDAX: The chemical compositions of the restorative composite resins, including the elements with relative values, expressed in weight percentage are presented in Figs. 2-4: similar elements, such as Al, O and Si, were detected. However, the concentration was different in every composite resin. The filler contents showed interesting differences in elemental composition and concentration.

The results were shown to confirm the reaction between the hydroxyl group ($OH^{\bullet}$) and samples of the Beautifil II group done by using the EDAX technique. It is clear from Fig. 2 that in the before bleaching and 1 week after bleaching groups the intensity of Al and Si reduced to 50 % and 55 %, respectively, whereas the amount of O element reduced to 20 % in 1 week after bleaching group, which is attributed to the reaction between $OH^{\bullet}$ radical and Beautifil II samples.

Also, the result of the IPS Empress Direct group confirmed the reaction with the hydroxyl group which occurred because the intensity of Al element reduced to 40 %, while the amount of O element remained the same. This gives a profit for the

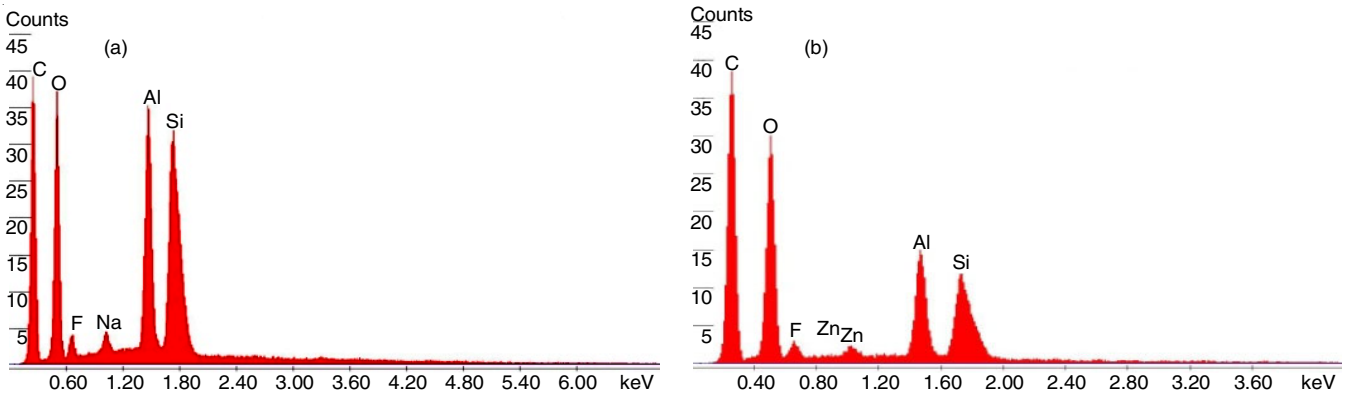


Fig. 2. EDAX diagram for Beautifil II composite group's samples (a) before bleaching and (b) after 1 week of bleaching

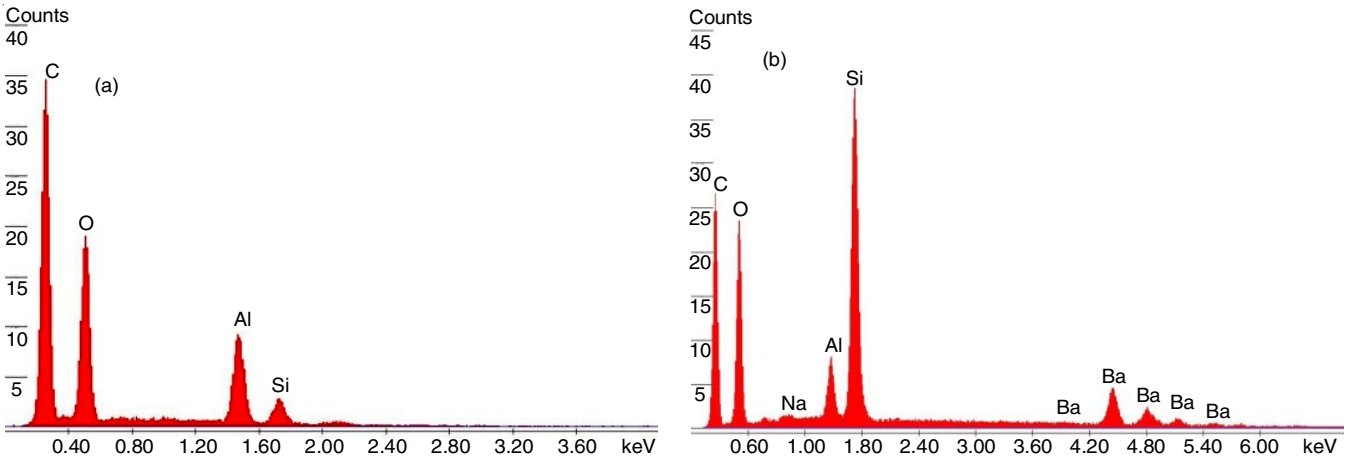


Fig. 3. EDAX diagram for IPS Empress direct composite group's samples (a) before bleaching and (b) after 1 week of bleaching

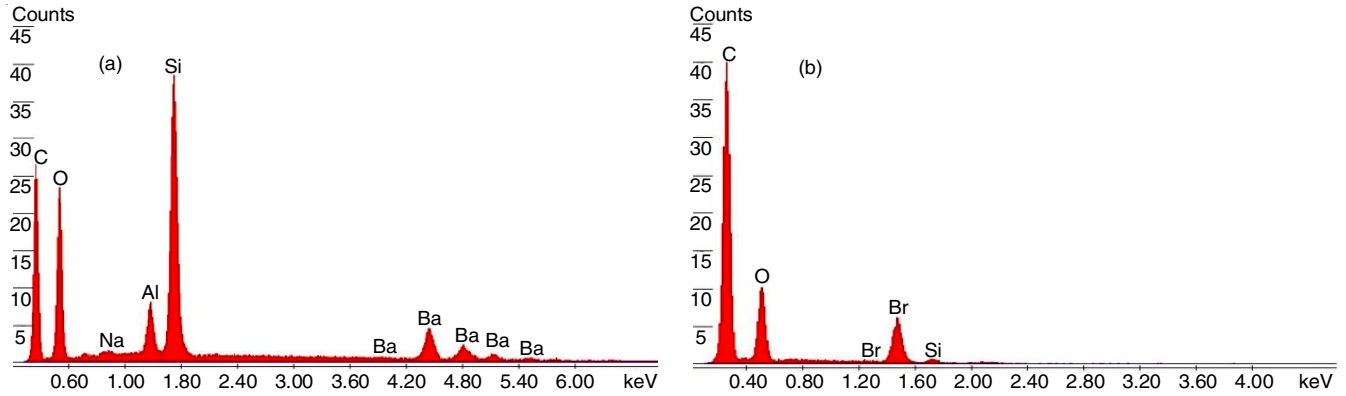


Fig. 4. EDAX diagram for Ceram-x-mono composite group's samples (a) before bleaching and (b) after 1 week of bleaching

reaction of $OH^{\bullet}$ radical with the IPS Empress Direct in E1 before bleaching group decreasing in intensity of Al element, thus causing an increase in the hardness because of the rearrangement phenomena or the adaptation on the surface of IPS Empress Direct in the after 1 week group (Fig. 3).

While the result of Ceram-x-mono before bleaching group showed that the amount of Al element to decrease at a very high percent 90 % and same for Si element, which caused a decrease in the hardness of Ceram-x-mono in 1 week after bleaching group, which is explained by a hard reaction between $OH^{\bullet}$ radical and Ceram-x-mono samples' surface as shown in (Fig. 4).

AFM analysis: The results for Beautifil II in after 1 week bleaching group showed the surface roughness (Sa) average will decrease by about 22 % compared to Beautifil II in 1 week after bleaching group because the amount of Al and Si decrease, as shown in Fig. 5. According to the above results and by use of Vicker test tool, the hardness of Beautifil II samples increases for 1 week after H_2O_2 treatment due to the effect of rearrangement on the surface of sample after reacting with $OH^{\bullet}$ radical.

Also, the results for IPS Empress Direct group showed that the surface roughness (Sa) average will decrease for 1 week after bleaching treatment, which is explained by the increase in the intensity of Si element after treatment as noted from the EDAX results, as shown in Fig. 6). So, according to the above results and by using the Vicker test tool, the hardness of the IPS Empress Direct samples increases after H_2O_2 treatment, which is explained by the effect of rearrangement on the surface of the sample after reaction with $OH^{\bullet}$ radical.

Whereas the results for Ceram-x-mono group showed that surface roughness (Sa) average decreases in after 1 week bleaching group and this may be due to rearrangement on the Ceram-x-mono samples' surface by reducing the high percentage of Al and Si (Fig. 7). So, according to the above results and by using the Vicker test tool, the hardness of the Ceram-x-mono samples decrease after H_2O_2 treatment, which is explained by the effect of rearrangement on the surface of samples after reaction with the $OH^{\bullet}$ radical.

Nevertheless, Ceram-x-mono presented the highest concentration of (C) after bleaching, suggesting that this composite was slightly lower-filled than the others and this could be

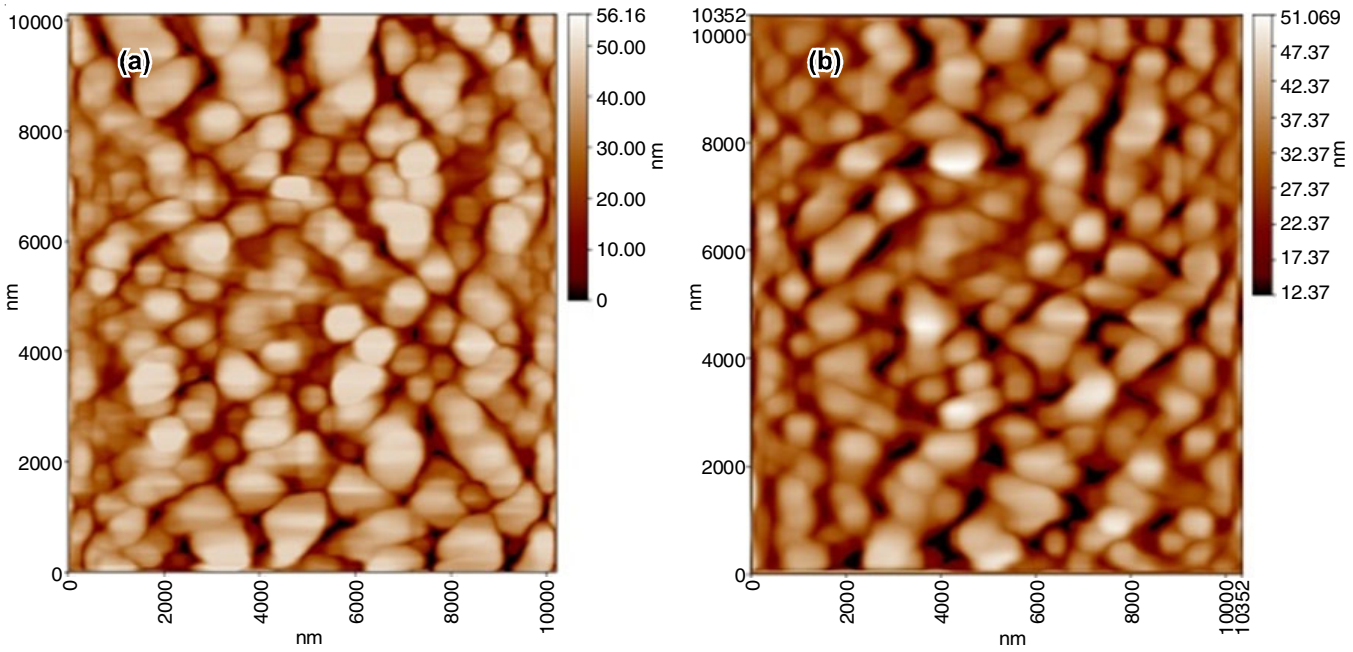


Fig. 5. AFM micrographs for Beautifil II composite group's samples (a) before bleaching and (b) after 1 week of bleaching

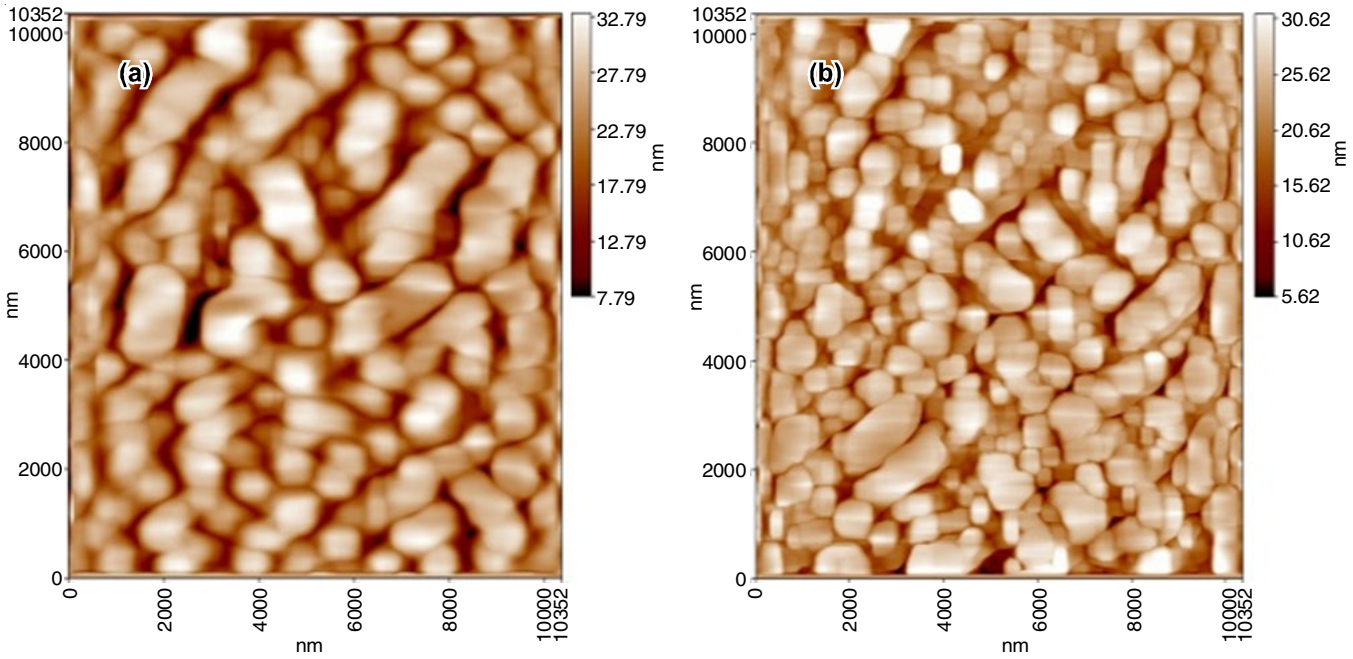


Fig. 6. AFM micrographs for IPS Empress direct composite group's samples (a) before bleaching and (b) after 1 week of bleaching

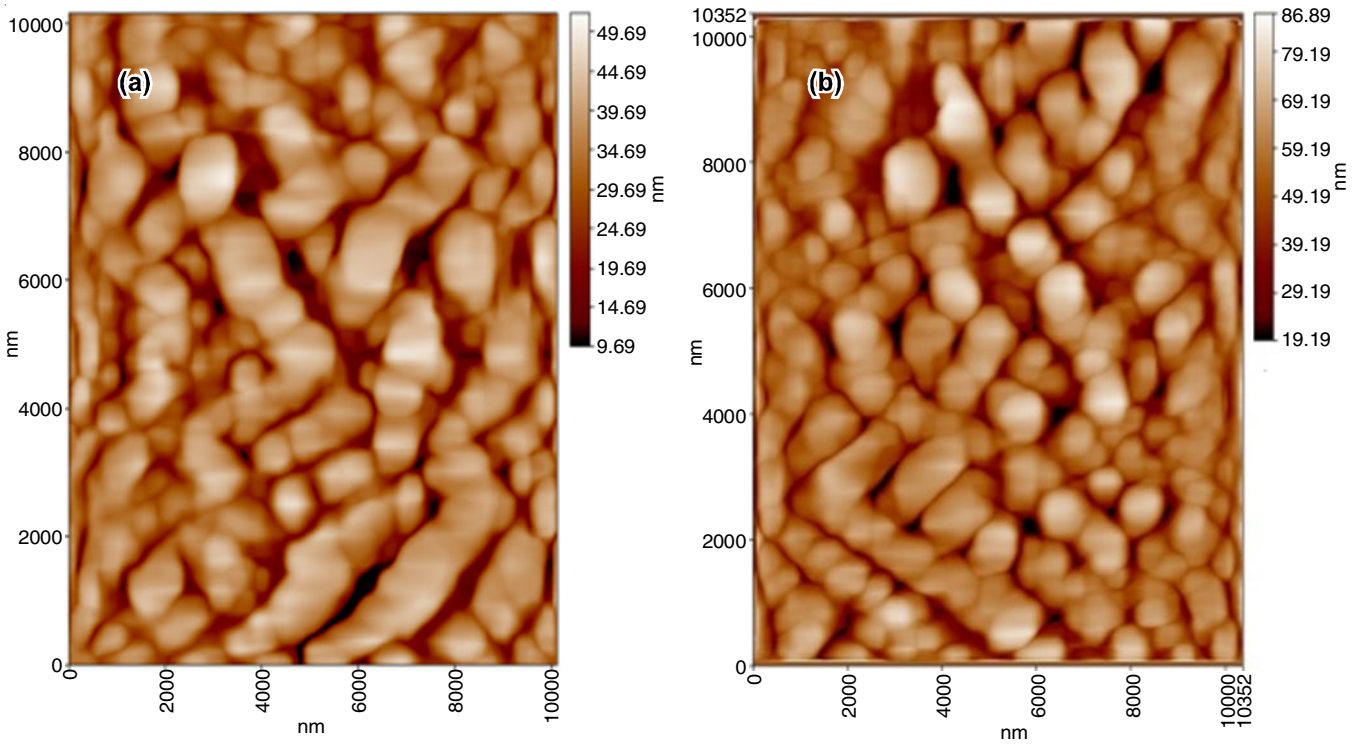


Fig. 7. AFM micrographs for Ceram-x-mono composite group's samples (a) before bleaching and (b) after 1 week of bleaching

related to its lowest Vickers hardness mean value. Secondary caries at the tooth-restoration margin is the most frequently cited reason for restoration replacements [33]. Based on previous studies that measured fluoride release from dental materials, fluoride has been shown to be effective in preventing caries development [34,35]. Among the composite resins evaluated in this study, fluoride was detected only in Beautifil II, which contained a surface pre-reacted glass ionomer (S-PRG) filler [26]. Nanocomposites claim to provide the esthetic properties required for anterior restorations, as well as mechanical properties. In addition, some scientific data from *in vitro* investigative studies indicated that the majority of nanofilled composites led to higher surface quality and superior polish retention. However, in a study by Jung *et al*. [36] Filtek Supreme (which is filled with nanoparticles) showed a surface quality that was no better than that of a traditional hybrid composite after polishing.

Conclusion

Within the limitations of current study, the following conclusions are drawn as:

• The surface topography, which includes the surface roughness and surface micro-hardness, revealed increases in the smoothness and hardness of the Beautifil II and IPS Empress Direct composite resin restorations. This increasing surface micro-hardness was associated with unaffected cores and resulted in increase in impact force (preventing fracturing of the restoration during mastication).Increasing surface micro-hardness could result in decreasing wear rates and extending the restorations' lives.

• These results explain the absence of cracking during surface roughness measurements (SEM and AFM micrographs) and surface micro-hardness tests.

• Increased surface microhardness values of the bleached Beautifil II and IPS Empress Direct groups and decreased values in the Ceram-x-mono group due to chemical changes and element rearrangements.

• Decreased surface roughness values of the bleached Beautifil II and IPS Empress Direct groups and increased values in theCeram-x-mono group are due to chemical changes and element rearrangements.

• The revolutionary technologies employed to manufacture composite resins have differently changed their properties, especially in terms of the size, shape and distribution of the filler particles.

• The SEM, EDAX and AFM methods used in this study were useful for examining the particles and elements of the composite resins. The size of the filler particles and the chemical composition of the composite resin had an impact on its Vickers hardness.

• Increasing smoothness represented a healthier field.

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