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Original research article

Color change, water sorption and solubility of two types of denture liners incorporated with carbon nanoparticles

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ABSTRACT

OBJECTIVE: **The aim of this manuscript was to investigate the effect of carbon nanoparticles (CNs) addition into denture liners on the color change and water absorption and solubility.**

MATERIALS AND METHOD: **Test specimens (n=10) of Visco-Gel (Group VG) and Ufi-Gel (Group UG) were created either without (Groups C-as control and W) or with the incorporation of 0.5%, 1% and 10% CNs synthesized from licorice root plant. The size of the CNs were measured with dynamic light scattering. The color of each specimen was measured with a spectrophotometer. Water sorption and solubility were determined by weight measurement. The data were analyzed by two-way ANOVA for sample size estimation and Mann-Whitney U and Kruskal-Wallis tests for analyses of main outcomes with significance at the p<0.05 level.**

RESULTS: **All CNs-added test groups showed statistically higher color change than control groups (p<0.0125). In Group UG, 10% CNs added test groups showed statistically higher water sorption and solubility values than Group C, W and 0.5% CNs added test groups (p<0.001). However, the addition of 0.5% and 1% CNs to Groups VG caused a statistical decrease in water sorption values compared to control groups and Group VG 10% (p<0.001).**

CONCLUSION: **Color change of CNs added denture liners were not within clinically accepted range of color difference regardless of addition rate. CNs addition in tested denture liners promoted changes in the liners' sorption/solubility. UG was more prone to increase in both water sorption and solubility than VG.**

KEYWORDS: **Color; denture liners; nanoparticles; sorption; solubility**

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INTRODUCTION

Denture liners are expected to absorb and uniformly distribute the biting force during chewing.[1-4] Since they are in contact with oral tissues, it is clinically important that they should have antimicrobial properties.[5]

Carbon nanoparticles (CNs) show antioxidant effects on the bacteria via on free-radicals and immobilizing capacities as reported by previous studies.[6–10]. In order to impart antibiofilm properties to denture liners, different nanoparticles have been used so far.[11–13] However, green synthesized nanoparticles have not been used with this aim in denture liners. Licorice is a rich carbon source for the green synthesis of CNs and has antioxidant properties.[14] This makes the procedure of CNs processing simple, chip and also biocompatible. Some of the previous studies have revealed that CNs present antibacterial properties.[15,16] However, there is no scientific data related with the usage of CNs in dental materials.

Bacterial contamination has been reported for denture liners generally due to surface roughness and water sorption and solubility.[1,17,18] In addition, color change is another crucial factor for the success of dental materials.[19,20] The color of denture liner may be reflected from the denture base material due to the high light transparency. Therefore, the addition of different additives into the denture liners for gaining antibiofilm property may cause color change, which may lead to the dissatisfaction of the patients. CNs clinically have a brown color and green-blue fluorescence most likely due to the polysaccharides and other macromolecules.[14] In addi-

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tion to CNs' antibacterial activities, its intense brown appearance reveals the need to investigate the effect of lining materials on color properties.

The objective of this *in vitro* study was to incorporate CNs at 0.5, 1 and 10% to two types of denture liners and evaluate the color change and water sorption/solubility. The null hypothesis was that color stability, water sorption, and solubility of denture liners would be affected by denture liner type used.

MATERIALS AND METHOD

Preparation and characterization of CNs

CNs were prepared using the method described in our previous report.[21] Primarily, 1.0 g of licorice root was extracted in ethanol/water (1:2 v/v) at 90°C in a beaker with stirring. Subsequently, this of 5 mL of licorice root extract and 2 mL of water/ethanol (1:1 v/v) were transferred into the Teflon oven vessel and kept at 250 °C for 30 mins. The resulting material was cooled down and dissolved 6 mL of MilliQ-water (Millipore Inc., Tokyo, Japan). Finally, this solution was centrifuged at 6000 rpm by 20 mins and taken supernatant was dried at 90 °C by 12 h in the oven (Binder GmbH, Germany) for the final product (Figure 1). The hydrodynamic nanoparticle size and zeta potential measurements of CNs were conducted using a Zetasizer nano-ZS ZEN 3600 series (Malvern Instruments Ltd., Malvern, Worcestershire, UK).

Fourier-transformed Infrared Spectroscopy

Fourier transformed infrared (FTIR) spectroscopy (Perkin Elmer, Waltham, MA, USA) was utilized to determine molecular bonds and transmittance values of CN and CN-embedded test samples. Measurements were carried out in the frequency range of 450-4000 cm^{-1} at a resolution of 4 cm^{-1}.

Preparation of the test specimens

In the present study, a commercially available silicone-based soft denture liner (Ufi Gel P, polydimethylsiloxane and platinum catalyst, chemically cured silicone based soft denture liner, VOCO Gmbh, Cuxhaven, Germany; Group UG) and one acrylic-based tissue conditioner (Viscogel, powder: polyethyl methacrylate liquid: ethanol Phthalyl butyl glycolate, dibutyl phthalate, chemically-cured acrylic based-tissue conditioner, Dentsply DeTrey GmbH, Konstanz, Germany; Group VG) were used. Each denture liner test groups were divided into five subgroups (n=10) according to the CN mixture ratios (totally n=100). Catalyst, base, and proportionally determined CNs were mixed simultaneously for Groups UG (n=50). On the other hand, CNs was incorporated into the liquid of VG, then, the modified liquid was mixed with powder for Groups VGs (n=50).

Group VG-UG C (as control): 0% CN addition; 0.2 g powder, 146.6 µl liquid - 0.1 g base, 0.1 g catalyst

Group VG-UG W: 0% CN addition (water addition without CN); 40 µl water, 0.2 g powder, 146.6 µl liquid - 40 µl water, 0.1 g base, 0.1 g catalyst

Group VG-UG 0.5: 0.5% CN addition; 30 µl water, 10 µl CN, 0.2 g powder, 146.6 µl liquid - 30 µl water, 10 µl CN, 0.1 g base, 0.1 g catalyst

Group VG-UG 1: 1% CN addition; 20 µl water; 20 µl water, 20 µl CN, 0.2 g powder, 146.6 µl liquid - 20 µl water, 20 µl CN, 0.1 g base, 0.1 g catalyst

Group VG-UG 10: 10% CN addition; 0 µl water, 200 µl CN, 0.2 g powder, 146.6 µl liquid - 0 µl water, 200 µl CN, 0.1 g base, 0.1 g catalyst

Test materials were mixed according to the manufacturer's recommendations and then they were molded in a round, stainless steel mold. To compress the material and prevent bubble formation, the glass slides was pressed under a constant vertical load of 9.8 N. The specimens were stored at room temperature (22±2°C) until its total chemically polymerization.

Color change

Measurements were performed according to the CIE (Commission International de I'Eclairage) color system using a reflection spectrophotometer (Analytik Jena, Specord 210 Plus, Jena, Germany). Fifty test specimens of each tested material (totally 100; 10 mm diameter, 2 mm thickness) (n=10) were tested for color change at three points for each specimen by the same operator. To evaluate the color change, color differences (ΔE) and color variables (ΔL*, Δa*, Δb*) were calculated relative to the baseline measurements in control groups using the following equation:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

If the color change value is $\Delta E \leq 3.7$, it is clinically acceptable.[22] To compare color changes in this study to a clinical situation, the color changes (ΔE) were converted to National Bureau of Standards (NBS) units using the following formula:[23]

$$\text{NBS units} = \Delta E \times 0.92$$

The result of this formula indicated clinically acceptable color changes defined by the following classifications: indicial (NBS = 0.0-0.5), slight (NBS = 0.5-1.5), noticeable (NBS = 1.5-3.0), considerable (NBS = 3.0-6.0), very (NBS = 6.0-12.0), and excessive (NBS=+12.0).

Water sorption and solubility

The disc shaped specimens (diameter of 50 mm and thickness of 0.5 mm) were prepared (n=10). The specimens' water sorption and solubility were evaluated according to the methodology described by ISO 10139-2:2009.[24] Then, they were placed in a desiccator (IL-DAM Ltd., Ankara, Turkey) that included newly dried silica gel (Sigma–Aldrich, Steinheim, Germany) at 37±1 °C for 24 hours. Described drying cycle was repeated again every day at the same time until the constant weight was obtained (M_1). They were placed in distilled water for 7 days at 37±1 °C. Then, they were removed, dried with filter paper, and weighed again (M_2). After this process, they were placed in the desiccator again until they reached a constant mass in the desiccator, as stated previously. This final mass was recorded as M_3. Water sorption and solubility were calculated using the following formula:

Water sorption (WS) (µg/mm³) = M_2 (µg) – M_3 (µg) / V (mm³)

Water solubility (WSL) (µg/mm³) = M_1 (µg) – M_3 (µg) / V (mm³)

SEM analysis

The surfaces of one specimen from water sorption and solubility test groups were randomly selected and inspected by Scanning Electron Microscope (SEM) (Zeiss, SUPRA-55, Carl Zeiss NTS GmbH, Oberkochen, Germany) ×50000, ×100000, ×200000 magnifications. The incorporation of CNs into tested Group VG and UG, and also the effect of this addition on the surface topography of test materials were analyzed.

Statistical analyses

Statistical analyses were carried out using statistical software (IBM SPSS Statistics version 17.0 software, IBM Corporation, Armonk, NY, USA). The primary outcome of the study was to determine the differences in terms of any main outcome variable (i.e., color change, water sorption and, solubility) among groups. A total sample size of 90 (9 per group) was required to detect at least a 0.40 effect size (Cohen's F) according to the interaction between testing materials and CN concentration levels with a power of 85% at the 5% significance level. It was decided to enroll 10 specimens for each sub-group. Sample size estimation was performed using G*Power (Franz Faul, Universität Kiel, Kiel, Germany) version 3.1.9.1 and, based on 2-Way analysis of variance (ANOVA) method. Cohen's large effect size of 0.40 was considered on the basis of our clinical predictions.

For the analyses of color change and water sorption/solubility, Mann-Whitney U test was performed for the comparisons among the tested materials according to the CN concentration added. When the p value from these test statistics were statistically significant, post-hoc Tukey HSD or Conover's multiple comparison test were used to understand which group differed from the others. Tip I error was controlled by applying the Bonferroni Correction for all possible multiple comparisons. The results were accepted as statistically significant for $p<0.0125$ according to the Bonferroni Correction. Kruskal-Wallis was performed for the comparisons among the CN concentrations for each tested material. These results were accepted as statistically significant for $p<0.025$ according to the Bonferroni Correction.

Table 1. *Median values and IQR of color change of the tested materials (ΔE)*

	Group VG	Group UG	p-value †
Group C-W	16.97 (9.52)^{a,b,c}	4.72 (4.76)^{a,b,c}	**0.002**
Group C-0.5%	27.62 (7.64)^{a}	8.64 (2.54)^{a}	**<0.001**
Group C-1%	29.51 (11.96)^{b}	10.15 (3.15)^{b}	**<0.001**
Group C-10%	28.43 (14.90)^{c}	9.95 (2.39)^{c}	**<0.001**
p-value ‡	**0.004**	**0.005**	

† Comparisons between Group VG and UG within CN addition rates, Mann Whitney U test, results for p<0.0125 according to Bonferroni Correction were considered statistically significant, ‡ Comparisons between CN addition rates within Group VG and UG, Kruskal Wallis test. The same superscript letters indicate statistically significant differences between the stated groups; a: Group W vs 0.5% (p<0.025), b: Group W vs 1% (p<0.001), c: Group W vs 10% (p<0.001)

Table 2. *Evaluation of the color change in the materials (NBS units)*

	Group VG	Group UG
Group C-W	15.6	4.34
Group C-0.5%	25.41	7.94
Group C-1%	27.14	9.33
Group C-10%	26.15	9.15

RESULTS

Characteristics of denture liners incorporated with CNs

The hydrodynamic size and surface zeta potential of the CNs were found to be 15–30 nm and 26.3mV±1.9 mV in dynamic light scattering (DLS) measurements, respectively.[21] The surface functional groups of test samples doped were examined by FTIR analysis, and it was observed that the presence of CN in these samples did not cause any change in functional groups even at high concentrations. Thus, it is understood that test samples protected its structure without chemical bonding with CN (Figure 2).

Color change

Statistically significantly higher color change was observed in Group VG than Group UG ($p<0.05$). This result showed that Group VG was more prone to color change related with CNs addition compared to Group UG. In both of VG and UG test groups, color change of CN added experimental groups (0.5%, 1%, and 10%) were statistically significantly higher than control groups ($p=0.004$, $p=0.005$ respectively) (Table 1). The amount of color change was insignificantly lower in the 0.5% CN addition rate groups compared to the 1% and 10% CN addition rates. Therefore, it was shown that the increase in the percentages of the addition of CNs to denture liners did not significantly affect the amount of color change. In addition, by analysis of the NBS system, clinically 'excessive' color change was observed in Group VG and 'considerable/very' color change in Group UG (Table 2).

Water sorption

In Groups VG, the results of this comparative study indicated that the sorption of the denture liner was highest in Group VG-W (4.68±10.42) followed by Group VG10 (4.28±24.25) and least in Group VG1 (1.66±21.15) (Table 3). In denture liner test groups, the comparative evaluation on water sorption showed the lowest sorption in Group UGC (0.09±7.01) followed by Group UGW (0.35±5.89) and highest in 10% CNs addition group (Group UG10) (4.95±13.20) (Table 3). In addition, VG test groups (Group VG) revealed statistically significantly higher water sorption values than Group UG in all tested subgroups ($p<0.001$).

Table 3. *Median values and IQR of water sorption of the tested materials (µg/mm³)*

	VG	UG	p-value †
Group C	4.07 (18.62)^{a,b}	0.09 (7.01)^{a,b,g}	**<0.001**
Group W	4.68 (10.42)^{c,d}	0.35 (5.89)^{c,d,h}	**<0.001**
Group 0.5%	2.03 (9.55)^{a,c,e}	1.95 (3.95)^{a,c,e}	**<0.001**
Group 1%	1.66 (21.15)^{b,d,f}	3.16 (8.38)^{b,d}	**<0.001**
Group 10%	4.28 (24.25)^{e,f}	4.95 (13.20)^{e,g,h}	**<0.001**
p-value ‡	**<0.001**	**<0.001**	

† Comparisons between Group VG and UG within CN addition rates, Mann Whitney U test, results for p<0.010 according to Bonferroni Correction were considered statistically significant, ‡ Comparisons between CN addition rates within Group VG and UG, Kruskal Wallis test. The same superscript letters indicate statistically significant differences between the stated groups; a: Group C vs W (p<0.001), b: Group C vs 1% (p<0.001), c: Group W vs 0.5% (p<0.025), d: Group W vs 1% (p<0.001), e: Group 0.5% vs 10% (p<0.01), f: Group 1% vs 10% (p<0.001), g: Group C vs 10% (p<0.001), h: Group W vs 10% (p<0.001)

Table 4. *Median values and IQR of water solubility of the tested materials (µg/mm³)*

	VG	UG	p-value †
Group C	11.44 (20.61)^{a}	1.05 (2.55)^{a,e,f}	**<0.001**
Group W	12.23 (9.83)^{b,c}	1.87 (1.68)^{c,g}	**<0.001**
Group 0.5%	8.85 (11.01)^{a,b,d}	4.54 (5.99)^{a,d}	**<0.001**
Group 1%	11.13 (19.31)^{c}	6.92 (10.85)^{c,e}	**<0.001**
Group 10%	13.17 (42.50)^{d}	9.85 (15.69)^{d,f,g}	**<0.001**
p-value ‡	**<0.001**	**<0.001**	

† Comparisons between Group VG and UG within CN addition rates, Mann Whitney U test, results for p<0.010 according to Bonferroni Correction were considered statistically significant, ‡ Comparisons between CN addition rates within Group VG and UG, Kruskal Wallis test. The same superscript letters indicate statistically significant differences between the stated groups; a: Group C vs 0.5% (p<0.025), b: Group W vs 0.5% (p<0.001), c: Group W vs 1% (p<0.01), d: Group 0.5% vs 10% (p<0.01), e: Group C vs 1% (p<0.001), f: Group C vs 10% (p<0.001), g: Group W vs 10% (p<0.001)

Water solubility

The addition of high percentages CNs (Group VG-UG10) into tested denture liners resulted in a statistically significantly increased water solubility compared to low percentage addition group (Group VG-UG0.5) (p<0.001) (Table 4). These results show that high percentage addition rate (10%) results in more deterioration than lowers (0.5% and 1%) in water solubility for two types of tested denture liners. In addition, VG test groups (Group VG) revealed statistically significantly higher water solubility values than Group UG in all tested subgroups (p<0.001).

SEM analyses

Morphological analysis by SEM imaging of test specimens is presented in Figures 3 and 4. Particle size measured from the SEM images showed similar size (~15-20 nm) to the particle size measured by DLS. Homogeneous dispersion was seen in both denture liners. Fracture formation was not observed in none of tested materials even at the highest concentration of CN (Figures 3E and 4E).

DISCUSSION

The null hypothesis that the color stability, water sorption, and solubility of the denture liners would be affected by the type of denture liner used was accepted. In addition, differences in color stability, water sorption, and solubility would be related with the concentration of CNs added in denture liners was rejected.

Although the distribution of the data in question was far from normal, the homogeneity of the variances could

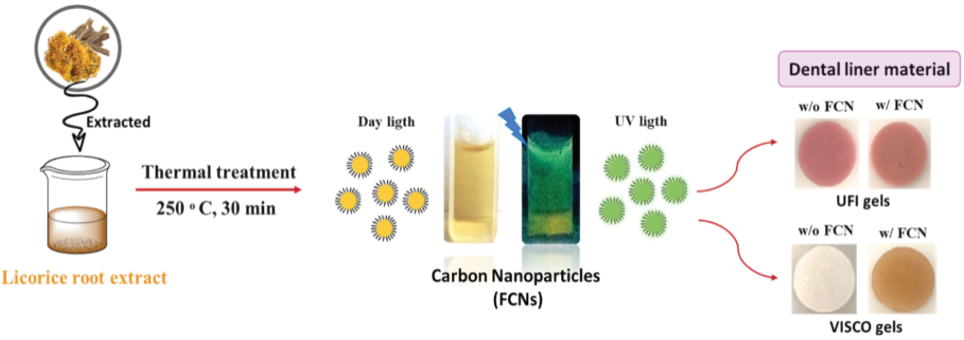

Figure 1. *Preparation procedure of the CNs.*

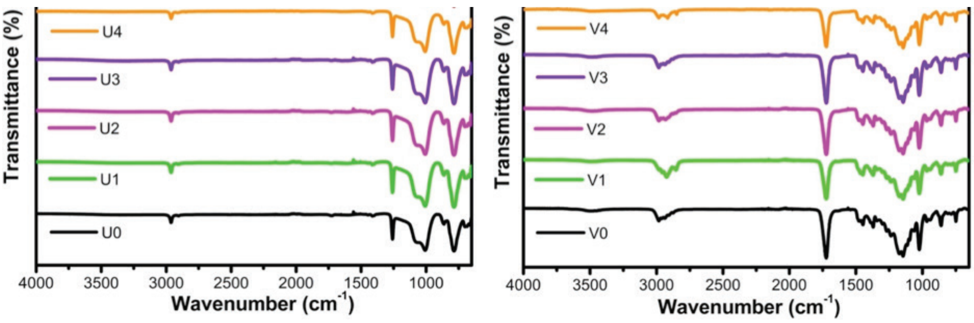

Figure 2. *FTIR spectrum of test specimens (A) Group UG and (B) Group VG*

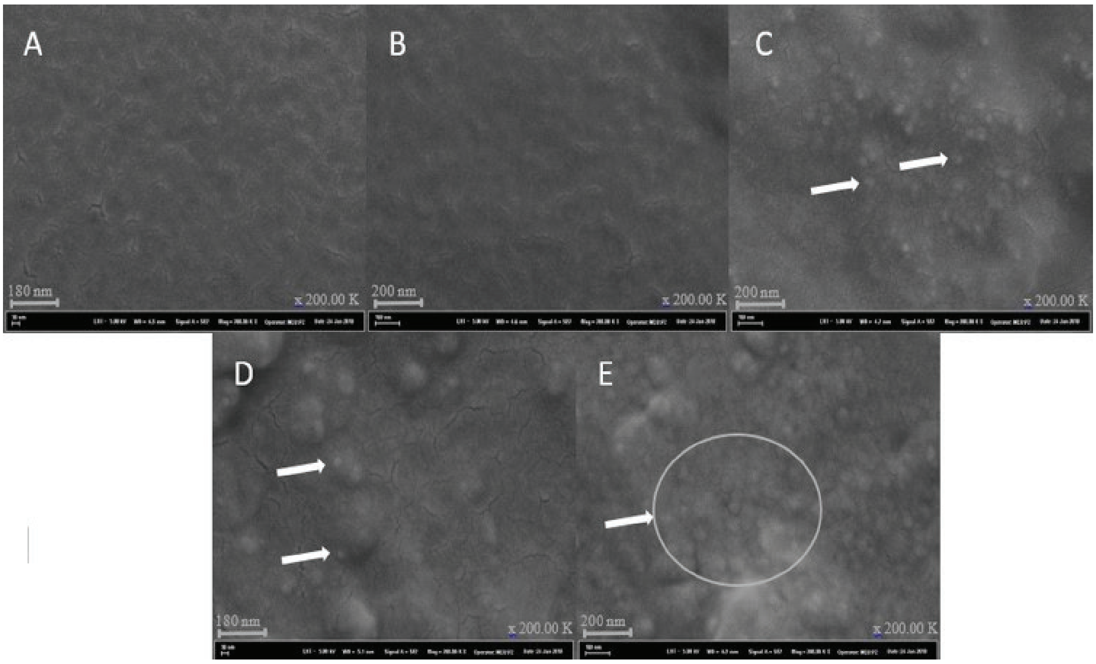

Figure 3. *Representative SEM images of the tested materials. (A) SEM image of Group UGC (control group without CN), (B) SEM image of Group UGW (incorporated with water without CN), (C) SEM image of Group UG0.5 (incorporated with water and 0.5% CN), (D) SEM image of Group UG1 (incorporated with water and 1% CN), (E) SEM image of Group UG10 (incorporated with water and 10% CN)*

not be assumed, so the median was used as the central location criterion, and the interquartile range (IQR) was used as the prevalence measure. Interquartile range width represents the difference between the 1st quartile (25th percentile) value and the 3rd quarter (75th percentile) value, and the large difference means that the data are distributed in a fairly wide range. Since the data of the existing variables do not show a symmetrical distribution around the mean, and the variances are not homogeneous, the IQR value is in a wide range.

The homogenous distribution of CN in two types of denture liners are presented in SEM images (Figures 3 and 4), which revealed that water was an appropriate solution for dispersing CNs. The molecular structures of denture liners did not change with CN incorporation and no chemical bond was formed between tested denture liners and CNs (Figure 2).

The addition of CNs into denture liners resulted in high color change ($\Delta E>3.5$) in all tested subgroups compared to control group. The significant color change in the test specimens was probably due to the individual characteristics of tested materials and CNs. The color change was visible, especially evident in Group VG compared to Group UG (Figure 1).

In Group VG, color change was similar among the tested CNs addition rates. However, addition of CN in three percentages resulted in statistically significantly higher color change compared to control group ($p<0.005$). This color change occurs due to higher plasticizer solubilization and consequently higher water sorption. The increased water sorption and water solubility, especially in higher percentage CN addition groups (Group 10%), might be partly result from the effect of CN incorporation. CN addition may have damaged the physical integrity of the tested denture liners, resulting in an increase in water sorption/solubility. Lower CNs addition rates (0.5% and 1%) presented similar water sorption/solubility. However, these values of 10% CN addition groups were generally higher than low percentage CNs addition groups. These results may be related to the lack of chemical bonding between FC and denture liners. The absence of chemical bonding may have resulted in inter-structural space and higher water sorption and solubility of Group VG.

The present study demonstrated that Group UG exhibited less color change than Group VG. These findings are consistent with the results of a previous study by Ahmadzade *et al.*[25] who showed higher color stability of silicone-based liners than acrylic-based liners. This may result from hydrophobic characteristics of the elastomers reducing water sorption.[26] In addition, CN incorporation into the test materials resulted in high color change values in all tested percentages compared to the control groups ($p<0.05$). In critical analysis of the color changes based on the NBS classification, the present study found that Group VG had clinically 'excessive', test groups of Group UG had 'very' and Group UGC had 'considerable' color variation (Table 2).

VG test groups displayed statistically significantly greater water sorption and solubility values than UGs tested ($p<0.05$) (except between Group 10 in water sorption). This can be explained by the differences in chemical composition between the materials.[27] Group VG contains acrylic polymers, a methyl methacrylate-based monomer, and plasticizers.[28] In addition, acrylic materials are more prone to water solubility due to the

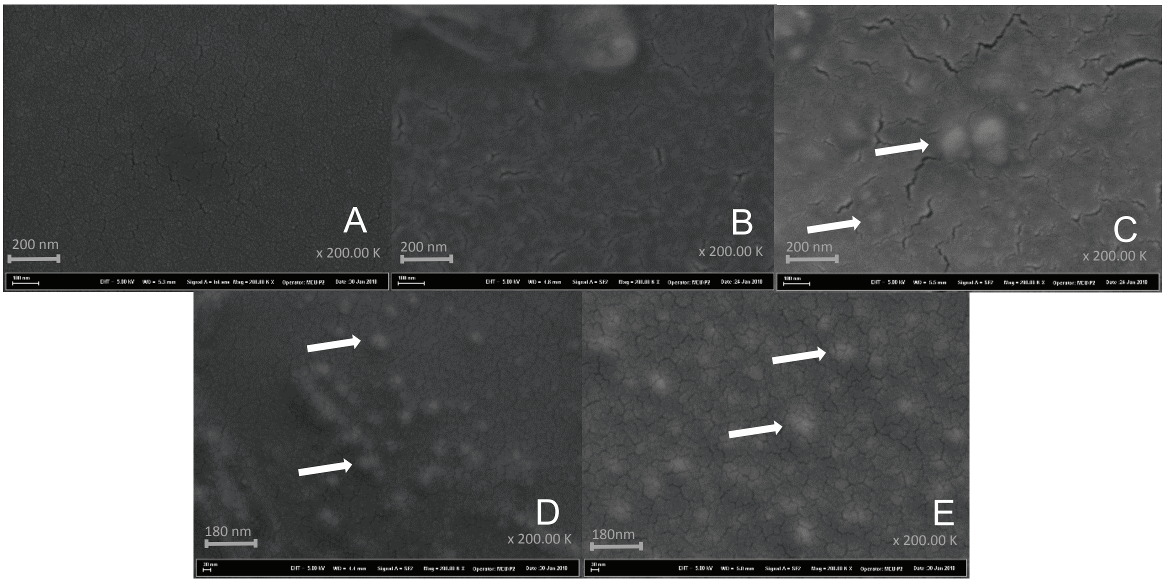

Figure 4. *Representative SEM images of the tested materials (A) SEM image of Group VGC (control group without CN), (B) SEM image of Group VGW (incorporated with water without CN), (C) SEM image of Group VG0.5 (incorporated with water and 0.5% CN), (D) SEM image of Group VG1 (incorporated with water and 1% CN), (E) SEM image of Group VG10 (incorporated with water and 10% CN)*

solubility of plasticizer.[29] As reported by Lima *et al.*[30] the plasticizer dibutyl phthalate in VG with low molecular weight (194.19 g/mol) and high ethanol concentration (8.3% volume) may be the reason of higher water solubility of VG compared to UG test groups. This process compromises the durability of the material and limits its use as a long-term soft liner.[27,30] On the other hand, Group UG is composed of dimethylsiloxane and poly dimethylsiloxane. Dimethylsiloxane based materials are hydrophobic and only a small amount of water sorption occurs.[27] In line with the study by Kanjanamekanant *et al.*[31] we also found that the percentage of water sorption was lower than water solubility in all tested groups. According to the ISO standard, the water sorption of long-term UG shall not exceed 20 μg/mm^3 and water solubility shall not exceed 3 μg/mm^3.[24] In the present study, the water sorption values of Group UG incorporated with CN were lower than 20 μg/mm^3 , which is compatible with ISO standards. However, water solubility of Group UG incorporated with CN were higher than 3 μg/mm^3, which is not compatible with ISO standards. It might be that the amount of leached out ethyl alcohol and plasticizer was higher than water sorption in Group VG.

Evaluation of the color change in tested materials showed that all tested percentages of CNs addition resulted in clinically unacceptable color change, especially in Group VG. Although, in Group UG, CNs addition in all tested percentages resulted in lower color change compared to Group VG, none of the tested CNs addition percentages could present clinically acceptable color change. In the current study, three percentages of CNs addition into two types of denture liner were tested. However, further investigation is required with different percentages to explain the results in more detail.

CONCLUSION

Soft denture liner (UG) was more prone to increase in water sorption and water solubility than tissue conditioner (VG). In addition, it can be concluded that CNs addition into denture liners resulted in clinically unacceptable color change at all the different ratios tested (0.5, 1 and 10%). Finally, tissue conditioner (VG) was seen to be more prone to color change than soft denture liner (UG).

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Karbon nanopartikül ilave edilmiş iki tip protez astarının renk değişimi, su emilimi ve suda çözünürlüğü

ÖZET

AMAÇ: Bu çalışmanın amacı, karbon nanopartikül (CN) ilavesinin protez astarlarının renk değişimi ve su emilimi ve sudaki çözünürlüğü üzerindeki etkisini araştırmaktır.

GEREÇ VE YÖNTEM: Visco-Gel (Group VG) ve Ufi-Gel'in (Group UG) disk şeklindeki örnekleri (n=10) CN ilave edilmeden (Grup C-kontrol ve W) veya %0.5, %1 ve %10 oranında meyan kökü bitkisinden sentezlenen CN ilave edilerek hazırlandı. CN'lerin boyutu dinamik ışık saçılımı ile ölçüldü. Herbir örneğin rengi bir spektrofotometre (Analytik Jena, Specord 210 Plus, Jena, Germany) kullanılarak ölçüldü. Su emilimi ve suda çözünürlük ağırlık ölçümü ile belirlendi. Veriler örneklem büyüklüğü hesaplanması için çift yönlü ANOVA ve ana sonuçların analizi için Mann-Whitney U ve Kruskal-Wallis testleri ile p<0.05 düzeyinde anlamlı olacak şekilde analiz edildi.

BULGULAR: Tüm CN eklenmiş test grupları, kontrol gruplarından istatistiksel olarak daha yüksek renk değişikliği gösterdi (p<0.0125). UG gruplarında, %10 CN eklenen test grupları, Grup C, Grup W ve %0.5 CN eklenen test gruplarından istatistiksel olarak daha yüksek su emilimi ve suda çözünürlük değerleri gösterdi (p<0.001). Bununla birlikte, Grup VG' ye %0.5 ve %1 CN ilavesi, kontrol gruplarına ve Grup VG %10'a kıyasla su emilimi değerlerinde istatistiksel olarak düşüşe neden oldu (p<0.001).

SONUÇ: CN eklenen protez astarlarının renk değişimi, ekleme oranına bakılmaksızın klinik olarak kabul edilen renk farkı aralığında değildir. Test edilen protez astarlarına CN ilavesi, astarların su emilimi ve çözünürlüğünde değişikliklere neden olmuştur. UG, VG'ye göre hem su emilimi hem de suda çözünürlükte artışa daha yatkındır.

ANAHTAR KELİMELER: emilim; çözülebilirlik; nanopartiküller; protez astarları; renk