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IZVORNI ZNANSTVENI RAD

Hazem Mofreh Altarawneh,[1] Mohammed Nasser Alhajj,[2] Nosizana Mohd Salleh,[2*] Aeman H. H. Elkezza,[2] Wan Adida Mahmood[3]

Effect of Denture Cleanser on the Physico-Mechanical Properties of Injection-Molded Thermoplastic Polyamides Denture Base Material: A preliminary Study

Učinak sredstva za čišćenje zubne proteze na fizikalno-mehanička svojstva termoplastičnoga poliamidnog materijala za bazu proteze za injekcijsko prešanje: preliminarno istraživanje

[1] Centre of Restorative Studies, Faculty of Dentistry, University Teknologi MARA, Sungai Buloh, Jalan Hospital, Sungai Buloh, Selangor, Malaysia.
Centar za restaurativna istraživanja Stomatološkog fakulteta Sveučilišta Teknologi MARA, Sungai Buloh, bolnica Jalan, Sungai Buloh, Selangor, Malezija
[2] Department of Restorative Dentistry, Faculty of Dentistry, Universiti Malaya, Kuala Lumpur, Federal Territory of Kuala Lumpur, Malaysia.
Zavod za restaurativnu stomatologiju Stomatološkog fakulteta Sveučilišta Malaya, Kuala Lumpur, Federalni teritorij Kuala Lumpur, Malezija
[3] Faculty of Dentistry, SEGI university, Jalan Teknologi, Kota Damansara, Petaling Jaya, Selangor, Malaysia.
Stomatološki fakultet Sveučilišta SEGI, Jalan Teknologi, Kota Damansara, Petaling Jaya, Selangor, Malezija

Abstract

Objectives: This study aimed to assess the color stability, surface roughness, and flexural properties of the injection-molded thermoplastic polyamide Vertex ThermoSens denture base resin following a 3-minute immersion in Polident 3-minute denture cleanser. **Methods:** Sixty specimens (Vertex ThermoSens) were processed and divided into two main groups (n = 30) based on the type of test. Group 1 was further subdivided into two subgroups (n = 15): the control group immersed in distilled water (G1DW) and the test group immersed in Polident cleanser solution (G1PD). Group 2 was divided into three subgroups: a non-immersed group (G2None), a group immersed in distilled water (G2DW), and a group immersed in Polident cleanser solution (G2PD). Color change (ΔE) and surface roughness measurements were conducted for group 1, and flexural modulus (*E*) test was performed for group 2. The CIE Lab* formula was utilized to calculate ΔE. An optical 3D surface analyzer and a three-point bending test were employed for surface roughness and *E* assessments, respectively. Data were subjected to statistical analysis using a paired-sample t-test for differences within each group before and after immersion. Furthermore, independent-sample t-tests and one-way ANOVA were conducted to analyze differences between groups. A significance level of $P < 0.05$ was considered. **Results:** The results revealed a slight, statistically insignificant ($P > 0.05$) ΔE in all color components (L*, a*, b*) after immersion in distilled water. However, after immersion in the denture cleanser, only the L* component exhibited a statistically significant ΔE ($P = 0.002$), which was slight in magnitude. Additionally, a significant difference was found in the ΔE between G1DW and G1PD, with G1PD showing a higher change ($P = 0.007$). A significant increase in surface roughness after immersion was observed in G1PD ($P = 0.017$), with a notable difference between G1DW and G **Conclusion:** Denture cleansers have the potential to modify the properties of thermoplastic polyamide resin. Further research is needed to explore the clinical implications of these observed changes on denture performance. 1PD. However, the *E* remained unaffected ($P = 0.537$).

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Address for correspondence
Nosizana Mohd Salleh
Universiti Malaya
Faculty of Dentistry
Department of Restorative Dentistry
50603 Kuala Lumpur
Federal Territory of Kuala Lumpur
Malaysia
nosizana@um.edu.my
Phone: +603 7967 4881

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Hazem Mofreh Altarawneh https://orcid.org/0009-0000-1280-1428
Mohammed Nasser Alhajj https://orcid.org/0000-0003-4477-3024
Nosizana Mohd Salleh https://orcid.org/0000-0001-5254-282X
Aeman H. H. Elkezza https://orcid.org/0000-0002-5507-0503
Wan Adida Mahmood https://orcid.org/0000-0003-0463-3211

Introduction

Dentures fabricated from polyamide thermoplastic materials are recommended for patients who experience frequent denture fractures, and numerous studies have document-

Uvod

Proteze izrađene od poliamidnih termoplastičnih materijala preporučuju se pacijentima kojima proteze često pucaju, a u mnogobrojnim je istraživanjima dokumentirana njiho-

ed their applicability for complete and partial denture cases (1, 2). The material's flexibility helped patients who clench, and removable denture wearers with bony undercuts to chew comfortably (1, 3). In addition to their flexibility, polyamide resins offer several other important features, including biocompatibility and allergen-free properties due to the absence of residual monomers. These resins also have a low density, resulting in lightweight prostheses. Furthermore, their high light transparency enhances the reflectivity of the gingival tissue color beneath the denture, providing excellent esthetic qualities that meet the demands of patients with high esthetic expectations (4, 5).

Despite denture wearers mechanically clean their dentures with tap water, a substantial 60% of them still experience poor denture hygiene (6). This plaque accumulation leads to denture stomatitis (7). Elderly denture wearers, particularly those with poor eyesight and decreased dexterity, often find it challenging to completely remove plaque by using just a toothbrush. In such cases, chemical denture cleaning with denture cleansers proves to be an effective method to maintain removable denture hygiene following mechanical cleaning. *In-vitro* studies demonstrated the efficacy of denture cleansers in removing *Candida albicans* from the denture base (8-10). However, concerns regarding the effect of chemical denture cleaning agents on denture base materials still remain. While certain studies (11, 12), reported color stability after immersion for the recommended duration, others documented some alterations in color and surface roughness. Specifically, polyamide materials showed a reduction in gloss and an increase in surface roughness following immersion in denture cleansers (12-18). Immersing polyamide dentures in chemical cleansers can lead to a decrease in the flexural modulus (*E*) of the material (18-20).

There is limited information regarding the effect of Polident 3-minute denture cleanser on the properties of polyamide Vertex ThermoSens denture base resin. Therefore, this study aimed to assess the effect of immersing polyamide Vertex ThermoSens denture base resin in Polident 3-minute denture cleanser on ΔE, surface roughness changes, and *E* changes. The null hypothesis was that the color stability, surface roughness, and *E* of the polyamide Vertex ThermoSens denture base resin remain unaffected following the immersion in Polident 3-minute denture cleanser.

Material and methods

This *in-vitro* experimental study used polyamide thermoplastic resin Vertex ThermoSens (Vertex ThermoSens, Vertex-Dental B.V, Netherlands). Sixty specimens were processed and divided into two main groups. Group 1 (n = 30) was further divided into two subgroups: the control group (G1DW; n = 15), immersed in distilled water, and the test group (G1PD; n = 15), immersed in the cleanser solution (Polident 3-minute denture cleanser, GSK, Brentford, UK). Group 1 was used for color analysis and surface roughness analysis before and after immersion. Group 2 was used for the flexibility test (n = 30) and divided into three subgroups: G2None (n = 10) for the flexibility test at baseline without

va primjenjivost za slučajeve potpune i djelomične bezubosti (1, 2). Fleksibilnost materijala pomogla je pacijentima koji stišću zube i onima koji nose mobilne proteze s nepravilnostima grebena da žvaču bez smetnji (1, 3). Osim fleksibilnosti, poliamidne smole imaju nekoliko drugih važnih značajki, uključujući biokompatibilnost i hipoalergena svojstva zbog odsutnosti zaostalih monomera. Te su smole također male gustoće, što rezultira laganim protezama. Nadalje, njihova visoka transparentnost pojačava refleksiju boje sluznice ispod proteze i osigurava estetska svojstva koja zadovoljavaju i visoke zahtjeve pacijenata (4, 5).

Unatoč tomu što nositelji proteza mehanički čiste svoje proteze vodom iz slavine, čak 60 % njih i dalje ima lošu higijenu proteza (6). Nakupljanje plaka završava protetičkim stomatitisom (7). Starijim osobama koje nose proteze, osobito onima sa slabijim vidom i smanjenom manualnom spretnošću, često je teško potpuno ukloniti plak samo četkicom za zube. U takvim se slučajevima kemijsko čišćenje proteza sredstvima za čišćenje pokazalo kao učinkovita metoda za održavanje higijene mobilne proteze nakon mehaničkog čišćenja. Istraživanja *in vitro* pokazala su učinkovitost sredstava za čišćenje proteza u uklanjanju *Candide albicans* s baze proteze (8 – 10). Međutim, i dalje postoji zabrinutost zbog učinka kemijskih sredstava za čišćenje proteza na materijal za bazu proteze. Dok su autori nekih istraživanja (11, 12) izvijestili o stabilnosti boje poslije uranjanja tijekom preporučenog trajanja, drugi su dokumentirali neke promjene boje i hrapavosti površine. Točnije, poliamidni materijali pokazali su smanjenje sjaja i povećanje hrapavosti površine poslije uranjanja u sredstva za čišćenje proteze (12 – 18). Uranjanje poliamidnih proteza u kemijska sredstva za čišćenje može smanjiti modul elastičnosti (E) materijala (18 – 20).

Postoje ograničeni podatci o učinku trominutnog sredstva za čišćenje proteza Polident na svojstva poliamidne baze proteze Vertex ThermoSens. Stoga je cilj ovog istraživanja bio procijeniti učinak uranjanja poliamidne smole za bazu proteze Vertex ThermoSens u trominutno sredstvo za čišćenje proteza Polident na ΔE na promjene hrapavosti površine i promjene E. Nulta hipoteza bila je da postojanost boje, hrapavost površine i E poliamidne smole za bazu proteze Vertex ThermoSens ostaju nepromijenjene poslije uranjanja u trominutno sredstvo za čišćenje proteze Polident.

Materijali i metode

U ovoj eksperimentalnoj studiji *in vitro* korištena je poliamidna termoplastična smola Vertex ThermoSens (Vertex ThermoSens, Vertex-Dental B.V, Nizozemska). Obrađeno je 60 primjeraka koji su podijeljeni u dvije glavne skupine. Skupina 1 (n = 30) dalje je podijeljena u dvije podskupine: kontrolnu skupinu (G1DW; n = 15) uronjenu u destiliranu vodu i testnu skupinu (G1PD; n = 15) uronjenu u otopinu za čišćenje Polident, trominutni čistač za proteze (GSK, Brentford, UK). Skupina 1 podvrgnuta je analizi boje i hrapavosti površine prije i poslije uranjanja. Skupina 2 podvrgnuta je testu fleksibilnosti (n = 30) i podijeljena u tri podskupine: G2None (n = 10) za test fleksibilnosti na početku bez uranja-

immersion in any solution, G2DW (n = 10) for the flexibility test after immersion in distilled water, and G2PD (n = 10) for the flexibility test after immersion in Polident 3-minute denture cleanser.

The specimens were prepared in accordance with the International Organization for Standardization (ISO) specification 20795-1:2013 [21] by using a rectangular-shaped wax pattern with the dimensions of 64 mm × 10 mm × 3.3 mm as a template. The pattern was placed into a metallic flask to produce gypsum molds. The processing was conducted using the Vertex ThermoJect 22 injection machine (Vertex-Dental B.V, Netherlands). In accordance with the manufacturer's instructions, the cylinder of the machine was primarily preheated to 290 °C for 8 minutes. Then, the polyamide material cartridge was inserted into the cylinder with the flask in position inside the machine. The machine started the injection procedure under the pressure of 6 bars at 290 °C for 18 minutes. The flask was then removed from the machine and left for bench cooling for 20 minutes.

Edges were smoothed with a cross-standard acrylic bur and polished with silicone polishers (Vertex Thermo Silicon Polisher, Vertex-Dental B.V, Netherlands). The finishing procedure was conducted using Thermo-Gloss paste (Vertex-Dental B.V, Netherlands) and a microfiber polishing brush (Vertex Gloss brushes, Vertex-Dental B.V, Netherlands). The accuracy of the dimensions was verified with a digital Vernier caliper (Mitutoyo Digital Caliper, Mitutoyo Co., Japan) with a precision of 0.05 mm.

After the baseline measurement of color analysis and surface roughness was applied, G1PD and G2PD were immersed manually in the commercially available neutral peroxide enzymatic denture cleanser Polident 3-minute. In accordance with the manufacturer's recommendations, G1PD and G2PD were immersed for 3 minutes in 200 ml-warm (40 °C) tap water with one tablet of denture cleanser and then washed thoroughly in running water. An immersion in distilled water was performed for G1DW and G2DW at room temperature (23 °C ± 2 °C). These procedures were repeated 180 times, simulating 180 days of patient cleansing (22).

Color analysis

The digital spectrophotometer CM-5 (Konica Minolta, Tokyo, Japan) was used to measure the color change (ΔE). Before the test, calibration was conducted in accordance with the manufacturer's instructions using the provided white calibration plate. The aperture size was 3 mm. Measurements were performed three times from three places with a 16 mm gap on the same side. ΔE was calculated by measuring the values at several wavelengths in the visual spectrum with the use of the Commission Internationale de l'Eclairage (CIE, L*, a*, and b*) uniform color scale (23). The CIE L*a*b* is a color system representing three-dimensional (3D) color space with components of lightness (L), red-green (a), and yellow-blue (b). The following equation was used to calculate ΔE after immersion in distilled water or cleanser solution:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2},$$

where ΔL, Δa, and Δb are the differences between the L, a,

nja u bilo koju otopinu, G2DW (n = 10) za test fleksibilnosti poslije uranjanja u destiliranu vodu i G2PD (n = 10) za test fleksibilnosti poslije uranjanja u trominutno sredstvo za čišćenje proteza Polident.

Uzorci su pripremljeni u skladu sa specifikacijom Međunarodne organizacije za standardizaciju (ISO) 20795-1:2013 [21] korištenjem voštanog uzorka pravokutnog oblika dimenzija 64 mm × 10 mm × 3,3 mm kao predloška. Uzorak je stavljen u metalnu kivetu za izradu kalupa od sadre. Obrada je provedena s pomoću Vertex ThermoJect 22 injekcijskog stroja (Vertex-Dental B.V, Nizozemska). U skladu s uputama proizvođača, cilindar stroja je prethodno zagrijan na 290 °C tijekom 8 minuta. Zatim je uložak od poliamidnog materijala umetnut u cilindar kivetom u definiranom položaju unutar stroja. Stroj je počeo postupak ubrizgavanja pod tlakom od 6 bara na 290 °C tijekom 18 minuta. Kiveta je zatim uklonjena iz stroja i ostavljena na stolu da se hladi 20 minuta.

Rubovi su zaglađeni standardnim križnim frezama za akrilat i polirani silikonskim polimerima (Vertex Thermo Silicon Polisher, Vertex-Dental B.V, Nizozemska). Završni postupak proveden je pastom Thermo-Gloss (Vertex-Dental B.V, Nizozemska) i četkom za poliranje od mikrovlakana (Vertex Gloss brushes, Vertex-Dental B.V, Nizozemska). Točnost dimenzija provjerena je digitalnom pomičnom mjerkom Vernier (Mitutoyo Digital Caliper, Mitutoyo Co., Japan) s preciznošću od 0,05 mm.

Nakon osnovnog mjerenja boje i hrapavosti površine, G1PD i G2PD ručno su uronjeni u komercijalno dostupno neutralno peroksidno enzimsko sredstvo za čišćenje proteza Polident tijekom 3 minute. U skladu s preporukama proizvođača, G1PD i G2PD uronjeni su 3 minute u 200 mL tople (40 °C) vode iz slavine s jednom tabletom sredstva za čišćenje proteza, a zatim su temeljito isprani tekućom vodom. Za G1DW i G2DW obavljeno je uranjanje u destiliranu vodu na sobnoj temperaturi (23 °C ± 2 °C). Ti su postupci ponovljeni 180 puta, simulirajući 180 dana čišćenja koje bi provodio pacijent (22).

Analiza boje

Za mjerenje promjene boje (ΔE) korišten je digitalni spektrofotometar CM-5 (Konica Minolta, Tokyo, Japan). Prije testa kalibracija je provedena u skladu s uputama proizvođača s pomoću priložene bijele kalibracijske ploče. Veličina otvora bila je 3 mm. Mjerenja su obavljena tri puta na trima mjestima s razmakom od 16 mm na istoj strani. ΔE je izračunat mjerenjem vrijednosti na nekoliko valnih duljina u vizualnom spektru uz korištenje jedinstvene ljestvice boja Commission Internationale de l'Eclairage (CIE, L*, a* i b*) (23). CIE L*a*b* sustav je boja koji predstavlja trodimenzionalni (3D) prostor boja s komponentama svjetline (L), crveno-zelene (a) i žuto-plave (b). Sljedeća jednadžba korištena je za izračunavanje ΔE poslije uranjanja u destiliranu vodu ili u otopinu sredstva za čišćenje:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2},$$

gdje su ΔL, Δ a i Δb razlike između vrijednosti L, a i b prije i

Table 1 National Bureau of Standards units for color change
Tablica 1 Jedinice Nacionalnog ureda za standarde za promjenu boje

NBS unit • NBS jedinica	Critical observation of color change • Kritičko promatranje promjene boje
< 0.5	Trace • U tragovima
0.5–1.5	Slight • Lagana
1.5–3.0	Noticeable, perceivable • Primjetna, uočljiva
3.0–6.0	Appreciable, marked change • Primjetna, izrazita promjena
6.0–12.0	Much, extreme • Ekstremna
≥ 12.0	Change to another color • Promjena u drugu boju

and b values before and after immersion, respectively. The color data were quantified by the National Bureau of Standards units (Table 1) by using the formula NBS units = ΔE × 0.92 to transmit the color differences (ΔE) to clinically understandable values (24-26).

Surface roughness analysis

The Ra (μm) was used to assess the surface roughness changes (27). The Ra values before immersion of the specimens in distilled water or cleanser solution were measured and compared with the surface roughness values after immersion. An optical 3D surface analyzer (Infinite Focus Standard; Alicona Imaging, Graz, Austria) was used to obtain the surface roughness measurements at 20× magnification, with 376 nm vertical resolution, and 2.93 nm lateral resolution. The mean Ra value was computed (IFM software 5.1, Alicona Imaging) from five different spots (712.14 μm × 540.25 μm) on each specimen on the same side and five lines on each spot (total = 25 measurements). The line width was one point, which equals 438.51 nm.

E test

A three-point bending test was used to determine the flexural elastic modulus of the specimens. The distance between the two supporting heads was 50 mm, and a vertical load was applied at the mid-point of the specimen at a crosshead speed of 5 mm/min by using a universal testing machine (AG-X model, Shimadzu, Kyoto, Japan), (1, 28). The *E* was determined after calibrating the machine, and the values were automatically computed using the following equation:

$$E = \frac{FL^3}{4bh^3d},$$

where *F* is the load (in Newtons); *L* is the distance (in mm) between the supports; *b* is the width (in mm) of the specimen; *h* is the height (in mm) of the specimen; and *d* is the deflection (in mm) at load *F*.

Statistical analysis

Statistical analyses were performed using statistical software (SPSS version 25.0 for Windows, SPSS Inc., Chicago, IL, USA). The collected data were verified for the normality of the distribution. Accordingly, a paired-sample t-test was used to compare the color parameters (L*, a*, and b*) and surface roughness before and after immersion. The Independent-sample t-test was used to compare the mean values of different groups after immersion. The *E* values were compared using one-way ANOVA. The level of statistical significance was set at $P < 0.05$.

poslije uranjanja. Podatke o boji kvantificirale su jedinice Nacionalnog ureda za standarde (tablica 1.) korištenjem formule NBS jedinice = ΔE × 0,92 za prijenos razlika u boji (ΔE) do klinički razumljivih vrijednosti (24 – 26).

Analiza hrapavosti površine

Ra (μm) korišten je za procjenu promjena hrapavosti površine (27). Vrijednosti Ra prije uranjanja uzoraka u destiliranu vodu ili otopinu za čišćenje izmjerene su i uspoređene s vrijednostima hrapavosti površine poslije uranjanja. Optički 3D površinski analizator (Infinite Focus Standard; Alicona Imaging, Graz, Austrija) korišten je za mjerenja hrapavosti površine pri povećanju od 20 puta, s okomitom razlučivošću od 376 nm i bočnom razlučivošću od 2,93 nm. Srednja vrijednost Ra izračunata je (softver IFM 5.1, Alicona Imaging) za pet različitih točaka (712,14 μm × 540,25 μm) na svakom uzorku na istoj strani i pet linija na svakoj točki (ukupno = 25 mjerenja). Širina linije bila je jedna točka, što je jednako 438,51 nm.

E test

Ispitivanje savijanjem u trima točkama korišteno je za određivanje modula elastičnosti pri savijanju uzoraka. Razmak između dviju potpornih glava bio je 50 mm, a okomito opterećenje primijenjeno je na središnju točku uzorka brzinom križne glave od 5 mm/min s pomoću univerzalnog ispitnog stroja (model AG-X, Shimadzu, Kyoto, Japan), (1, 28). E je određen nakon kalibracije stroja, a vrijednosti su automatski izračunate s pomoću sljedeće jednadžbe:

$$E = \frac{FL^3}{4bh^3d},$$

gdje je F opterećenje (u Newtonima); L je udaljenost (u mm) između nosača; b je širina (u mm) uzorka; h je visina (u mm) uzorka; a d je progib (u mm) pri opterećenju F.

Statistička analiza

Statističke analize obavljene su korištenjem statističkog softvera (SPSS verzija 25.0 za Windows, SPSS Inc., Chicago, IL, SAD). Prikupljeni podatci verificirani su s obzirom na normalnost distribucije. U skladu s tim, t-test uparenog uzorka korišten je za usporedbu parametara boje (L*, a* i b*) i hrapavosti površine prije i poslije uranjanja. T-test neovisnog uzorka korišten je za usporedbu srednjih vrijednosti različitih skupina poslije uranjanja. E vrijednosti uspoređene su korištenjem jednosmjerne ANOVA-e. Razina statističke značajnosti postavljena je na $P < 0,05$.

Results

Table 2 shows the measurements of the color components (L*, a*, and b*) and the ΔE and NBS values for the control and test groups before and after immersion. The paired-sample t-test showed a significant increase (P = 0.002) in the L* values following immersion in cleanser solution. However, no significant differences were found for other components. The ΔE value of the test group was significantly (P = 0.007) higher than that of the control group (0.88 ± 0.73 compared with 0.27 ± 0.22).

The results of a paired-sample t-test showed a significant difference (P = 0.017) in the surface roughness of the test group following immersion in the denture cleanser. However, no statistically significant difference (P = 0.546) was found in the surface roughness of the control group before and after immersion in distilled water. A comparison between test and control groups (after immersion) showed a significantly (P = 0.048) higher value of the test group than of the control group (0.24 ± 0.05 and 0.21 ± 0.03, respectively). Further details are presented in Table 3.

Rezultati

Tablica 2. prikazuje mjerenja komponenti boje (L*, a* i b*) te vrijednosti ΔE i NBS za kontrolnu i ispitnu skupinu prije i poslije uranjanja. T-test uparenih uzoraka pokazao je značajno povećanje (P = 0,002) vrijednosti L* poslije uranjanja u otopinu sredstva za čišćenje. No nisu pronađene značajne razlike za ostale komponente. Vrijednost ΔE ispitivane skupine bila je značajno (P = 0,007) viša od vrijednosti kontrolne skupine (0,88 ± 0,73 u usporedbi s 0,27 ± 0,22).

Rezultati t-testa uparenih uzoraka pokazali su značajnu razliku (P = 0,017) u površinskoj hrapavosti testne skupine poslije uranjanja u sredstvo za čišćenje proteze. No nije pronađena statistički značajna razlika (P = 0,546) u hrapavosti površine kontrolne skupine prije i poslije uranjanja u destiliranu vodu. Usporedba testne i kontrolne skupine (poslije uranjanja) pokazala je značajno (P = 0,048) veću vrijednost testne skupine nego kontrolne skupine (0,24 ± 0,05 odnosno 0,21 ± 0,03). Daljnji detalji nalaze se u tablici 3.

Iako jednosmjerna ANOVA nije pokazala statistički značajnu razliku (P > 0,05) između triju skupina za vrijednosti

Table 2 Color measurements before and after immersion in distilled water and cleanser solution
Tablica 2. Mjerenja boja prije i poslije uranjanja u destiliranu vodu i otopinu za čišćenje

		Mean±SD • Srednja vrijednost ± SD	Mean Difference • Srednja razlika	95% CI of the Difference • 95 % IP razlike		P
				Lower • Donja vrijednost	Upper • Gornja vrijednost	
Distilled water • Destilirana voda	L* before immersion • L* prije uranjanja	38.01 ± 5.98	−0.06	−0.19	0.08	0.390[α]
	L* after immersion • L* poslije uranjanja	38.07 ± 6.00				
	a* before immersion • a* prije uranjanja	5.54 ± 3.23	0.01	−0.07	0.10	0.729[α]
	a* after immersion • a* poslije uranjanja	5.53 ± 3.20				
	b* before immersion • b* prije uranjanja	−2.68 ± 1.97	0.04	−0.06	0.15	0.409[α]
	b* after immersion • b* poslije uranjanja	−2.72 ± 2.00				
Cleanser solution • Otopina za čišćenje	L* before immersion • L* prije uranjanja	37.54 ± 5.51	−0.75	−1.17	−0.32	0.002[α]
	L* after immersion • L* poslije uranjanja	38.29 ± 5.41				
	a* before immersion • a* prije uranjanja	5.76 ± 3.13	0.08	−0.09	0.25	0.355[α]
	a* after immersion • a* poslije uranjanja	5.68 ± 3.09				
	b* before immersion • b* prije uranjanja	−3.19 ± 2.09	−0.06	−0.22	0.09	0.387[α]
	b* after immersion • b* poslije uranjanja	−3.13 ± 2.07				
Change in color (ΔE)	Distilled water • Destilirana voda	0.27 ± 0.22	−0.61	−1.02	−0.19	0.007[β]
	Cleanser solution • Otopina za čišćenje	0.88 ± 0.73				

[α] Paired t-test was used • Upareni t-test; [β] Independent t-test was used • t-test za neovisne uzorke

Table 3 Surface roughness (Ra) before and after immersion in distilled water and cleanser solution
Tablica 3. Hrapavost površine (Ra) prije i poslije uranjanja u destiliranu vodu i otopinu za čišćenje

		Mean±SD • Srednja vrijednost ± SD	Mean Difference • Srednja razlika	95% CI of the Difference • 95 % IP razlike		P
				Lower • Donja vrijednost	Upper • Gornja vrijednost	
Distilled water (N = 15) • Destilirana voda (N = 15)	Before immersion	0.21 ± 0.03	0.00	−0.01	0.00	0.546[α]
	After immersion	0.21 ± 0.03				
Cleanser solution (N = 15) • Otopina za čišćenje (N = 15)	Before immersion	0.21 ± 0.03	−0.03	−0.06	−0.01	**0.017**[α]
	After immersion	0.24 ± 0.05				
Distilled water - Cleanser solution (after immersion) • Destilirana voda – otopina za čišćenje (poslije uranjanja)			−0.03	−0.07	0.00	**0.048**[β]

[α] Paired t-test was used; [β] Independent t-test was used • [α] Upareni t-test; [β] t-test za neovisne uzorke

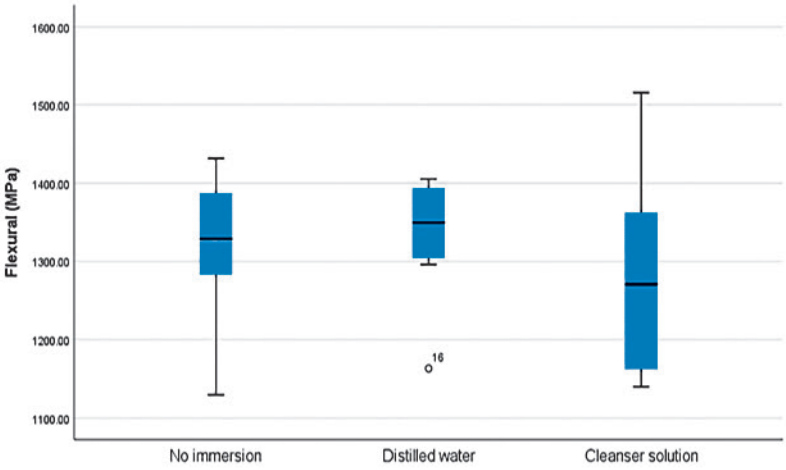

Figure 1 Flexural modulus of different groups of polyamide resin according to immersion status
Slika 1. Modul savijanja različitih skupina poliamidne smole prema statusu uranjanja

Although the one-way ANOVA showed no statistically significant difference (P > 0.05) among the three groups for the flexural elastic modulus values (Figure 1), the test group immersed in cleanser solution showed the lowest value (1289.48 ± 125.05 MPa). By contrast, the control group immersed in distilled water had the highest value (1337.89 ± 73.67 MPa).

Discussion

The immersion of Vertex ThermoSens denture material in Polident 3-minute denture cleanser did not produce a significant effect on *E*. However, notable changes in color and surface roughness were observed, leading to the partial rejection of the null hypothesis. This study involved immersing the material in the denture cleanser solution 180 times, simulating the typical 6-month cleansing regimen adopted by patients (29, 30). A spectrophotometer was used in the present study because its readings are objective, quantifiable, and rapidly compared with visual color assessment [31]. The CIE L*a*b* system is employed to translate combinations of color differences into mathematical data, thus allowing for the determination of chromatic differences and an approximation of the uniform color space with coordinates for lightness (23). These calculations are designed to align with human visual perception.

Prior studies indicated that ΔE in denture base materials can result from alterations in the matrix of material. Additionally, external colorants, solubility, water sorption, leakage, surface roughness, and chemical degradation may contribute to the staining effect (18, 32-35). The polyamide samples in the present study exhibited color change; however, the changes were less than 1.5 NBS units, and were considered slight (NBS value classification 0.5–1.5). The ΔEs were attributed to the increase in L* parameter, which may be related to the effect of peroxide within the cleanser. A previous study (28) reported a significant change in polyamide color after soaking in different denture cleansers. However, the polyamide used in the present study is different (Valplast), and the denture cleanser is a neutral cleanser that minimal-

modula elastičnosti pri savijanju (slika 1.), ispitna skupina uronjena u otopinu za čišćenje pokazala je najnižu vrijednost (1289,48 ± 125,05 MPa). Nasuprot tomu, kontrolna skupina uronjena u destiliranu vodu imala je najvišu vrijednost (1337,89 ± 73,67 MPa).

Rasprava

Uranjanje Vertex ThermoSens materijala za protezu u trominutno sredstvo za čišćenje proteze Polident nije imalo značajan učinak na E. Međutim, uočene su značajne promjene u boji i hrapavosti površine, pa je nulta hipoteza djelomično odbačena. Ovo je istraživanje uključivalo uranjanje materijala u otopinu sredstva za čišćenje proteze 180 puta, simulirajući tipičan šestomjesečni režim čišćenja koji su usvojili pacijenti (29, 30). U ovom istraživanju korišten je spektrofotometar jer su njegova očitanja objektivna, mjerljiva i brzo se uspoređuju s vizualnom procjenom boje [31]. Sustav CIE L*a*b* koristi se za prevođenje kombinacija razlika u boji u matematičke podatke, čime se omogućuje određivanje kromatskih razlika i aproksimacija ujednačenog prostora boja s koordinatama za svjetlinu (23). Ti su izračuni osmišljeni kako bi se uskladili s ljudskom vizualnom percepcijom.

Dosadašnja istraživanja pokazala su da ΔE u materijalima za bazu proteza može biti rezultat promjena u matrici materijala. Dodatno, vanjska bojila, topljivost, apsorpcija vode, curenje, hrapavost površine i kemijska degradacija mogu pridonijeti učinku obojenja (18, 32 – 35). Uzorci poliamida u ovom istraživanju pokazali su promjenu boje; međutim, promjene su bile manje od 1,5 NBS jedinica i smatrane su neznatnima (NBS klasifikacija vrijednosti 0,5 – 1,5). Vrijednosti ΔE-a pripisane su povećanju parametra L*, što može biti povezano s učinkom peroksida unutar sredstva za čišćenje. U dosadašnjim istraživanju (28) izviješteno je o značajnoj promjeni boje poliamida poslije namakanja u različitim sredstvima za čišćenje proteza. No poliamid korišten u ovom istraživanju je drukčiji (Valplast), a sredstvo za čišćenje proteza neutralno je sredstvo za čišćenje koje minimalno utječe na

ly affects color stability. Meanwhile, the ΔEs in the present study are similar to those in previous reports (13, 16).

Rough surfaces were found to encourage plaque and microorganism adherence if the Ra exceeded 0.2 μm (36, 37). The 3D optical interferometric profilometer used to analyze surfaces revealed a significant roughness change following the immersion in cleanser solution, and the obtained results are similar to those of previous reports (16, 38). Relatively small rectangular samples are difficult to finish and polish and the low melting point of polyamide may be a paramount factor to this increase in roughness (32). Comparable results were obtained after evaluating the effects of three sodium perborate-containing denture cleansers (Corega, Protefix, and Valclean) on the surface roughness of the two polyamides (Valplast and Deflex), where the surface roughness of the polyamide increased after 20 days of repeated immersion regardless of the type of the solution used (13). Polyamide-based resins have a higher fibrous structure, lower modulus of elasticity, lower surface hardness, and higher roughness than the conventional PMMA dentures (1, 13, 31). According to the ISO specifications (21), the *E* of the processed thermoplastic polymer should be at least 2000 MPa. However, following immersion, it decreased to 1289 MPa. The lower *E* exhibited by the thermoplastic material could be due to the chemical effect of the cleanser, the perborate content, and the effervescent effect of the denture cleanser used. The oxygen in its structure is decomposed to free oxygen radicals, and thus, water molecules are removed. Oxygen may cause a chemical softening of the resin surface by damaging the interchain forces in the polymer (13). Similar results were obtained when the *E* of a thermoplastic denture base material (Lucitone FRS) decreased after immersion in two denture-cleansing tablets (19). Meanwhile, the specimens immersed in distilled water showed the highest *E*, may be due to the absorption of water. The specimens were impregnated with water, which may increase the flexibility of the specimens compared with non-immersed specimens. Although a decrease in the values was observed, none of the specimens broke during the test. Shah et al.(20) had a similar experience, where none of the polyamide (Valplast) specimens broke when subjected to three-point bending test. Polyamide is promoted as a denture base material based on its flexibility, thus allowing a certain degree of undercuts for retention.

This study has several limitations that must be acknowledged. First, only one denture base material and one denture cleanser were utilized, thereby limiting the generalizability of the findings. Additionally, the study cannot fully replicate the clinical behavior of dentures because it did not account for several factors such as mastication, saliva, and food interaction, during actual use. Furthermore, the specimens used in this study were smaller than the base of a typical denture, thus presenting challenges in handling. This situation could have influenced the results of baseline surface roughness test. Moreover, direct comparisons with previous research were hindered by the presence of numerous variables and the use of different materials. Further *in-vitro* studies on this material are recommended to address these limitations. These studies should consider incorporating conditions of the oral envi-

stabilnost boje. Vrijednosti ΔE-a u ovom istraživanju slične su onima u prethodnim izvješćima (13, 16).

Utvrđeno je da hrapave površine potiču prianjanje plaka i mikroorganizama ako Ra prelazi 0,2 μm (36, 37). 3D optički interferometrijski profilometar korišten za analizu površina otkrio je značajnu promjenu hrapavosti poslije uranjanja u otopinu za čišćenje, a dobiveni rezultati slični su onima iz prethodnih izvješća (16, 38). Razmjerno male pravokutne uzorke teško je doraditi i polirati, a nisko talište poliamida može biti glavni čimbenik za to povećanje hrapavosti (32). Usporedni rezultati dobiveni su nakon procjene učinaka triju sredstava za čišćenje proteza koja sadržavaju natrijev perborat (Corega, Protefix i Valclean) na hrapavost površine dvaju poliamida (Valplast i Deflex), pri čemu se hrapavost površine poliamida povećala poslije 20 dana korištenja bez obzira na vrstu korištene otopine (13). Smole na bazi poliamida imaju vlaknastiju strukturu, niži modul elastičnosti, nižu površinsku tvrdoću i veću hrapavost od konvencionalnih PMMA proteza (1, 13, 31). Prema ISO specifikacijama (21), E prerađenoga termoplastičnog polimera treba biti najmanje 2000 MPa. Međutim, poslije uranjanja smanjio se na 1289 MPa. Niži E koji je pokazao termoplastični materijal mogao bi biti posljedica kemijskog učinka sredstva za čišćenje, sadržaja perborata i pjenušavog učinka korištenog sredstva za čišćenje proteza. Kisik u njegovoj strukturi razgrađuje se na slobodne radikale kisika, čime se uklanjaju molekule vode. Kisik može prouzročiti kemijsko omekšavanje površine smole oštećujući međulančane sile u polimeru (13). Slični rezultati dobiveni su kada se E termoplastične baze proteze (Lucitone FRS) smanjio poslije uranjanja u otopinu od dviju tableta za čišćenje proteze (19). U međuvremenu su uzorci uronjeni u destiliranu vodu pokazali najviši E, što može biti posljedica apsorpcije vode. Uzorci su impregnirani vodom, što može povećati njihovu fleksibilnost u usporedbi s uzorcima koji nisu uronjeni. Iako je primijećen pad vrijednosti, nijedan uzorak nije se slomio tijekom ispitivanja. Shah i suradnici (20) imali su slično iskustvo i nijedan se poliamidni uzorak (Valplast) nije slomio kada je bio podvrgnut testu savijanja u trima točkama. Poliamid se promovira kao materijal za bazu proteze zbog njegove fleksibilnosti, čime se dopušta određeni stupanj savijanja za bolju retenciju.

Ovo istraživanje ima nekoliko ograničenja. Prvo, korišten je samo jedan materijal za bazu proteze i jedno sredstvo za njezino čišćenje, čime je ograničena generalizacija nalaza. Osim toga, istraživanje ne može potpuno replicirati kliničko ponašanje proteza jer nije uzeto u obzir nekoliko čimbenika kao što su žvakanje, slina i interakcija s hranom tijekom stvarne uporabe. Drugo, uzorci korišteni u ovom istraživanju bili su manji od baze tipične proteze, što je izazov u rukovanju. Ova situacija mogla je utjecati na rezultate osnovnog ispitivanja hrapavosti površine. Štoviše, izravne usporedbe s dosadašnjim istraživanjima bile su otežane zbog mnogobrojnih varijabli i upotrebe različitih materijala. Preporučuju se daljnja istraživanja *in vitro* ovog materijala kako bi se prevladala ta ograničenja. Ta istraživanja trebala bi razmotriti uključivanje uvjeta oralne okoline, kao što je kontinuirano cikličko opterećenje, i produljiti razdoblje uranjanja kako bi se simulirala dugotrajna uporaba. Osim toga, opravdano je istražiti poten-

ronment, such as continuous cyclic loading, and extend the immersion period to simulate long-term use. Additionally, exploring the potential effect of mechanical cleaning methods on surface roughness is warranted. Finally, further clinical *in-vivo* studies are needed to assess the effect of daily denture cleanser use on mucosal irritation.

Conclusions

Based on the findings of this *in-vitro* study, the following conclusions can be drawn: The color change in the thermoplastic denture base material (Vertex ThermoSens) after immersion in the Polident 3-minute denture cleanser was minimal, and was considered clinically acceptable. The use of Polident 3-minute denture cleanser resulted in a significant increase in the surface roughness of the thermoplastic denture base material. Although the flexural modulus of the tested thermoplastic denture base material decreased following the immersion in denture cleanser, this decrease did not reach statistical significance.

Ethics approval and consent to participate

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are available from the corresponding author at a reasonable request.

Conflict of Interests

The authors declare that they have no competing interests.

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Author contribution: **H. M. A.** - Conceptualization and study design, Data collection, Writing- Original Draft. **M. N. A.** - Data Curation, Formal analysis, Writing-Review & Editing. **N. M. S.** - Conceptualization and study design, Methodology, Validation, Writing-Review & Editing, Visualization, Supervision, Project administration, Funding acquisition. **A. H. H. E.** - Validation, Writing-Review & Editing, Supervision. Wan Adida Mahmood: Validation, Writing- Review & Editing, Supervision.

cijalni učinak metoda mehaničkog čišćenja na hrapavost površine. Konačno, potrebna su daljnja klinička istraživanja *in vivo* kako bi se procijenio učinak svakodnevne upotrebe sredstva za čišćenje proteza na iritaciju sluznice.

Zaključak

Na temelju nalaza dobivenih ovim istraživanjem *in vitro* mogu se izvući sljedeći zaključci: promjena boje u termoplastičnom materijalu baze proteze (Vertex ThermoSens) poslije uranjanja u trominutno sredstvo za čišćenje proteze Polident bila je minimalna i smatrala se klinički prihvatljivom. Korištenje trominutnog sredstva za čišćenje proteza Polident rezultiralo je značajnim povećanjem hrapavosti površine termoplastične baze proteze. Iako se modul savijanja testiranoga termoplastičnog materijala baze proteze smanjio poslije uranjanja u sredstvo za čišćenje proteze, to smanjenje nije dosegnulo statističku značajnost.

Etičko odobrenje i pristanak za sudjelovanje

Nije primjenjivo.

Dostupnost podataka i materijala

Svi podatci generirani ili analizirani tijekom ovog istraživanja dostupni su na zahtjev.

Sukob interesa

Autori nisu bili u sukobu interesa.

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Autorski doprinos: **H. M. A.**– konceptualizacija i studijski dizajn, prikupljanje podataka, pisanje – izvorni nacrt; **M. N. A.** – prikupljanje podataka, formalna analiza, pisanje, recenzija i uređivanje; **N. M. S.** – konceptualizacija i studijski dizajn, metodologija, validacija, pisanje, recenzija i uređivanje, vizualizacija, nadzor, administracija projekta, pribavljanje sredstava; **A. H. H. E.** – validacija, pisanje, pregled i uređivanje, nadzor; **W. A. M.** – validacija, pisanje, pregled i uređivanje, nadzor.

Sažetak
Svrha istraživanja: Svrha ovog istraživanja bila je procijeniti postojanost boje, hrapavost površine i svojstva savijanja termoplastične poliamidne smole za proteze za injekcijsko prešanje Vertex ThermoSens poslije trominutnog uranjanja u sredstvo za čišćenje proteza Polident. Materijali i metode: Obrađeno je šezdeset uzoraka (Vertex ThermoSens) i podijeljeno u dvije glavne skupine (n = 30) na temelju vrste ispitivanja. Skupina 1 dalje je podijeljena u dvije podskupine (n = 15): kontrolnu skupinu uronjenu u destiliranu vodu (G1DW) i testnu skupinu uronjenu u otopinu za čišćenje Polident (G1PD). Skupina 2 podijeljena je u tri podskupine: skupinu koja nije uronjena (G2None), skupinu uronjenu u destiliranu vodu (G2DW) i skupinu uronjenu u otopinu za čišćenje Polident (G2PD). Mjerenja promjene boje (ΔE) i hrapavosti površine provedena su za skupinu 1, a ispitivanje modula savijanja (E) za skupinu 2. Za izračun ΔE korištena je formula CIE Lab*. Optički 3D površinski analizator i test savijanja u trima točkama korišteni su za procjenu hrapavosti površine, odnosno E. Podatci su podvrgnuti statističkoj analizi korištenjem t-testa uparenih uzoraka za razlike unutar svake skupine prije i poslije uranjanja. Nadalje, t-testovi neovisnog uzorka i jednosmjerna ANOVA obavljeni su da bi se analizirale razlike između skupina. Uzeta je u obzir razina značajnosti P < 0,05. Rezultati: Rezultati su pokazali blagi, statistički beznačajan (P > 0,05) ΔE u svim komponentama boje (L*, a*, b*) poslije uranjanja u destiliranu vodu. Međutim, poslije uranjanja u sredstvo za čišćenje proteze, samo je komponenta L* pokazala statistički značajan ΔE (P = 0,002) koji je bio male veličine. Osim toga, pronađena je značajna razlika u ΔE-u između G1DW-a i G1PD-a, pri čemu je G1PD pokazao veću promjenu (P = 0,007). Značajno povećanje hrapavosti površine poslije uranjanja uočeno je kod G1PD-a (P = 0,017), uz primjetnu razliku između G1DW-a i G1PD-a. No E je ostao nepromijenjen (P = 0,537). Zaključak: Sredstva za čišćenje proteza mogu modificirati svojstva termoplastične poliamidne smole. Potrebna su daljnja istraživanja kako bi se istražile kliničke implikacije tih uočenih promjena na kvalitetu proteze.

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Adresa za dopisivanje
Nosizana Mohd Salleh
Universiti Malaya
Faculty of Dentistry
Department of Restorative Dentistry
50603 Kuala Lumpur
Federal Territory of Kuala Lumpur
Malaysia
tel.: +603 7967 4881
nosizana@um.edu.my

MeSH pojmovi: sredstva za čišćenje zubnih proteza; baza zubne proteze; najloni; boja; površinska svojstva; čvrstoća na savijanje
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