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Effect of polishing and denture cleansers on the surface roughness of new-generation denture base materials and their color change after cleansing

Gülce Çakmak DDS, PhD[1] | Julia Anouk Hess Med dent[1] | Mustafa Borga Dönmez DDS, PhD[1,2] | Deniz Yılmaz DDS, PhD[3] | Abdulaziz Alhotan BSc, MPhil, PhD[4] | Martin Schimmel PD, MAS, Prof Dr med dent[1,5] | Anne Peutzfeldt DDS, PhD, DrOdont[6,7] | Burak Yilmaz DDS, PhD[1,6,8]

[1]Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

[2]Department of Prosthodontics, Faculty of Dentistry, Istinye University, Istanbul, Turkey

[3]Department of Prosthodontics, Faculty of Dentistry, Alanya Alaaddin Keykubat University, Antalya, Turkey

[4]Dental Health Department, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

[5]Division of Gerodontology and Removable Prosthodontics, University Clinics of Dental Medicine, University of Geneva, Geneva, Switzerland

[6]Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland

[7]Department of Odontology, Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark

[8]Division of Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Columbus, Ohio, USA

Correspondence
Dr Mustafa Borga Dönmez, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Freiburgstrasse 7 3007, Bern, Switzerland.
Email: mustafa-borga.doenmez@unibe.ch

Abstract

Purpose: To evaluate the effect of polishing and denture cleansers on the surface roughness (R_a) of new-generation denture base materials that are additively, subtractively, and conventionally fabricated, while also assessing their color change after cleansing.

Material and Methods: One hundred and fifty disk-shaped specimens (Ø10 × 2 mm) were prepared from five denture base materials (one subtractively manufactured nanographene-reinforced prepolymerized polymethylmethacrylate (PMMA) (SM-GC), one subtractively manufactured prepolymerized PMMA (SM-PM), two additively manufactured denture base resins (AM-DT and AM-ND), and one heat-polymerized PMMA (CV) ($n = 30$). The R_a of the specimens was measured before and after conventional laboratory polishing, while color coordinates were measured after polishing. Specimens were then divided into three subgroups based on the denture cleanser: distilled water, 1% sodium hypochlorite (NaOCl), and effervescent tablet ($n = 10$). The R_a and color coordinates were remeasured after nine cleansing cycles over a period of 20 days. The CIEDE2000 formula was used to calculate the color differences (ΔE_{00}). Two-way analysis of variance (ANOVA) was used to analyze the R_a values before ($n = 30$) and after ($n = 10$) cleansing, while repeated measures ANOVA was used to analyze the R_a of material-time point pairs within each denture cleanser ($n = 10$). ΔE_{00} data after denture cleansing was also analyzed by using two-way ANOVA ($n = 10$) ($\alpha = 0.05$).

Results: Before polishing, R_a varied significantly among the materials. SM-GC and SM-PM had the lowest and AM-ND the highest R_a values ($P < 0.001$). Polishing significantly reduced R_a of all materials ($P < 0.001$), and after polishing, R_a differences among materials were nonsignificant ($P \geq 0.072$). Regardless of the denture cleanser, the R_a of AM-DT, AM-ND, and CV was the highest before polishing when different time points were considered ($P < 0.001$). After cleansing, AM-ND had the highest R_a of all the materials, regardless of the cleanser ($P \leq 0.017$). AM-DT had higher R_a than SM-PM when distilled water ($P = 0.040$) and higher R_a than SM-GC, SM-PM, and CV when NaOCl was used ($P < 0.001$). The type of cleanser significantly influenced the R_a of AM-DT, AM-ND, and CV. For AM-DT, NaOCl led to the highest R_a and the tablet led to the lowest R_a ($P \leq 0.042$), while for AM-ND, distilled water led to the lowest

R_a ($P \leq 0.024$). For CV, the tablet led to lower R_a than distilled water ($P = 0.009$). Color change varied among the materials. When distilled water was used, SM-GC had higher ΔE_{00} than SM-PM and AM-DT ($P \leq 0.034$). When NaOCl was used, AM-ND had higher ΔE_{00} than SM-GC, SM-PM, and AM-DT, while CV and SM-GC had higher ΔE_{00} than SM-PM and AM-DT ($P \leq 0.039$). Finally, when the tablet was used, AM-ND and CV had the highest ΔE_{00}, while AM-DT had lower ΔE_{00} than SM-GC ($P \leq 0.015$).
Conclusions: The tested materials had unacceptable surface roughness (>0.2 μm) before polishing. Roughness decreased significantly after polishing (<0.2 μm). Denture cleansers did not significantly affect the surface roughness of the materials, and roughness remained clinically acceptable after cleansing (<0.2 μm). Considering previously reported color thresholds, AM-ND and CV had unacceptable color change regardless of the denture cleanser, and the effervescent tablet led to perceptible, but acceptable color change for SM-GC, SM-PM, and AM-DT.

KEYWORDS
additive manufacturing, chemical disinfection, color change, denture base, surface roughness

Computer-aided design and computer-aided manufacturing (CAD-CAM) denture base materials, which can be processed additively or subtractively, have reduced the costs and the number of appointments needed to produce removable prostheses.[1] Subtractively manufactured polymethylmethacrylate (PMMA) denture bases exhibit favorable mechanical properties as they involve a prepolymerization process that involves high pressure and temperature.[2,3] However, reinforcement of PMMA to improve its mechanical properties has been reported[4] and a prepolymerized nanographene-reinforced PMMA that can be subtractively manufactured has recently been introduced.[5,6] Graphene is a crystalline form of carbon[6] in which atoms are arranged in a honeycomb-shaped pattern.[7] Previous studies on nanographene-reinforced PMMA have reported promising results considering its mechanical properties, optical characteristics, and antibacterial adhesion effect.[7–11] Nevertheless, a primary disadvantage of prepolymerized PMMA is that subtractive manufacturing generates a large amount of waste material, regardless of the chemical structure of the material.[8,12] In contrast, additive manufacturing generates less material waste and enables the fabrication of complex structures.[13,14]

Regardless of the denture base material, daily denture cleansing is critical to prevent biofilm accumulation and denture stomatitis.[15] Using denture cleansers is a relatively easy method to perform denture cleansing, particularly for elderly patients with reduced cognitive abilities to perform mechanical cleaning.[16–18] Denture cleansers have antimicrobial properties and are available in various forms, such as tablets, pastes, gels, or solutions.[18] Alkaline peroxide tablets and sodium hypochlorite (NaOCl) are among the commonly used denture cleansers.[2] However, the potential detrimental effects of denture cleansers on denture base materials, such as increased surface irregularities, leading to denture base bleaching, have been reported.[18] Surface roughness (R_a) values higher than 0.2 μm might result in increased bacterial plaque retention and faster discoloration.[2,19,20] Therefore, the effect denture cleansers have on the R_a and stainability of new-generation CAD-CAM denture base materials should be thoroughly investigated.

Previous studies have examined the effect of denture cleansers on the R_a and color stability of heat-polymerized,[21–26] subtractively manufactured PMMA,[2,27–29] and additively manufactured denture base resins.[30,31] However, to the authors' knowledge, no such studies have been carried out on subtractively manufactured nanographene-reinforced PMMA compared with other new-generation denture base materials. Therefore, the present study aimed to investigate the R_a of different denture base materials (one subtractively manufactured nanographene-reinforced prepolymerized PMMA, one subtractively manufactured prepolymerized PMMA, two additively manufactured denture base resins, and one heat-polymerized PMMA) after polishing and after use of different denture cleansers (distilled water, 1% NaOCl, and denture cleanser effervescent tablet). The effect of the cleansers on the color stability of the denture base materials was also tested. The null hypotheses were that (i) material type and polishing would not affect the R_a of the denture base materials before cleansing, (ii) material type and denture cleanser would not affect the R_a after cleansing (iii) material-time point pair would not affect the R_a for each denture cleanser, and (iv) material type and denture cleanser type would not affect the color change.

MATERIALS AND METHODS

Table 1 presents the denture base materials tested in the present study. The number of specimens was based on previous studies on the R_a and stainability of CAD-CAM denture base materials.[2,12,32] A total of 150 disk-shaped specimens (Ø10 mm × 2 mm) were produced from five denture base resins (G-CAM Pink (SM-GC), M-PM Disc Pink (SM-PM), Denturetec (AM-DT), NextDent Denture 3D+ (AM-ND), and Promolux High Impact Rosa (CV) ($n = 30$). Specimens

TABLE 1 Denture base materials tested.

Material	Type	Chemical composition	Abbreviation	Manufacturer
G-CAM Pink	Subtractively manufactured nanographene-reinforced prepolymerized PMMA	Not disclosed	SM-GC	Graphenano Dental, Valencia, Spain
M-PM Disc Pink	Subtractively manufactured prepolymerized PMMA	PMMA, methyl 2-methylprop-2-enoate, methyl 2-methylpropenoate, methyl methacrylate, dibenzoyl peroxide, benzoyl peroxide	SM-PM	Merz Dental GmbH, Lütjenburg, Germany
Denturetec	Additively manufactured denture base resin	Ethoxylated bisphenol A dimethacrylate, aliphatic urethane dimethacrylate, triethyleneglycoldimethacrylate	AM-DT	Saremco Dental AG, Rebstein, Switzerland
NextDent Denture 3D+	Additively manufactured denture base resin	Ethoxylated bisphenol A dimethacrylate, 7,7,9-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, 2-hydroxyethyl methacrylate, silicon dioxide, diphenyl(2,4,6- trimethylbenzoyl)phosphine oxide, titanium dioxide	AM-ND	NextDent B.V., Soesterberg, The Netherlands
Promolux High Impact Pink	Heat-polymerized PMMA	PMMA copolymer, dibenzoyl peroxide, organic colorants, inorganic pigments, methylmethacrylate, dimethacrylate	CV	Merz Dental GmbH, Lütjenburg, Germany

were fabricated and polished in line with a previous study on the R_a and color stability of CAD-CAM denture base materials.[32] Briefly, a 10 mm-wide cylinder was designed (Meshmixer v3.5.474; Autodesk Inc.), subtractively manufactured (PrograMill PM7; Ivoclar Vivadent AG), and then wet-sliced (Vari/cut VC-50; Leco Corp) into 2 mm-thick specimens by using SM-PM and SM-GC. To fabricate AM-DT and AM-ND specimens, a 2 mm-thick disk of 10 mm diameter was designed and additively manufactured by using proprietary digital light processing three-dimensional printers (MAX UV; Asiga for AM-DT and MoonRay S100; SprintRay Inc for AM-ND). Specimens were printed with a 50 μm layer thickness and a 60° angle relative to the build platform. Post-polymerization processes were carried out in line with the respective manufacturer's recommendations. CV specimens were manufactured by flask-press-packing wax patterns (Æ10 mm × 2 mm) at 74°C for 8 h. After fabrication, a non-contact optical profilometer (FRT MicroProf 100; Fries Research & Technology GmbH) and its integrated software (Mark III; Fries Research & Technology GmbH) were used to measure the R_a values before and after polishing.[32] Three horizontal and three vertical traces with a length of 5.5 mm, a point/line pixel density of 5501, a cut-off value (Lc) of 0.8 mm (ISO Norm 4287), and a distance of 1 mm between them were measured for each specimen before the mean values were calculated. Silicon carbide papers (Struers Labo-Pol 21 #280, #360, #1000, and #2400; Struers) were then used to smooth one surface of each specimen, which was then polished using a mixture of pumice and water (Pumice fine; Benco Dental) for 90 s at 1500 rpm, and with a polishing paste (Fabulustre; Grobet) for 90 s. Specimens were ultrasonically cleaned in distilled water for 10 min at 40 kHz (Eltrosonic Ultracleaner 07−08; Eltrosonic GmbH) and air-dried before the R_a values were remeasured.

Each specimen's color coordinates were measured three times against a gray background by using a digital spectrophotometer (CM-26d; Konica Minolta), which had an 8-mm aperture and estimated coordinates with Commission International de I'Eclairage Standard (2°) human observer characteristics. The optical contact between the gray background and the specimen was ensured by using a saturated sucrose solution. All measurements were performed by a single operator (G.C) in a room with controlled humidity, temperature, and natural light. The spectrophotometer was calibrated before each measurement, and the average values of three measurements were calculated.

After the initial color coordinate measurements, specimens were randomly divided (Excel; Microsoft Corp) into three groups according to denture cleanser used (distilled water (control), 1% NaOCl, and denture cleanser effervescent tablet containing alkaline peroxide (Corega Tablet; Block Drug Company) ($n = 10$). Specimens paired with 1% NaOCl were immersed in a 200-mL glass beaker containing a 1% NaOCl solution for 10 min.[2,27] Specimens paired with an effervescent tablet were immersed in 200 mL tap water (40°C), in which a tablet had been dissolved for 15 min. Nine cleansing cycles were performed over a span of 20 days to replicate 180 days of denture cleansing[2,27] and specimens were stored in distilled water at 37 ± 2°C between cycles. Before each cleansing cycle, specimens were rinsed under running tap water for 60 s and immersed in a freshly prepared solution.[27] Specimens paired with distilled water were stored in beakers

TABLE 2 Surface roughness (R_a) of each material before cleansing (μm; mean ± standard deviation) (n = 30).

Material	Before polishing	After polishing
SM-GC	0.48 ± 0.08^{Ba}	0.13 ± 0.10^{Aa}
SM-PM	0.43 ± 0.05^{Ba}	0.09 ± 0.05^{Aa}
AM-DT	3.06 ± 1.51^{Bb}	0.09 ± 0.09^{Aa}
AM-ND	6.77 ± 1.26^{Bc}	0.14 ± 0.04^{Aa}
CV	3.47 ± 0.79^{Bb}	0.09 ± 0.06^{Aa}

Different superscript uppercase letters indicate significant differences in rows, while different superscript lowercase letters indicate significant differences in columns ($P > 0.05$).

containing distilled water (37 ± 2°C) during the 20-day period. After completing nine denture cleansing cycles, all specimens were cleaned in an ultrasonic bath and air-dried. Finally, the R_a and color coordinate measurements were repeated. The CIEDE2000 formula with parametric factors (kL, kC, and kH) set to 1[32] was used to determine the color difference (ΔE_{00}) of each material after denture cleansing. All procedures were performed by a single operator (J.A.H).

A two-way analysis of variance (ANOVA) test was used to evaluate the R_a values before (n = 30) and after (n = 10) cleansing, with material type and polishing as the main effects, and their interaction was included. Repeated measures ANOVA was used to evaluate the R_a of material-time point pairs within each denture cleanser. ΔE_{00} values after denture cleansing were evaluated by using two-way ANOVA followed by post-hoc Tukey HSD tests with material and denture cleanser as main effects, and the interaction was included (n = 10). All analyses were performed by using statistical analysis software (SPSS v27.0; IBM Corp) with a significance level of $\alpha = 0.05$. ΔE_{00} values were also analyzed according to previously set perceptibility (1.72 units) and acceptability (4.08 units) thresholds for denture base resins.[33]

RESULTS

The main factors of material type and polishing as well as their interaction significantly affected R_a before cleansing ($P < 0.001$). Thus, before polishing, SM-GC and SM-PM had statistically similar R_a ($P > 0.05$), which was significantly lower than that of the other materials ($P < 0.001$). AM-ND had the highest R_a ($P < 0.001$), while the difference between AM-DT and CV was nonsignificant ($P = 0.445$). Polishing reduced the R_a of each material significantly ($P < 0.001$). After polishing, the R_a differences among tested materials were nonsignificant ($P \geq 0.072$) (Table 2).

After cleansing, R_a was significantly affected by the main factors of material type and denture cleanser as well as by their interaction ($P \leq 0.010$). AM-ND had the highest R_a among materials, regardless of the denture cleanser ($P \leq 0.017$). Also, AM-DT had higher R_a than SM-PM when distilled water was used ($P = 0.040$) and higher than SM-GC, SM-PM, and CV when NaOCl was used ($P < 0.001$). The type of cleanser significantly influenced the R_a of AM-DT, AM-ND, and CV. For AM-DT, NaOCl led to the highest R_a and the tablet to the lowest R_a ($P \leq 0.042$), while for AM-ND, distilled water led to the lowest R_a ($P \leq 0.024$). For CV, the tablet led to lower R_a than distilled water ($P = 0.009$) (Table 3).

The time-point at which R_a was measured significantly influenced the R_a of three of the five denture base materials. Thus, for AM-DT, AM-ND, and CV, R_a was the highest before polishing regardless of the denture cleanser ($P < 0.001$), while the differences between after polishing and after denture cleansing R_a values were nonsignificant ($P \geq 0.767$) (Table 4).

ΔE_{00} values were also significantly affected by the main factors of material type and denture cleanser as well as by their interaction ($P \leq 0.009$). When distilled water was used, SM-GC had higher ΔE_{00} than SM-PM and AM-DT ($P \leq 0.034$), while every other pairwise comparison was nonsignificant ($P \geq 0.114$). When NaOCl was used, AM-ND had higher ΔE_{00} than the other materials ($P \leq 0.034$), except for CV ($P = 0.187$). SM-PM and AM-DT had similar ΔE_{00} values ($P = 0.246$), which were lower than that of SM-GC and CV ($P \leq 0.039$). The difference between SM-GC and CV was nonsignificant ($P = 0.414$). Finally, when a tablet was used, AM-ND and CV had similar ΔE_{00} values ($P = 0.869$) that were higher than those of the other materials ($P \leq 0.015$), while AM-DT had lower ΔE_{00} than SM-GC ($P = 0.001$). Type of cleanser affected the ΔE_{00} of SM-GC and AM-DT ($P \leq 0.032$), but not of the other three denture base materials ($P \geq 0.054$ for SM-PM, $P \geq 0.115$ for AM-ND, and $P \geq 0.164$ for CV). For both SM-GC and AM-DT distilled water led to the highest ΔE_{00} ($P \leq 0.038$), while NaOCl and tablet led to similar ΔE_{00} values ($P \geq 0.533$) (Table 5). Figure 1 shows the trend of surface texture and color change for each denture base material at each time point.

TABLE 3 Surface roughness (R_a) of each material-surface cleanser pair after cleansing (μm; mean ± standard deviation) (n = 10).

Denture cleanser	Material				
	SM-GC	SM-PM	AM-DT	AM-ND	CV
Distilled water	0.10 ± 0.04^{ABa}	0.08 ± 0.03^{Aa}	0.12 ± 0.06^{Bb}	0.16 ± 0.03^{Ca}	0.11 ± 0.07^{ABb}
NaOCl	0.08 ± 0.01^{Aa}	0.08 ± 0.01^{Aa}	0.16 ± 0.06^{Bc}	0.21 ± 0.04^{Cb}	0.08 ± 0.05^{Aab}
Tablet	0.09 ± 0.02^{Aa}	0.07 ± 0.02^{Aa}	0.07 ± 0.01^{Aa}	0.20 ± 0.04^{Bb}	0.07 ± 0.01^{Aa}

Different superscript uppercase letters indicate significant differences in rows, while different superscript lowercase letters indicate significant differences in columns ($P > 0.05$).

TABLE 4 Surface roughness (R_a) of each material according to cleansing protocol and time point (μm; mean ± standard deviation) (n = 10).

Material	Before polishing	After polishing	After cleansing	Cleansing protocol
SM-GC	0.45 ± 0.07^a	0.11 ± 0.06^a	0.10 ± 0.04^a	Distilled water
	0.50 ± 0.05^a	0.09 ± 0.04^a	0.08 ± 0.01^a	NaOCl
	0.49 ± 0.10^a	0.18 ± 0.16^a	0.09 ± 0.02^a	Tablet
SM-PM	0.44 ± 0.05^a	0.13 ± 0.06^a	0.08 ± 0.03^a	Distilled water
	0.43 ± 0.05^a	0.07 ± 0.03^a	0.08 ± 0.01^a	NaOCl
	0.41 ± 0.06^a	0.06 ± 0.01^a	0.07 ± 0.02^a	Tablet
AM-DT	3.44 ± 1.94^b	0.12 ± 0.16^a	0.12 ± 0.06^a	Distilled water
	3.25 ± 1.37^b	0.08 ± 0.02^a	0.16 ± 0.06^a	NaOCl
	2.50 ± 1.09^b	0.06 ± 0.01^a	0.07 ± 0.01^a	Tablet
AM-ND	6.66 ± 0.91^b	0.12 ± 0.05^a	0.16 ± 0.03^a	Distilled water
	6.64 ± 1.05^b	0.12 ± 0.03^a	0.21 ± 0.04^a	NaOCl
	7.02 ± 1.26^b	0.17 ± 0.03^a	0.20 ± 0.04^a	Tablet
CV	3.47 ± 0.78^b	0.11 ± 0.08^a	0.11 ± 0.07^a	Distilled water
	3.40 ± 0.72^b	0.08 ± 0.05^a	0.08 ± 0.05^a	NaOCl
	3.55 ± 0.94^b	0.08 ± 0.04^a	0.07 ± 0.01^a	Tablet

Different superscript lowercase letters indicate significant differences in rows (P < 0.05).

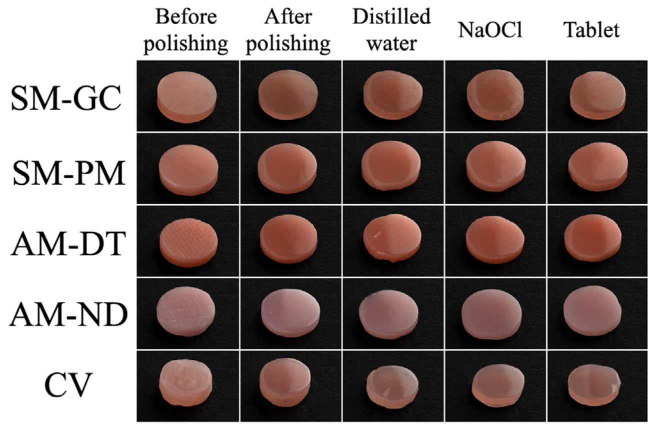

FIGURE 1 Representative images of specimens from each group before polishing, after polishing, and after each denture cleanser.

DISCUSSION

Tested materials had significantly different R_a before and after polishing, as polishing significantly reduced the R_a of each material. Thus, the first null hypothesis was rejected. While none of the materials had acceptable R_a before polishing, SM-GC and SM-PM had significantly lower R_a than the other materials. This aligns with previous studies that found low R_a values for prepolymerized PMMA compared to additively manufactured denture base resins or heat-polymerized PMMA.[12,20,31,32] These outcomes could be attributed to the fact that fabrication of SM-GC and SM-PM involves standardized polymerization under high temperature and pressure, which increases the degree of conversion and reduces residual monomers.[3] Even though there were significant differences in R_a among materials after polishing, they all had clinically acceptable R_a, which is also in line with previous studies.[1,12,19,20,32]

After denture cleansing, significant differences were observed in R_a among certain materials and denture cleansers, which led to the rejection of the second null hypothesis. R_a of SM-GC and SM-PM was not affected by denture cleansers, which may indicate that the R_a of subtractively manufactured specimens is similarly affected by the denture cleansers used. In addition, it should be noted that none of the material-cleanser pairs had unacceptable R_a after denture cleansing. Therefore, it may be speculated that the tested materials are resistant to the topographical changes caused by the denture cleansers tested and may potentially have similar bacterial plaque accumulation after cleansing. However, this hypothesis needs further support. The authors are aware of only one study, which also tested AM-ND, for the comparisons between the R_a of additively, subtractively, and conventionally manufactured denture base materials after being subjected to different denture cleansers.[31] Alfouzan et al.[31] found that subtractively manufactured PMMA had the lowest and AM-ND had the highest R_a after denture cleansing irrespective of the denture cleanser; denture cleansers affected the R_a of subtractively and conventionally manufactured PMMA, and none of the material-cleanser pairs had acceptable R_a after denture cleansing. Even though distilled water and 1% NaOCl were also used by Alfouzan et al.,[31] the specimens were cleansed without polishing, which may explain the differences between their findings and the current study.

The third null hypothesis was rejected as the R_a of AM-ND, AM-DT, and CV varied significantly across different time points (before polishing, after polishing, and after cleansing). Before polishing, the R_a values were above the clinically acceptable threshold of 0.2 μm for all materials, whereas after polishing and after cleansing, the R_a values of

TABLE 5 ΔE_{00} values for each material-surface cleanser pair (mean ± standard deviation) (n = 10).

Denture cleanser	Material				
	SM-GC	SM-PM	AM-DT	AM-ND	CV
Distilled water	4.90 ± 1.26^{Bb}	4.04 ± 1.69^{Aa}	4.09 ± 1.99^{Ab}	4.32 ± 0.68^{ABa}	4.64 ± 0.19^{ABa}
NaOCl	4.11 ± 0.42^{Ba}	3.33 ± 0.15^{Aa}	2.89 ± 0.26^{Aa}	4.92 ± 0.36^{Ca}	4.42 ± 0.23^{BCa}
Tablet	3.96 ± 0.25^{Ba}	3.31 ± 0.20^{ABa}	2.65 ± 0.17^{Aa}	4.89 ± 0.34^{Ca}	4.95 ± 1^{Ca}

Different superscript uppercase letters indicate significant differences in rows, while different superscript lowercase letters indicate significant differences in columns (P > 0.05).

each material-cleanser pair were below 0.2 μm, except for AM-ND cleansed with NaOCl (R_a = 0.21 μm). However, the difference between the mean R_a value of AM-ND-NaOCl after cleansing and the clinically acceptable threshold was 0.01 μm, which can be considered clinically irrelevant. The differences among time points were statistically nonsignificant for SM-GC and SM-PM, which may be associated with the number of specimens in each material-surface cleanser pair. Despite the lack of statistically significant differences in R_a at different time points for SM-GC and SM-PM, the reductions in R_a obtained after polishing, and maintained after cleansing, may be considered clinically significant given that the reductions observed were 0.31 μm or higher and thus, also higher than the clinically acceptable threshold of 0.2 μm.

ΔE_{00} values were significantly affected by material type and denture cleanser. Therefore, the fourth null hypothesis was rejected. According to perceptibility (1.72 units) and acceptability (4.08 units) thresholds set by Ren et al.[33] all material-denture cleanser pairs showed perceptible color change (ΔE_{00} > 1.72) while several of these color changes were also unacceptable (ΔE_{00} > 4.08). Looking at each denture base material separately, SM-GC showed unacceptable color changes when distilled water or NaOCl was used, while SM-PM showed acceptable color changes regardless of the denture cleanser. AM-DT showed unacceptable color change only when distilled water was used. It should be emphasized that the difference between the mean ΔE_{00} values of SM-GC-NaOCl and AM-DT-distilled water pairs and the acceptability threshold[33] was 0.03 and 0.01 units, respectively, and that these differences may not be clinically perceivable. Finally, AM-ND and CV showed unacceptable color change regardless of the denture cleanser. A previous study on the color stability of an additively manufactured denture base resin after immersion in different denture cleansers for different durations concluded that the tested resin had higher ΔE_{00} values than heat-polymerized PMMA, regardless of the denture cleanser used.[30] In addition, the authors[30] reported perceptible but acceptable color changes for both materials when distilled water was used, and for heat-polymerized PMMA when effervescent tablets were used. Differences in materials tested and how these were subjected to denture cleansers may have led to the contradictory results between the present study and that of Coelho et al.[30]

Comparing the two subtractively manufactured denture base materials, SM-GC had either significantly or nonsignificantly higher ΔE_{00} than SM-PM. As both specimens were subtractively manufactured from prepolymerized PMMA pucks, the addition of nanographene might have led to PMMA's increased susceptibility to discoloration. However, the manufacturer of SM-GC has not disclosed the material's exact chemical composition and other components of SM-GC may have also led to higher ΔE_{00} values. A previous study on the stainability of tooth-colored SM-GC concluded that it had similar, and imperceptible, ΔE_{00} values to those of prepolymerized PMMA after coffee thermocycling.[6] Therefore, it can be hypothesized that SM-GC's resistance to discoloration depends on the material's inherent properties and the external stress to which it is subjected. Looking at the two additively manufactured denture base materials, AM-ND was more prone to discoloration as it had either significantly higher or nonsignificantly higher, and always unacceptable, ΔE_{00} values than AM-DT. In addition, AM-DT had ΔE_{00} values that were either similar to or lower than those of subtractively manufactured materials. This difference between AM-DT and AM-ND may be attributed to their chemical compositions, with AM-ND having a more heterogeneous composition of methacrylates and oxides. Furthermore, even though both materials contain ethoxylated bisphenol A dimethacrylate (BisEMA), AM-ND had a higher ratio (75wt%) of BisEMA than AM-DT ($25 \leq 50\%$wt) did.[12] Another factor that may have contributed to AM-DT's higher color stability is the fact that it was polymerized for a longer duration, which may have led to a higher degree of conversion. The authors are aware of only one study that investigated the color stability of AM-ND and AM-DT.[32] Although Çakmak et al.[32] studied the effect of simulated brushing and thermocycling, they also found AM-DT to have better color stability.

Even though the number of specimens in each group was based on previous studies that reported significant differences[2,12,32] and statistical differences were observed among test groups in the present study, the absence of a priori power analysis is a limitation of the present study. However, post hoc sensitivity power analyses were performed, and the sample size was deemed adequate for 80% power with a minimum effect size of 0.78 and $\alpha = 0.05$. All specimens were polished by a single operator for standardization and conventional laboratory procedures were used. However, polishing could be subjective, and different surface treatments may affect both R_a and ΔE_{00} values. In addition, the in vitro design of the present study could not simulate intraoral factors, like saliva, which may have affected the parameters tested. Another limitation of the present study was that only the effect of chemical denture cleansing methods was investigated, and mechanical or combined methods may have had different effects. The results of the present study simulated denture cleansing over a period of approximately six months.[2,27] The use of other durations may also have affected the parameters tested.[30] Finally, even though surface roughness and color stability affect the longevity of denture base materials, mechanical properties such as flexural strength and hardness should also be investigated to complement the findings of the present study.

CONCLUSIONS

Polishing significantly reduced the roughness of all five denture base materials. AM-DT, AM-ND, and CV had the highest roughness before polishing, and regardless of the denture cleanser, roughness decreased after polishing and did not change after cleansing. Even though the roughness after cleansing varied between materials and denture cleansers, roughness never exceeded the previously reported threshold of 0.2 μm for acceptable roughness. The materials had perceptible color change after cleansing when reported, recognized thresholds were considered; while the color changes of AM-ND and CV were deemed unacceptable, regardless of the denture cleanser. The effervescent tablet tested may be recommended for the cleansing of SM-GC, SM-PM, and AM-DT as it generally led to less color change than other cleansers. Based on the parameters tested, both of the subtractively manufactured materials and one of the additively manufactured (AM-DT) denture base materials may be expected to have comparable or even better clinical longevity than the conventional denture base material when tested cleansers are used.

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ORCID

Gülce Çakmak DDS, PhD https://orcid.org/0000-0003-1751-9207
Mustafa Borga Dönmez DDS, PhD https://orcid.org/0000-0002-3094-7487
Deniz Yılmaz DDS, PhD https://orcid.org/0000-0003-4570-9067
Abdulaziz Alhotan BSc, MPhil, PhD https://orcid.org/0000-0002-9036-0485
Burak Yilmaz DDS, PhD https://orcid.org/0000-0002-7101-363X

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