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RESEARCH AND EDUCATION

Optical properties and surface roughness of prepolymerized poly(methyl methacrylate) denture base materials

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ABSTRACT

Statement of problem. Studies of the color stability, relative translucency, and surface roughness of newly introduced computer-assisted design and computer-assisted manufacturing (CAD-CAM) prepolymerized poly(methyl methacrylate) (PMMA) denture base materials are lacking.

Purpose. The purpose of this in vitro study was to evaluate the color stability, relative translucency, and surface roughness of conventional and different prepolymerized CAD-CAM PMMA denture base materials after coffee thermocycling (CTC).

Material and methods. Six disk-shaped specimens (10×2 mm) were prepared from 3 different brands of prepolymerized CAD-CAM PMMA and a conventional heat-polymerized PMMA denture base material (N=24). Specimens were polished conventionally in 2 stages. The specimens were subjected to 5000 coffee thermocycles. The surface roughness (R_a) of each specimen was measured 3 times before and after CTC, using a contact profilometer, and the mean roughness (R_a) values were calculated. The color coordinates of the specimens were determined by using a noncontact spectroradiometer, and color differences and relative translucency parameter (RTP) values were calculated by using CIEDE2000 color difference and $RTP_{CIEDE2000}$ formulas. ANOVA was used to analyze surface roughness values, CIEDE2000 color differences, and RTP values (α=.05).

Results. CTC did not change the color of the tested materials. However, with regard to relative translucency, 2-way ANOVA revealed a significant interaction between the material and CTC (*P*=.011). Also, although CTC increased the surface roughness of all tested materials (*P*=.031), R_a values were lower than the plaque accumulation threshold of R_a=0.2 μm.

Conclusions. Mean color changes in all materials were clinically imperceptible after 5000 coffee thermocycles. One tested material had significantly lower relative translucency than other materials before and after CTC. The surface roughness values of all tested denture base materials were below the plaque accumulation threshold. (J Prosthet Dent 2019;121:347-52)

Poly(methyl methacrylate) (PMMA) resin is the material of choice for 95% of complete dentures because it is easily processed, repaired, and polished; and it offers low cost and good physicochemical properties and acceptable esthetics.[1-6] For more than 80 years, complete dentures have been fabricated from PMMA resin by using different processing methods, including pouring a fluid resin and mold-filling techniques (compression and injection molding).[7-9] With the development of computer-assisted design and computer-assisted manufacturing (CAD-CAM) technology, complete dentures can be fabricated by milling prepolymerized blocks of acrylic resin[7-12] or by rapid prototyping technology without the need for flasking or other processing methods.[13,14]

In addition to its advantages during fabrication, CAD-CAM-fabricated complete dentures have improved material properties because denture bases are milled from prepolymerized acrylic resin blocks, which are polymerized under high pressure and temperature conditions.[15-17] Regardless of the fabrication technique used, denture base materials should be compatible with the color and appearance of the underlying soft tissues because these materials replace the oral mucosa and gingiva.[18-20] The color and translucency of denture base materials should remain stable during processing and clinical service.[21] Color changes in denture base materials are an indicator of

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Clinical Implications

The color and surface roughness of conventional heat-polymerized and prepolymerized denture base materials may be considered stable after short-term coffee consumption. Certain CAD-CAM materials may be preferred when higher translucency is needed.

aging and material damage[2,19] and may lead to unesthetic dentures that need to be replaced.[22-26]

The surface roughness (R_a) of denture base materials affects staining, patient comfort, and esthetics and plays a key role in plaque accumulation and bacterial adhesion.[4,5,27,28] The roughness of denture base materials is affected by material properties, polishing techniques, and the dental hygiene habits of patients.[4,27] Based on in vivo studies, R_a threshold of 0.2 μm has been reported for clinically acceptable prostheses.[29]

A knowledge of the surface roughness and optical properties of denture base materials is important for achieving clinically successful complete dentures.[30] Although the color stability and surface roughness of conventional denture base materials have been reported,[5,19] studies of the color changes, relative translucency, and surface roughness of newly introduced prepolymerized CAD-CAM PMMA denture base materials are lacking. The purpose of this study was to investigate the surface roughness and optical properties of conventional and different prepolymerized CAD-CAM PMMA denture base materials after coffee thermocycling (CTC). The first null hypothesis was that CTC would not affect the color stability of these materials. The second null hypothesis was that CTC would not affect the relative translucency of these materials. The third null hypothesis was that CTC would not affect the surface roughness of these materials.

MATERIAL AND METHODS

Three different brands of prepolymerized PMMA and a conventional heat-polymerized PMMA denture base material, as described in Table 1, were tested for color stability, relative translucency, and surface roughness before and after CTC. Six disk-shaped (10×2 mm) specimens were prepared for each resin material as follows: prepolymerized PMMA denture base materials were designed as standard tessellation language (STL) files, 10 mm in diameter, and milled by using a CAD-CAM milling system (M1 Wet Milling Unit; Zirkonzahn). The specimens were then sliced using a cutting machine (Vari/cut VC-50; Leco Corp) and a diamond-wafering blade (Buehler series 15 LC diamond; Microstructural Analyses Division) to obtain disk-shaped specimens 2 ±0.03 mm in thickness.

A polyvinyl siloxane mold (Elite HD; Zhermack SpA) was fabricated from previously prepared CAD-CAM specimens to produce a wax pattern for heat-polymerized conventional PMMA specimens. This method enabled the wax pattern to be prepared in the same dimensions used for CAD-CAM specimens, and dimensions were checked by using digital calipers (Digimatic Indicator 0001 to 2°; Mitutoyo). For the fabrication of conventional heat-polymerized PMMA specimens, the wax patterns were put into flasks at the dough stage, and the wax was eliminated. The manufacturer's recommendations were followed for liquid-to-powder ratio, and the mixture was packed under pressure. Heat polymerization of the conventional PMMA specimens was performed in a water bath at 74°C for 8 hours.[31] After specimens were removed from the flasks, they were trimmed and smoothed with silicon carbide abrasive papers (600-grit) (Leco; Leco Corp) under running water. The specimens were conventionally polished in 2 stages: first by using a slurry of coarse pumice (Pumice fine; Benco Dental) in water for 90 seconds (1500 rpm)[5] and then fine polished with polishing paste (Fabulu stre; Grobet USA) for 90 seconds (Red-Wing; Handler Mfg). All specimens were ultrasonically cleaned (Jelsonic; Jelenko) in distilled water for 10 minutes and dried with a paper towel.

The R_a value for each resin specimen was measured 3 times before and after CTC with a contact profilometer (Surftest SV-3100; Mitutoyo Corp). The tracing length was 5.5 mm, the cut-off length was 0.8 mm, and the stylus speed was 1 mm/s. The average R_a value was used for each specimen at each time. A plaque accumulation threshold of R_a=0.2 μm[5] was used for comparison.

The baseline spectral radiance and reflectance spectra of each acrylic resin specimen was determined by using a noncontact spectral radiance-measuring system. This system consisted of a spectroradiometer (SpectraScan PR705; Photo Research) and a fiber optic light cable (Model 70050; Newport Stratford) with a xenon arc lamp (300 W; Newport Stratford) positioned on an optical table (Mecom) to achieve a 0-degree observer and 45-degree illuminant angle.[32] Each specimen was measured on 3 different backings (black, gray, and white) with a measuring aperture size of 1.1 mm, and the distance between the specimen and the lens was set to 80 mm. A thin layer of saturated sucrose solution was used for the optical contacts between the backings and the specimens.

Table 1. Acrylic resin materials studied

Material	Composition	Code	Manufacturer	Translucency/Shade	Lot No.
Vynacron	Heat-polymerized PMMA	Conv	Vynacron Dental Resins Inc	Pink	32538
AvaDent	Prepolymerized PMMA	Avad	Global Dental Science	Pink	14988
Pink M-PM Disc	Prepolymerized PMMA	Mer	Merz Dental GmbH	Pink	Z5355486
Polident CAD-CAM discs	Prepolymerized PMMA	Poli	Polident d.o.o	Pink	31215

Avad, AvaDent; Conv, Vynacron; Mer, Merz; PMMA, poly(methyl methacrylate); Poli, Polident.

Measurements of spectral radiance (W/sr/m^2) were recorded in increments of 2 nm from 380 to 780 nm and converted to reflectance determinations as follows[33]:

$$\text{Reflectance}_{\text{Specimen}} = \left(\text{Radiance}_{\text{Specimen}} / \text{Radiance}_{\text{Standard}}\right) \times \text{Reflectance}_{\text{Standard}},$$

where the radiance of the white reflectance standard (S3796A; Labsphere) was measured before and after radiance measurement. Each reflectance spectrum was then converted to Commission Internationale De L'éclairage (CIE) color parameters by using the CIE Standard Human Observer (2°) and D65 CIE illumination.[34]

After we made baseline measurements, the specimens were subjected to staining by thermocycling (Buchi 461 Water Bath; Fisher Scientific) in coffee solution (5°C/55°C, 30 seconds dwell time, 10 seconds transfer time) for 5000 cycles.[35,36] The coffee solution was prepared by filtering 1 tablespoon of coffee (Maxwell House; Kraft) in 177 mL of water[35] according to the manufacturer's instructions and changed every 12 hours. After CTC, the specimen surface was cleaned by brushing 10 times, using toothpaste (Crest; Procter and Gamble) under running tap water, and dried. Reflectance measurements and color calculations from each specimen were made again by using the same protocol as that for the baseline measurements.

The color difference values of the materials on the gray backing were determined by using the CIEDE2000 color difference formula.[34] The parametric factors of K_L, K_C, and K_H were set to 1.[33] In this study, CIEDE2000 values were evaluated in terms of perceptibility and acceptability. Ren et al[23] reported that the 50% perceptibility threshold was 1.72 CIEDE2000 units and that the 50% acceptability threshold was 4.08 CIEDE2000 units for denture base acrylic resin materials. These were considered perceptibility and acceptability thresholds in the current study.

The relative translucency parameter (RTP) for each specimen at each time was calculated from the color difference between the opaque black backing (where parameter L [lightness]=9.1; a [green-red]=–0.2; and b [blue-yellow]=0.3) and the white backing (L=93.7; a=–0.3; b=2.9) by using the CIEDE2000 formula.[34] These backings then provided a maximum RTP value of 84.1 and provided RTP values which were valid for the comparisons made here.

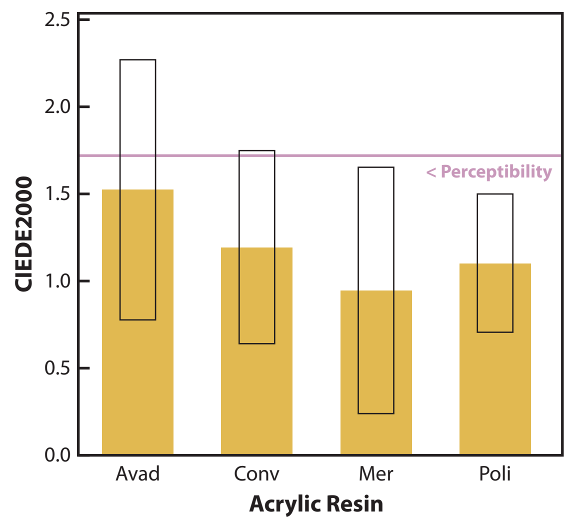

Figure 1. Mean and 95% confidence limits of color difference values caused by CTC. Green horizontal line represents perceptibility threshold.[23] Acrylic resin material codes are as shown in Table 1. Avad, AvaDent; Conv, Vynacron; Mer, Merz; Poli, Polident.

Means and 95% confidence limits were used to summarize the color difference values caused by thermocycling in coffee, the RTPs, and the roughness for each subgroup. Color difference values were analyzed by using an analysis of variance (ANOVA) with the restricted maximum likelihood estimation method (REML) with the main effect being the material. Relative translucency and roughness values were each evaluated by a repeated-measures ANOVA, with the interaction included and using the REML and Satterthwaite degrees of freedom methods. Any significant effect with degrees of freedom greater than 1 was resolved by using the Student t test with Bonferroni correction adjustment for pairwise comparisons of interest, that is those within the same material between conditions and within the same condition between materials (α=.05 for all tests).

RESULTS

Means and 95% confidence limits for color differences due to CTC for different acrylic materials are presented in Figure 1. The material tested was not found to affect these color difference values (dfnum=3, dfden=20, F-ratio=1.03, P=.401).

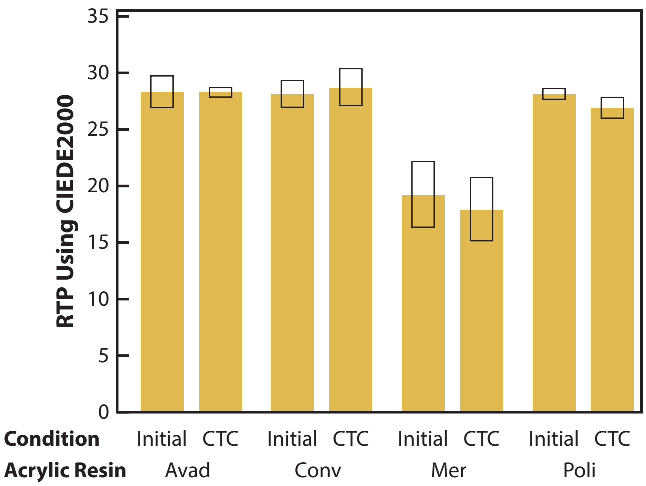

Figure 2. Mean and 95% confidence limits of RTP values of materials before and after CTC. Acrylic resin material codes are as shown in Table 1. Avad, AvaDent; Conv, Vynacron; CTC, coffee thermocycling; Mer, Merz; Poli, Polident; RTP, relative translucency parameter.

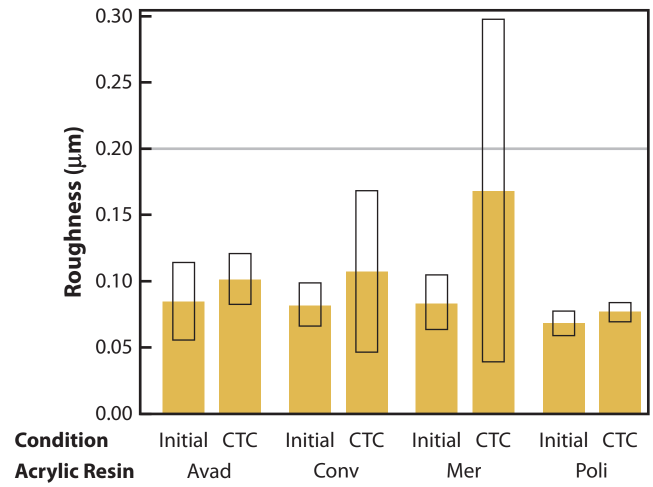

Figure 3. Mean surface roughness (R_a, μm) of materials before and after coffee thermocycling CTC. Gray horizontal line represents threshold level of surface roughness of 0.2 μm for clinically acceptable prosthesis.[29] Acrylic resin material codes are as shown in Table 1. Avad, AvaDent; Conv, Vynacron; CTC, coffee thermocycling; Mer, Merz; Poli, Polident.

Table 2. Summary of ANOVA of RTP data

Effect	*df*	F	*P*
Material	3	56.40	<.001
Coffee thermocycling	1	5.58	.028
Material×coffee thermocycling	3	4.85	.011

df, numerator degrees of freedom; denominator degrees of freedom, 20; RTP, relative translucency parameter.

Table 3. Summary of ANOVA of surface roughness data

Effect	*df*	F	*P*
Material	3	2.28	.111
Coffee thermocycling	1	5.42	.031
Material×coffee thermocycling	3	1.41	.268

df, numerator degrees of freedom; denominator degrees of freedom, 20.

Means and 95% confidence limits for RTP values are presented in Figure 2 for all subgroups. ANOVA for these data are provided in Table 2 and revealed significant interactions between the material and CTC. For each material, no significant differences were found ($P\geq.090$) between the 2 conditions. For each condition, the mean RTP of the Merz Dental GmbH prepolymerized PMMA material was significantly lower than that of each of the other materials ($P<.001$).

Means and 95% confidence limits for R_a values are presented in Figure 3 for all subgroups. ANOVA for these data are provided in Table 3 and show CTC significantly increased surface roughness of all tested materials. However, mean R_a values for all subgroups were below the plaque accumulation threshold of R_a=0.2 μm.

DISCUSSION

The first null hypothesis, that the material would not affect the color change due to CTC, was accepted as the material was not found to have an effect on this color change and the mean color difference for each material after CTC was below the perceptibility threshold.[23] The second null hypothesis that neither material nor CTC would affect the relative translucency was rejected because of the significant interaction between the material and CTC on the relative translucency of the materials studied. Furthermore, one material had a lower mean RTP than all other materials studied before and after CTC. The third null hypothesis that neither material nor CTC would affect the surface roughness was rejected because CTC had a significant effect on this property. The mean surface roughness values of these materials (range, 0.068 to 0.084 mm) increased after CTC (0.076 to 0.168 mm). However, the material tested was not found to have an effect on the surface roughness of the studied materials. Regardless, surface roughness means were lower than the 0.2-μm threshold.[29]

Coffee has been reported to significantly increase the staining of dental materials[19] and the discoloration of polymeric materials by coffee has been associated with surface sorption.[2,19] In the present study, coffee was used as a staining substance, and CTC was not found to affect the color change of the studied materials. Imirzalioglu et al[19] investigated the effect of different solutions on the color stability of different denture base acrylic resins (heat-polymerized, injection-molded, autopolymerized) and a soft denture liner material and in contrast with the present study, they reported that clinically perceptible color changes occurred in different denture base acrylic resins due to staining in tea, coffee, or nicotine solutions.

Although coffee is a hydrophobic beverage, fewer polar colorants from coffee could penetrate deeply into the materials.[19] The differences found in the present study may be due to the low water absorption properties of prepolymerized PMMA denture base materials, as reported by their manufacturers and the hydrophilic properties of denture base materials.

Zuo et al[2] also evaluated color stability and water absorption and solubility of 4 organic-inorganic hybrid coated heat-polymerized denture base resins by immersing them in tea, red wine, coffee, and cola for 1, 7, and 28 days. The authors reported that all specimens were stained or discolored to varying degrees and the discoloration was seen in a time-dependent manner and increased with prolonged immersion times (28 days). In contrast, water absorption into denture base resins tends to stabilize after approximately 28 days.[24] The imperceptible color change of denture base materials in the present study may be due to stabilization of water absorption into denture base resins.[24] No comparison with the translucency results of other studies was possible as no previous studies were found that evaluated the translucency of denture base materials.

Rough surfaces also have been significantly associated with the color change of specimens.[5] Prepolymerized PMMA blocks[9,14,16] have been reported to be highly condensed resins that have higher polishability and minimal porosity[16] compared with conventionally processed denture base materials because they have been processed under high pressure and heat conditions.[15] However, in the present study, the surface roughness and color change in heat-polymerized and different prepolymerized CAD-CAM PMMA specimens were not significantly different. This may be attributed to the 8 hours of heat polymerization of the heat-polymerized control group, which increases physical properties.[31]

According to previous studies,[4] polishing techniques significantly affect the surface roughness of denture base materials. Conventional laboratory polishing was the most effective polishing technique with lower surface roughness values[4,27] than chairside polishing kits. Therefore, in the present study, conventional laboratory polishing was applied. Consistent with these studies, surface roughness values of all tested materials were below clinically acceptable threshold. These similar results might be due to the similar polishing techniques applied.

Shinawi et al[12] evaluated the influence of tooth brushing (40 000 and 60 000 brushing strokes) on abrasion resistance and surface roughness of prepolymerized CAD-CAM acrylic resin material. Although not high, the initial surface roughness values of that study (0.3 ±0.07 μm)[24] were higher than those in the present study (≤0.084 μm). The difference may be due to various polishing techniques as conventional laboratory polishing was applied additionally to polishing with 600 grit silicon carbide abrasive papers in the present study.

In the present study, coffee was used as the staining solution. The specimens were thermocycled 5000 times to simulate short-term artificial aging that corresponds to 6 months of coffee consumption.[33]

Although there are no universally accepted thresholds of acceptability and perceptibility for the color stability of acrylic resins, different acceptability and perceptibility thresholds have been published.[23] Ren et al[23] reported that the CIEDE2000 color difference formula provided a better fit for evaluating the perceptible color difference threshold of denture base acrylic resin than CIELab.[23] Therefore, in the present study, the CIEDE2000 color difference formula was used.

Both surfaces of the specimens were exposed to coffee staining, whereas, only 1 surface would be exposed to discoloration solutions intraorally. Therefore, the color changes may be of a different level intraorally, and studies should evaluate the color change when only one surface is exposed to coffee. Regardless, the color changes that took place when even 2 surfaces were exposed were imperceptible.

Immersion in different liquids may cause different staining characteristics.[2] In addition, in clinical practice, the effectiveness of polishing is operator-dependent,[27] and different polishing techniques may yield different results. Based on the results of this study, further studies should be performed to address the effect of different polishing techniques and immersion in different staining solutions on the optical properties and surface roughness of denture base materials.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Material was not found to affect the color change due to coffee thermocycling (CTC) after 5000 cycles. All materials studied had imperceptible color changes after this CTC.
2. The Merz Dental GmbH prepolymerized PMMA material had the lowest relative translucency values before and after CTC.
3. The surface roughness of the specimens was higher after CTC regardless of the material.
4. All tested denture base materials had a surface roughness lower than the plaque accumulation threshold of Ra=0.2μm.

REFERENCES

1. Bilgin MS, Erdem A, Aglarci OS, Dilber E. Fabricating complete dentures with CAD/CAM and RP technologies. J Prosthodont 2015;1:1-4.

2. Zuo W, Feng D, Song A, Gong H, Zhu S. Effects of organic-inorganic hybrid coating on the color stability of denture base resins. J Prosthet Dent 2016;115:103-8.
3. Singh S, Palaskar JN, Mittal S. Comparative evaluation of surface porosities in conventional heat-polymerized acrylic resin cured by water bath and microwave energy with microwavable acrylic resin cured by microwave energy. Contemp Clin Dent 2013;4:147-51.
4. Gungor H, Gundogdu M, Duymus ZY. Investigation of the effect of different polishing techniques on the surface roughness of denture base and repair materials. J Prosthet Dent 2014;112:1271-7.
5. Sahin O, Koroglu A, Dede DÖ, Yilmaz B. Effect of surface sealant agents on the surface roughness and color stability of denture base materials. J Prosthet Dent 2016;116:610-6.
6. Murakami N, Wakabayashi N, Matsushima R, Kishida A, Igarashi Y. Effect of high-pressure polymerization on mechanical properties of PMMA denture base resin. J Mech Behav Biomed Mater 2013;20:98-104.
7. Goodacre BJ, Goodacre CJ, Baba NZ, Kattadiyil MT. Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques. J Prosthet Dent 2016;116:249-56.
8. Artopoulos A, Juszczyk AS, Rodriguez JM, Clark RK, Radford DR. Three-dimensional processing deformation of three denture base materials. J Prosthet Dent 2013;110:481-7.
9. Wimmer T, Gallus K, Eichberger M, Stawarczyk B. Complete denture fabrication supported by CAD/CAM. J Prosthet Dent 2016;115:541-6.
10. Kattadiyil MT, Jekki R, Goodacre CJ, Baba NZ. Comparison of treatment outcomes in digital and conventional complete removable dental prosthesis fabrications in a predoctoral setting. J Prosthet Dent 2015;114:818-25.
11. Fernandez MA, Nimmo A, Behar-Horenstein LS. Digital denture fabrication in pre- and postdoctoral education: a survey of U.S. Dental Schools. J Prosthodont 2016;25:83-90.
12. Shinawi LA. Effect of denture cleaning on abrasion resistance and surface topography of polymerized CAD CAM acrylic resin denture base. Electron Physician 2017;25:4281-8.
13. Inokoshi M, Kanazawa M, Minakuchi S. Evaluation of a complete denture trial method applying rapid prototyping. Dent Mater J 2012;31:40-6.
14. Bidra AS. The 2-Visit CAD-CAM Implant-retained overdenture: a clinical report. J Oral Implantol 2014;40:722-8.
15. Infante L, Yilmaz B, McGlumphy E, Finger I. Fabricating complete dentures with CAD/CAM technology. J Prosthet Dent 2014;111:351-5.
16. Bidra AS, Taylor TD, Agar JR. Computer-aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives. J Prosthet Dent 2013;109:361-6.
17. Steinmassl PA, Wiedemair V, Huck C, Klaunzer F, Steinmassl O, Grunert I, et al. Do CAD/CAM dentures really release less monomer than conventional dentures? Clin Oral Investig 2017;21:1697-705.
18. Bonatti MR, Cunha TR, Regis RR, Silva-Lovato CH, Paranhos HFO, de Souza RF. The effect of polymerization cycles on color stability of microwave-processed denture base resin. J Prosthodont 2009;18:432-7.
19. Imirzalioglu P, Karacaer O, Yilmaz B, Ozmen I. Color stability of denture acrylic resins and a soft lining material against tea, coffee, and nicotine. J Prosthodont 2010;19:118-24.
20. Bidra AS, Farrell K, Burnham D, Dhingra A, Taylor TD, Kuo CL. Prospective cohort pilot study of 2-visit CAD/CAM monolithic complete dentures and implant-retained overdentures: clinical and patient-centered outcomes. J Prosthet Dent 2016;115:578-86.
21. Shotwell JL, Razzoog ME, Koran A. Color stability of long-term soft denture liners. J Prosthet Dent 1992;68:836-8.
22. Sepulveda-Navarro WF, Arana-Correa BE, Borges CP, Jorge JH, Urban VM, Campanha NH. Color stability of resins and nylon as denture base material in beverages. J Prosthodont 2011;20:632-8.
23. Ren J, Lin H, Huang Q, Zheng G. Determining color difference thresholds in denture base acrylic resin. J Prosthet Dent 2015;114:702-8.
24. Lai YL, Lui HF, Lee SY. In vitro color stability, stain resistance, and water sorption of four removable gingival flange materials. J Prosthet Dent 2003;90:293-300.
25. Ayaz EA, Altintas SH, Turgut S. Effects of cigarette smoke and denture cleaners on the surface roughness and color stability of different denture teeth. J Prosthet Dent 2014;112:241-8.
26. Sagsoz NP, Yanıkoglu N, Ulu H, Bayındır F. Color changes of polyamide and poly(methyl methacrylate) denture base materials. Open J Stomatol 2014;4:489-96.
27. Kuhar M, Funduk N. Effects of polishing techniques on the surface roughness of acrylic denture base resins. J Prosthet Dent 2005;93:76-85.
28. Taylor R, Maryan C, Verran J. Retention of oral microorganisms on cobalt-chromium alloy and dental acrylic resin with different surface finishes. J Prosthet Dent 1998;80:592-7.
29. Bollen CML, Papaioannou W, Van Eldere J, Schepers E, Quirynen M, Van Steenberghe D. The influence of abutment surface roughness on plaque accumulation and peri-implant mucositis. Clin Oral Imp Res 1996;7:201-11.
30. Moon A, Powers JM, Kiat-Amnuay S. Color stability of denture teeth and acrylic base resin subjected daily to various consumer cleansers. J Esthet Restor Dent 2014;26:247-55.
31. Jadhav R, Bhide SV, Prabhudesai PS. Assessment of the impact strength of the denture base resin polymerized by various processing techniques. Indian J Dent Res 2013;24:19-25.
32. Azer SS, Hague AL, Johnston WM. Effect of pH on tooth discoloration from food colorant in vitro. J Dent 2010;38:106-9.
33. Kurklu D, Azer SS, Yilmaz B, Johnston WM. Porcelain thickness and cement shade effects on the colour and translucency of porcelain veneering materials. J Dent 2013;41:1043-50.
34. Commission Internationale de l'Eclairage. Colorimetry—technical report. CIE publication no. 15:2004. Vienna: Bureau Central de la CIE; 2004.
35. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent 1999;27:89-99.
36. Acar O, Yilmaz B, Altintas SH, Chandrasekaran I, Johnston WM. Color stainability of CAD/CAM and nanocomposite resin materials. J Prosthet Dent 2016;115:71-5.

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