

ORIGINAL ARTICLE

Effects of cleansing methods on 3-D surface roughness, gloss and color of a polyamide denture base material

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Objective. The purpose of this study was to determine the effects of two denture cleansing methods on 3-D surface roughness, gloss and color of denture base materials. **Materials and methods.** Thirty disks from nylon (Valplast) and 30 from heat-polymerized acrylic denture base material (Paladon 65) were made and 10 of each material were immersed in water (control), Val-Clean (peroxide cleanser) and Corega Extradent (peroxide cleanser) plus microwaving for a period simulating 30 days of daily cleansing. 3-D surface roughness, gloss and color parameters were measured before and after cleansing using an interferometric profilometer, a gloss meter and a colorimeter. The results were statistically analysed by regression, paired-*t*, Mann-Whitney and Kruskal-Wallis tests at $\alpha = 0.05$ level of significance. **Results.** The results showed significant differences at baseline in L^* and b^* parameters between materials ($p < 0.01$), with a significantly lower gloss ($p < 0.05$) and higher roughness ($p < 0.05$) for Valplast. After cleansing, $\Delta\epsilon^*$ was significantly greater in Valplast than Paladon 65 ($p < 0.05$). Gloss of both materials decreased significantly within the Corega Extradent plus microwave solution ($p < 0.05$), while roughness increased significantly only for Paladon 65 ($p < 0.05$). **Conclusions.** Valplast was found to have a significantly lower gloss and a higher roughness than Paladon 65 before cleansing. After cleansing, ΔE^* increased more in Valplast than in Paladon 65, gloss of both materials decreased and roughness only of Paladon 65 increased within the Corega extradent plus microwaving method.

Key Words: denture cleansers, microwave irradiation, nylon, PMMA**Introduction**

The need for dentures has been estimated to reach 37.9 million adults in the US alone [1]. The material most commonly used for the construction of denture prostheses is acrylic or polymethyl methacrylate (PMMA). The primary reason for this selection is that the material satisfies most of the requirements as a denture base material [2].

However, PMMA presents important disadvantages like low impact strength and fatigue properties [2–4]. Combining disadvantages with allergic reactions in hypersensitive patients to residual monomer, one can easily understand the efforts of researchers to introduce alternative materials for the fabrication of denture prostheses. Some potential alternative materials to PMMA include polycarbonate and nylon. Nylon is a generic name of polyamide materials

($\text{NH}(\text{CH}_2)_m\text{CON}$). It has been attempted to use this as a denture base material since 1950, but only in recent years, due to new nylon generations, its use was extended for the construction of removable denture prostheses [5,6]. The advantages of polyamides, as denture base materials, depending on the specific trade product, include high flexibility, low density, high impact resistance, low water sorption and solubility [7–12]. They are free residual monomers containing materials and, thus, non-toxic, with a low possibility of allergic reactions, presenting a relatively good color stability [9,10]. However, the main concerns of polyamides as denture base materials are centered in its low modulus of elasticity, flexural and tensile strength [12,13], its low adherence ability with denture liners [14] and its inability for a chemical retention of acrylic teeth and repair [15]. There is also a concern for the staining of the material following a

prolonged use of drinks and beverages [10] or denture cleansers [9], due to difficulty in finishing and polishing [8,16,17]. Denture cleansers are widely used to control denture plaque formation and prevent colonization by *Candida albicans* and other species [18–21]. Continuous and prolonged use of such active chemicals can affect some properties of the denture base materials such as gloss, surface roughness and color, which play a significant role in esthetic appearance [22] and longevity of the appliance [23]. Immersion denture cleansers are classified into enzymes, neutral or alkaline peroxides with enzymes, acids, sodium hypochlorites, peroxides and mouth rinses [24].

Recently, microwave irradiation has been introduced as an alternative to immersion cleansers for daily cleansing of dentures, to overcome the problems of special storage and expiration date of cleansers [25–29]. Senna et al. [29] found that microwave irradiation at 450 W for 2 min combined with a denture cleanser solution (alkaline peroxide containing enzyme) produced an effective cleansing at a temperature below 71°C, over which a possible distortion of the denture base may occur.

Color and gloss are important factors for the esthetic appearance and acceptance of removable prostheses, whereas changes in color and gloss could be an indicator of aging or degradation of the denture base material. Such changes can be described as visually perceptible or clinically acceptable [30]. The influence of different food colorants [31] or drinks and beverages [10] on the color of denture base materials has been reported, but little information is available on the influence of denture cleansers [32]. Hong et al. [33] tested the color change of three different types of commercial acrylic resins after immersion in eight denture cleansers for 1 year and found a statistically significant color change. Durkan et al. [9] recorded no significant differences in the color between nylon and PMMA material after cleansing for 20 days.

Surface roughness and gloss are also recognized among the important properties affecting the appearance of denture base material. A smooth surface improves esthetics and reduces plaque retention avoiding tissue inflammation [8,34]. Surface roughness of resin materials depends on structural conditions, degree of cure and polishing technique [35]. No difference was found by Sartori et al. [26] in a PMMA material after 2 weeks of chemical cleansing, while microwave cleansing resulted in significant changes. Recently, a new generation of nylon denture materials has been introduced into the market [6,12], increasing the need for further research on gloss, surface roughness and color changes after cleansing.

The purpose of this study was to investigate the effect of two different cleansing methods on 3-D surface roughness gloss and color of nylon and acrylic

denture base materials. The ability to predict the effect of cleansing methods on the materials was also investigated. The null hypotheses tested were that the effect of cleansing methods on the above properties was not different between materials or among methods.

Materials and methods

Specimen preparation

Sample size was estimated *a priori* using G*Power software (G*Power v.3.1.5, Franz Faul, Universitat Kiel, Germany). The indicated required sample size for each group, with an effect size of 0.40, $\alpha = 0.05$ and $P(1 - \beta) = 0.80$, was less than 9.

Ten identical machined stainless steel disks were fabricated (25 mm in diameter and 3 mm in thickness), for the investing procedure. At the metallic patterns intended to make polyamide specimens, a wax sprue (3 mm in diameter) was positioned before investing. In every flask were three metallic patterns invested with ISO type III dental stone (Microstone, Whip-Mix). After boiling out, the metallic patterns were removed and the mold cavities were filled with the respective material for the fabrication of the disk specimens. Sixty specimens were produced, 30 from a pink polyamide material (Valplast) and 30 from a pink veined 3-conventional heat polymerized acrylic denture base material (Paladon 65) (Table I).

Before the injection of polyamide material into the mold cavities, it was plasticized around 280°C for 11 min in a digital melting Valplast furnace. The flask was pressed for 3 min in a Valplast injection press and then allowed to bench cool before opening.

Acrylic material was manipulated according to the manufacturer's instructions using the conventional flasking and pressure-pack technique. The flask allowed cooling in the water bath before opening.

All specimens were finished up to 1200-grit on their upper surface using silicon carbide papers in Ecomet III polishing equipment (Buehler Ltd, Evanston, Ill, USA) under wet conditions and polished with a high shine polishing agent (KMG, Candulor AG, Zurich, Switzerland) on a cotton wheel.

Cleansing methods

Specimens were immersed in two cleansing solutions, namely Val-Clean and Corega Extradent, whereas distilled water was used as control (Table I). Ten specimens of each material were used for each cleansing method and the control.

Specimens were placed in a separate beaker and were hung by a plastic thread from a small rod on the top of the beaker, ensuring that all surfaces were covered with the solution.

Table I. Type, composition and manufacturer of the materials used.

Material	Type	Composition (Batch.no)	Manufacturer
Paladon-65 (Denture Base Resin)	Conventional heat cured acrylic	Powder: PMMA (L012346) Liquid: MMA, DMA (L010149)	Heraus-Kulzer GmbH, Hanau, Germany
Valplast (Denture Base Resin)	High purity nylon	Polyamide-12 (Lot#111248)	Valplast Int. Corp, Long Island City, NY, USA
Corega Extradent (Disinfectant)	Alkaline peroxide	Sodium bicarbonate, Citric acid, Potassium caroate, Sodium carbonate, Sodium carbonate peroxide, TAED, Sodium benzoate, PEG-180, Subtilisin, Sodium lauryl sulfoacetate, Aroma, PVP/VA copolymer, (CI 42090, CI 73015)	Glaxo Smith Kline, Brentford, Middlessex, UK
Val-Clean (Disinfectant)	Alkaline peroxide	Potassium peroxymonopersulfate, Citric acid, Potassium bisulfate, Magnesium carbonate, Potassium sulfate, Peppermint extract, Potassium peroxydisulfate, Sucrose. (Batch no. 52306)	Valplast Int. Corp, Long Island City, NY, USA

Ten specimens from each material were immersed in a solution prepared by stirring 1.5 g Val-Clean powder in 8 oz (236 mL) distilled water at 50°C, in a beaker. Val-Clean solution was renewed every 7 days. Specimens remained in the solution for 10 days, corresponding to 240 h of immersion. This period simulates a month of overnight cleansing (8 h/day) of the removable prosthesis.

Another group of 10 specimens from each material were immersed in a solution, prepared by dissolving a Corega Extradent tablet in 200 mL of distilled water at 50°C for 3 min, in a beaker. The beaker was placed in a microwave oven (Siemens Electrogeräte GmbH) and was irradiated at 450W for 2 min [29]. Corega Extradent solution was renewed after each cleansing cycle (~ 5–6 min).

Finally, 10 specimens of each material were immersed in 200 mL of distilled water (control groups) at room temperature (23 ± 2°C) throughout the experimental period, renewed every 8 h.

Before immersion of all specimens in the renewed solutions they were rinsed with distilled water for 10 s. Roughness tests, gloss and color, were measured on all specimens before and after immersion, at a pre-defined central area.

Color measurements

Color measurements of the disks were taken using a portable contact type colorimeter against a white background (Shade Eye NCC, Shofu Inc, Kyoto, Japan). The measurement window was 3 mm and the light beam angle 90°. Color changes were examined in the CIEL*a*b* system representing lightness (L*), red–green dimension (a*) and yellow–blue (b*) color dimensions. Measurements were performed at four different points for each specimen to obtain a

mean value. The color difference (ΔE^*) was calculated by the equation: $\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.

Gloss measurements

A gloss meter (Novo-Curve, Rhopoint, Bexhill-on-Sea, UK) was used for measuring surface gloss on a 2 mm × 1 mm window, after calibration at 5.5 gloss units (GU). The specimens were protected from ambient interferences using a black shield. The average of four measurements was taken on a scale from 0–100. Each measurement was taken at 60° light incidence and reflection angles, turning the specimen 90° for each measurement.

3-D surface roughness measurements

The 3-D surface roughness was measured by a non-contact optical interferometric profilometer (Wyko NT1100, Veeco, Santa Barbara, CA, USA). The instrument was operated under the following conditions: vertical scan image mode Myro lens (5 × 2 FOV), 20.4× total magnification to include as much specimen area as possible in roughness calculations, 10 µm back scan length, 30 µm scanning length and a modulation length of 2. One scan was performed per specimen surface. The measured surface parameter was Sa, representing the average roughness in nm, as evaluated over a complete 3D surface [36].

Statistical analyses

Unpaired *t*-tests with or without a Welch's approximation or Mann-Whitney tests were initially used to detect differences between the two materials, before the use of cleansing methods.

Table II. Means (SD) of L*, a*, b*, Gloss and Sa parameters of denture base materials at baseline ($n = 30$).

Parameter	Paladon 65	Valplast	p^*
L*	52.0 (0.7)	53.3 (0.8)	< 0.0001 ^a
a*	19.6 (0.5)	20.0 (1.0)	0.099 ^b
b*	10.1 (0.5)	9.5 (1.1)	0.009 ^b
Gloss	80.9 (5.8)	22.8 (15)	< 0.0001 ^c
Sa	60.1 (27.5)	328.4 (111.4)	< 0.0001 ^a

*Two-tailed probability of the difference between materials.
^a t -test; ^bWelch's correction t -test; ^cMann-Whitney test.

To investigate the effect of cleansing methods on the materials, the difference after cleansing from the initial (baseline) values in all parameters were estimated and the results were analyzed by Kruskal-Wallis non-parametric test with Conover's post-hoc pairwise comparisons.

The coefficient of determination (R^2) of the values before and after cleansing was estimated, to evaluate the ability to predict the outcome of cleansing on the investigated parameters and materials. The inter-parameter coefficient of determination for the denture materials was also calculated in order to evaluate the ability to predict the outcome of one parameter from another. All analyses were performed by MedCalc v.10.2.0.0 software (MedCalc Software; Bvba, Ostend, Belgium) at a significance level of $\alpha = 0.05$.

Results

Measurements of color, gloss and surface roughness of both materials before the application of cleansing methods are shown in Table II and Figures 1 and 2. The change (difference) in these parameters after cleansing is shown in Table III and Figures 3,4,5,6,7,8.

Analysis of material differences at baseline

Table II shows small differences between the two materials in respect to the primary color parameters L*, a* and b* at baseline, but large in gloss and Sa. Unpaired t -test with or without Welch's approximate and Mann-Whitney tests indicated significant differences between the materials for all parameters, except a*.

Changes in parameters after material cleansing

Changes after cleansing for all parameters are shown in Table III. Kruskal-Wallis tests for each parameter at $\alpha = 0.05$ and post-hoc multiple comparisons indicated significant differences among groups. These are also shown in Table III.

Color measurements indicated that Valplast presents significantly greater color change than Paladon 65, although cleansing methods had no significant effect from the control, for each tested material.

Corega Extradent plus microwave irradiation reduced significantly the gloss values of both materials and especially of Paladon 65. Both cleansing methods did not affect Valplast's surface roughness, whereas Paladon 65 was greatly affected by Corega Extradent plus microwaves (Figure 9).

Regression analysis

Regression analysis of the values before and after cleansing showed higher values of r^2 for Valplast (Table IV), for all tested parameters, although significant differences were found only for Sa and gloss. Inter-parameter coefficient of determination (r^2) for the changes after cleansing is shown in Table V. The results indicated that ΔE^* is not a predictor for the changes in gloss and roughness. However, dL^* can predict the change in gloss and only for Paladon

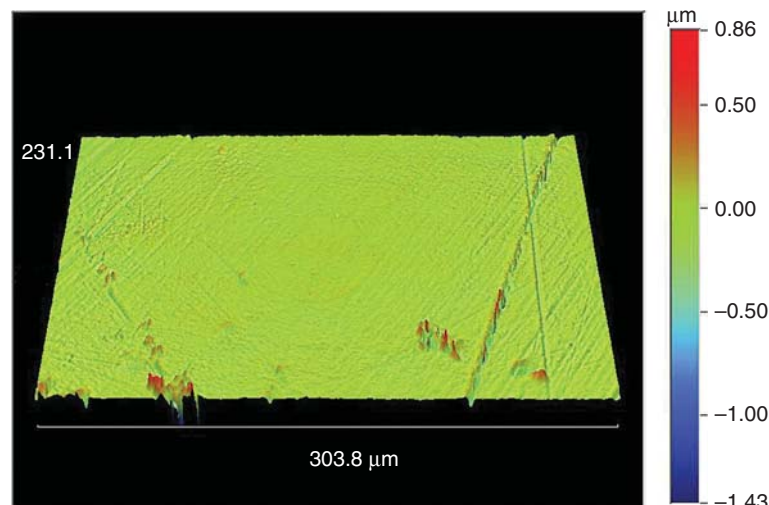


Figure 1. 3-D interactive display of Paladon 65 specimen (20.4 \times) before applying any cleansing method.

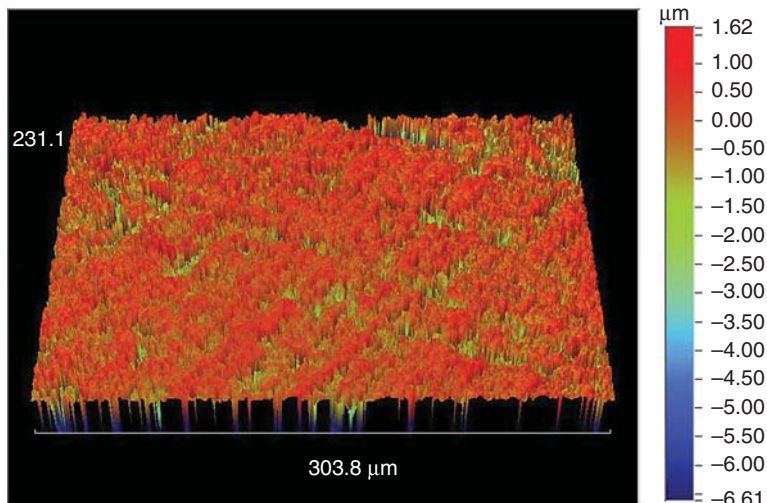


Figure 2. 3-D interactive display of Valplast surface (20.4×) before applying any cleansing method.

Table III. Means (SD) of the changes (d) in color, gloss and surface roughness of denture base materials after immersion in cleansing solutions (n = 10).

Parameter	Paladon 65			Valplast			p-value*
	Control (Water)	Val-Clean	Corega Extradent + Microwaves	Control (Water)	Val-Clean	Corega Extradent + Microwaves	
dL*	-0.27 (0.29) ^a	0.14 (0.29) ^b	0.54 (0.17) ^{bc}	0.42 (0.38) ^{bc}	0.22 (0.56) ^b	-0.40 (0.29) ^a	< 0.001
da*	-0.14 (0.24) ^{ab}	0.14 (0.28) ^{abc}	0.15 (0.33) ^{ac}	-0.31 (0.30) ^a	-0.31 (0.35) ^a	-0.20 (0.34) ^a	0.003
db*	-0.43 (0.27)	0.01 (0.26) ^a	0.11 (0.19) ^a	-1.18 (0.53) ^{bc}	-1.36 (0.54) ^b	-0.92 (0.51) ^c	< 0.001
ΔE*	0.63 (0.30) ^a	0.47 (0.16) ^a	0.67 (0.18) ^a	1.37 (0.52) ^b	1.54 (0.56) ^b	1.11 (0.50) ^b	< 0.001
dGloss	0.74 (1.83) ^b	1.98 (2.90) ^b	-23.2 (2.65)	0.98 (5.07) ^{ab}	-1.87 (5.63) ^a	-4.83 (2.96)	< 0.001
dSa	6.32 (23.03) ^a	22.04 (15.25) ^a	103.9 (32.67) ^{bc}	82.24 (96.75) ^{bc}	50.53 (67.92) ^{ab}	70.38 (74.66) ^{bc}	< 0.001

*p-value is the probability of Kruskal-Wallis test for significant differences among groups of the same parameter (horizontal groups). Post-hoc multiple comparisons indicated no differences for the groups with the same superscript letter, at α = 0.05.

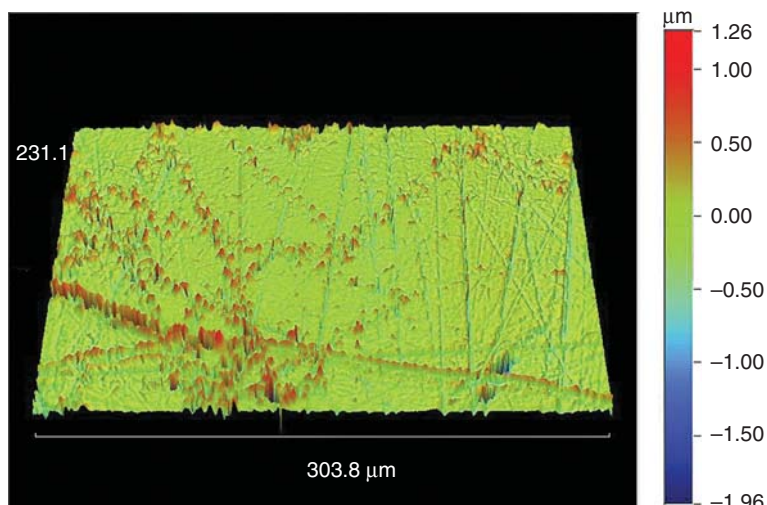


Figure 3. 3-D interactive display of Paladon 65 specimen (20.4×) after immersion for a simulated period of 30 days in distilled water.

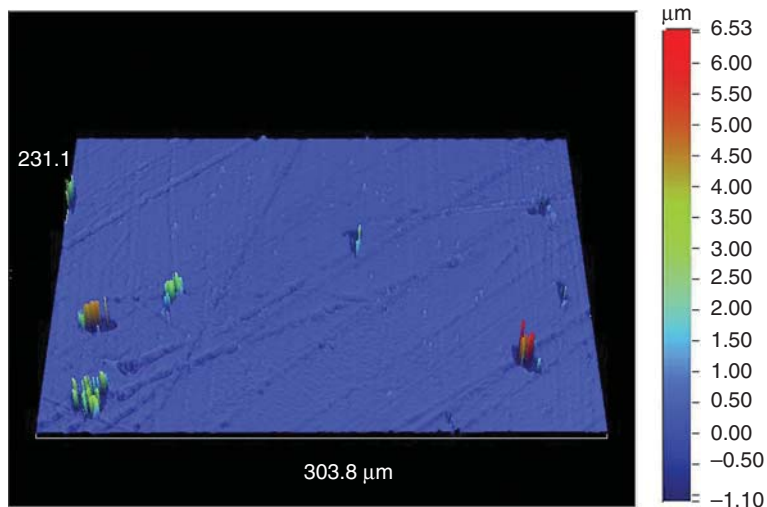


Figure 4. 3-D interactive display of Paladon 65 specimen (20.4×) after immersion for a simulated period of 30 days in Val-Clean.

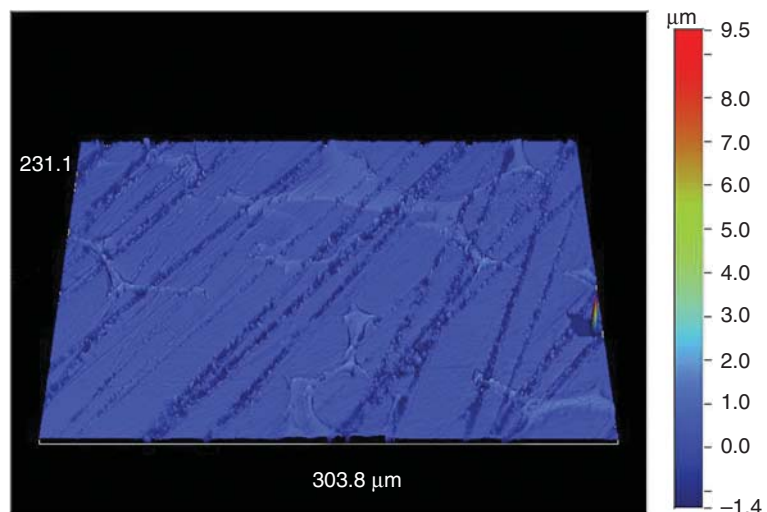


Figure 5. 3-D interactive display Paladon 65 specimen (20.4×) after immersion for a simulated period of 30 days in Corega Extradent combined with microwave irradiation.

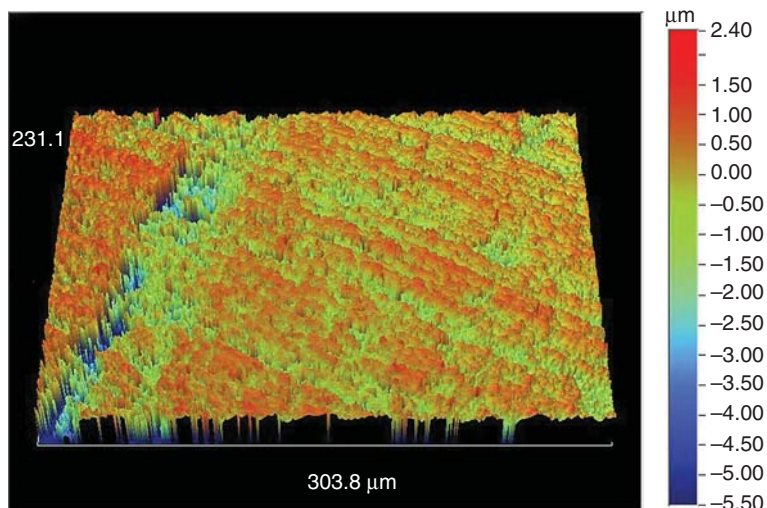


Figure 6. 3-D interactive display of Valplast surface (20.4×) after immersion for a simulated period of 30 days in distilled water.

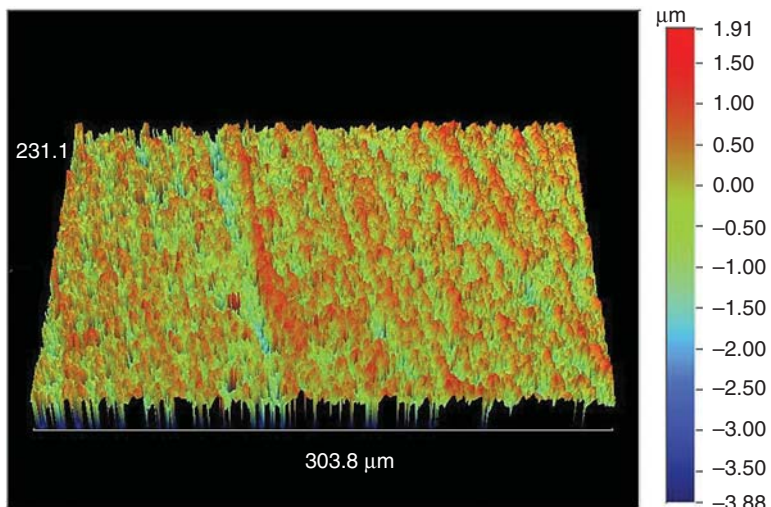


Figure 7. 3-D interactive display of Valplast surface (20.4×) after immersion for a simulated period of 30 days in Val-Clean.

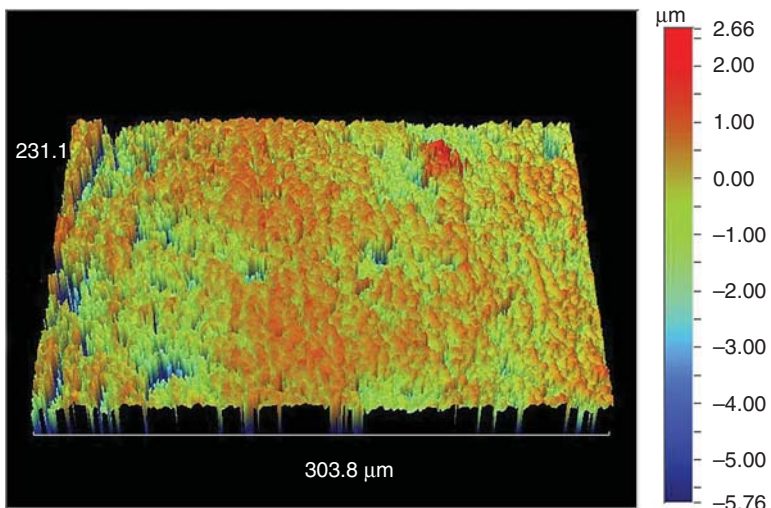


Figure 8. 3-D interactive display of Valplast surface (20.4×) after immersion for a simulated period of 30 days in Corega Extrudent combined with microwave irradiation.

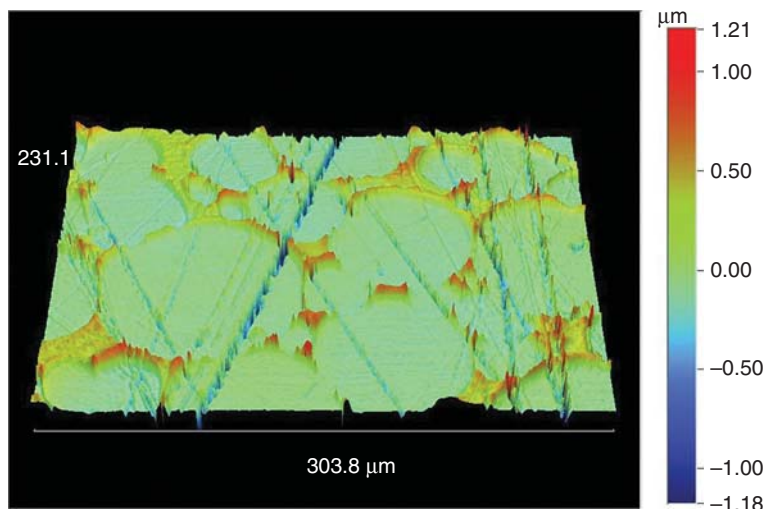


Figure 9. 3-D interactive display of a Paladon 65 surface after the immersion in Corega extrudent plus microwaves cleansing solution. Swelling of inter-bead polymer matrix is evident.

Table IV. Coefficient of determination (before/after cleansing) of the parameters for both materials and the probability of their difference ($n = 20$).

Parameter	Coefficient of determination (r^2)		p
	Paladon 65	Valplast	
L*	0.69	0.63	0.747
a*	0.63	0.83	0.177
b*	0.66	0.76	0.550
Gloss	0.05	0.93	< 0.001
Sa	0.15	0.70	0.020

Table V. Inter-parameter coefficient of determination (r^2) for the changes after cleansing (P = Paladon 65 and V = Valplast).

	dL*	da*	db*	$\Delta\epsilon^*$	dGloss
da* P	0.021				
V	-0.014				
db* P	0.315	-0.149			
V	0.227	0.669**			
$\Delta\epsilon^*$ P	0.804**	0.311	0.653**		
V	0.371*	0.704**	0.980**		
dGI P	0.558**	0.234	-0.272	0.265	
V	-0.128	0.077	-0.157	-0.143	
dSa P	0.467**	0.225	-0.131	0.288	0.843**
V	0.285	-0.083	0.161	0.189	0.006

* r^2 is significant at the 0.05 level (2-tailed).

** r^2 is significant at the 0.01 level (2-tailed).

65 changes in roughness. Gloss found to be an accurate predictor of dSa but again only for Paladon 65.

Discussion

The study accepted the hypothesis of no differences between cleansing methods for their effect on color of the same denture base material and rejected the hypothesis that this effect was not different between different materials. The study also rejected the hypothesis of no differences between cleansing methods for their effect on the gloss for the same or different denture base materials. For surface roughness, the study accepted the hypothesis of no differences between different materials and rejected this hypothesis for the same materials but only for the Paladon 65.

Both cleansing methods affected the color of denture materials in the same degree with the corresponding control group, although the effect on Valplast was much greater than Paladon 65 (0.5 and 1.5 ΔE^* units, respectively). The changes were well below the clinically acceptable and perceptible level of 5.5 [30] and 2.7 [30], respectively; however; they

represent a 30 days effect and show that these levels can be reached much sooner with Valplast, if cleansing acts longer. This was shown by Hong et al. [33] in their 90–180 days study of immersion in cleansing solutions, reporting a ΔE^* value of 2–2.5 after the immersion. Polyzois et al. [32] reported also an intense effect of alkaline peroxide type cleansing solution on color of denture base resins, after 100 days of immersion. Although in their study only monophasic denture base materials were included (acetal, PMMA), data analysis indicated no differences between control (water) and cleansing solution, as our study indicated. No differences between control and cleansing solution were also found in a recent study by Durkan et al. [9]. In the present study, color changes of Paladon 65 derived mainly from an increase in L* and a* primary parameters, although Valplast derived mainly from a decrease in b* and a* parameters. The changes should be considered as the result of the bleaching action of peroxide content of disinfectants, even if this action alone did not cause the difference between the materials. Structure and compositional differences would probably play a significant role, but only a longer period of immersion can indicate this. A greater vulnerability to color changes of nylon denture base material in staining solutions was already shown in the study of Sepulveda-Navarro et al. [10] and Wieckiewicz et al. [16]. Although polyamides and PMMAs absorb water molecules facilitated by the polarity of the polymeric molecules, a diffusion mechanism is mainly responsible. For this reason, a greater diffusion coefficient of water in Valplast might explain the greater effect of the cleansing solutions on its molecular chains. It is believed that whitening of denture base acrylics is due to a mismatch in the refractive index between bead and matrix polymer, as a result of structural changes from cleansing solutions [2]. However, this explanation alone cannot be applied on the polyamide-12 material Valplast, since a definite action on the b* parameter indicates action on colorants, demonstrated also by Hong et al. [33]. More studies are needed to give answers in this field.

Valplast was found to have significantly higher roughness than Paladon 65 at baseline (almost 5-times), as other studies have shown [8,17]. This initial higher roughness of polyamide 12 than PMMA material could be explained by the difficulty to be polished due to its lower than PMMA heat distortion temperature (48–55°C and 95°C, respectively) and of course to the nature of its microstructure. Baseline data show that the surface roughness of Paladon 65 material was well below the clinically acceptable threshold level [34] (0.2 μm or 200 nm) while Valplast's was above this value. A rougher surface of the polyamide against PMMA was also shown in other studies [8,17]. Cleansing methods affected Paladon 65 differently, since the enhanced by

microwaves method increased its roughness almost 5-times more than unenhanced. Such an effect was not noted for Valplast material. Senna et al. [28] and Sartori et al. [26], studying the effect of microwave cleansing on PMMA denture base materials, also found a significant increase in their roughness. Our results of no significant effect of unenhanced cleansing solutions are in agreement with the results of Paranhos et al. [37] on heat-polymerized materials and of Durkan et al. [9] on heat-polymerized and nylon denture base materials, however not much of an explanation was given. In our study, the 3-D topographic images of PMMA material after their immersion in the cleansing solutions showed that the increase in roughness resulted from a swelling of the polymer matrix over the polymer bead surface, probably from a higher diffusion of water in this phase (Figure 9). The matrix phase is known to contain more low-molecular weight chains and residual monomer than bead polymer and, for this reason, a higher diffusion of water or other small molecules is logical to be expected. It also seems that microwaves act as a diffusion enhancer, since microwaves may additionally increase the molecular mobility in the polymer and allow more small molecules to entrap in its structure. We must also note that cleansing also affects the bead/matrix interface which may not be a result of the polymer matrix expansion only, but also the effect of the disinfectant itself on this low energy area of the structure. Valplast is a polyamide monophasic material with a rather complex fibrous structure [9] and such effects are not likely to take place. However, the material seems to be more vulnerable to temperature rise and water uptake than PMMA and, for this reason, a higher diffusion of water and the subsequent swelling may explain the higher roughness of the material in cleansing solutions. Further studies are needed to investigate this hypothesis as well.

Denture base materials showed significant differences in gloss. Since gloss expresses the reflectivity of a smooth surface, it is logical to be related to the surface roughness of the material and the polishing method that was followed to give a surface shine. In this study, the gloss of Paladon 65 at baseline, according to Cook and Tomas [38] was considered excellent (>80 GU), while Valplast's was poor (<60 GU). Cleansing methods also showed differences in their effect on the materials. The plain alkaline peroxide solution had the same with the control (water) effect on the gloss, while the microwave method affected (decreased) significantly the gloss of both materials by 23 GU of Paladon's and almost 5 GU of Valplast's. According to Malaga and Bengtsson [39], 23 GU are considered high and 5 GU are very small but visible for most people (>2 GU). The study by Polyzois et al. [32] showed an effect on gloss of a PMMA denture base material after its immersion in an alkaline peroxide solution. This is in contrast with our results, but

it is possible that our microwave cleansing results include a strong effect of this material alone, something that we did not investigate. The decrease of Paladon's gloss can be explained by the previously mentioned increase of its roughness within microwaved disinfectant, but it cannot explain the decrease for polyamide-12 since no change of its roughness was noted. Regression analysis in this study showed a high coefficient of determination between gloss and Sa ($r^2 = 0.843$), as studies on composite resins have shown [35,40], but this is true only for the Paladon 65. We must, however, mention that even small changes of surface roughness in some materials may cause a significant part of the transmitted light to diffuse, resulting in a reduced gloss of its surface. This again needs to be explored by further studies. Regression analysis for each of the tested parameters showed a high coefficient of determination for the gloss of Valplast, indicating a high prediction of gloss after cleansing from the values before cleansing and that low initial values also give low ones after cleansing.

The results of this study showed that the investigated parameters, although all connected with the appearance of the materials, present differences in the behavior of cleansing methods upon them, not always predictable. Our study shows that the prediction of the effect of cleansing methods on the tested materials from their state before cleansing is possible only for the Valplast material, either for gloss or Sa. No prediction can be made for the heat-cured Paladon 65. The study also shows that gloss and roughness are highly connected for the prediction of each other after cleansing, but only for Paladon 65. This means that, knowing the changes in gloss after cleansing, we can expect similar changes in roughness.

Limitations of the present *in vitro* study could be considered the use of the same polishing method on both materials. While this was decided on the basis of uniformity, a technique exists that may give a higher polish to the nylon material. This, however, needs special attention and investigation. The limited to 1-month effect of cleansing methods on the materials, especially the one enhanced by microwaves, would also be considered as a limitation.

Under the limitations of the present *in vitro* study the following conclusions can be derived: Cleansing methods had no different effect on color than the control, for the same material. However, the effect on Valplast was higher than Paladon 65, both at a clinically perceptible level. Only the Val-Clean method had no different effect than the control on gloss, for both materials. Corega Extradent plus microwaves decreased significantly the gloss of both materials. Surface roughness was affected significantly only by Corega Extradent plus microwaves and only for the Paladon 65 material. Color change as an effect of

cleansing is not associated with gloss or surface roughness in none of the materials. However, gloss and surface roughness are highly associated in Paladon 65 and can be used for the prediction of each other.

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References

- [1] Douglash CW, Shih A, Ostry L. Will there be a need for complete dentures dentures in the United States in 2020? *J Prosthet Dent* 2002;87:5–8.
- [2] McCabe JF, Walls AWG. *Applied dental materials*. 9th ed. Oxford: Blackwell Publishing Ltd; 2008. p 101–23.
- [3] Faot F, Costa MA, Del Bel Cury AA, Rodrigues Garcia RCM. Impact strength and fracture morphology of denture acrylic resins. *J Prosthet Dent* 2006;96:367–73.
- [4] Stafford GD, Bates GF, Huggett R, Handley RW. A review of the properties of some denture base polymers. *J Dent* 1980;8: 292–306.
- [5] Matthews E, Smith DC. Nylon as a denture base material. *Br Dent J* 1955;98:231–7.
- [6] Hargreaves AS. Nylon as a denture base material. *Dent Pract Dent Rec* 1971;22:122–8.
- [7] Soygun K, Bolayir G, Boztug A. Mechanical and thermal properties of polyamide versus reinforced PMMA denture base materials. *J Adv Prosthodont* 2013;5:153–60.
- [8] Abuzar MA, Bellur S, Duong N, Kim BB, Lu P, Palfreyman N, et al. Evaluating surface roughness of a polyamide denture base material in comparison with poly (methyl methacrylate). *J Oral Sci* 2010;52:577–81.
- [9] Durkan R, Ayaz EA, Bagis A, Gurbuz A, Ozturk N, Korkmaz FM. Comparative effects of denture cleansers on physical properties of polyamide and polymethyl methacrylate base polymers. *Dent Mater J* 2013;32:367–75.
- [10] Sepulveda-Navarro WF, Arana-Correa BE, Borges CPF, Jorge JH, Urban VM, Campanha NH. Color stability of resins and nylon as denture material in beverages. *J Prosthodont* 2011; 20:632–8.
- [11] Stafford GD, Huggett R, McGregor AR, Graham G. The use of nylon as a denture base material. *J Dent* 1986;14:18–22.
- [12] Yunus N, Rashid AA, Azmi LL, Abu-Hussan MI. Some flexural properties of a nylon denture polymer. *J Oral Rehabil* 2005;32:65–71.
- [13] Takabayashi Y. Characteristics of denture thermoplastic resins for non-metal clasp dentures. *Dent Mater J* 2010;29: 352–61.
- [14] Kim JH, Choe HC, Son MK. Evaluation of adhesion of reline resins to the thermoplastic denture base resins for non-metal clasp dentures. *Dent Mater J* 2014;33:32–8.
- [15] Katsumata Y, Hojo S, Hamano N, Watanabe T, Yamaguchi H, Okada S, et al. Bonding strength of autopolymerizing resin to nylon denture base polymer. *Dent Mater J* 2009;28:409–18.
- [16] Wieckiewicz M, Opitz V, Richter G, Boening KW. Physical properties of polyamide-12 versus PMMA denture base material. *Biomed Res Int* 2014;2014:150298.
- [17] Kawara M, Yoshihiro I, Masatoshi I, Yoshihiro K, Takashi I, Takashi A, et al. Scratch test of thermoplastic denture base resins for non-metal clasp dentures. *J Prosthodont Res* 2014;58:35–40.
- [18] Nikawa H, Hamada T, Yamamoto T, Kumagai H. Effects of salivary or serum pellicles on the *Candida albicans* growth and biofilm formation on soft lining materials *in vitro*. *J Oral Rehabil* 1997;24:594–604.
- [19] Fernandes F, Pereira-Cenci T, Jose Da Silva W, Filho A, Straioto F, Del Bel Cury AA. Efficacy of denture cleansers on candida spp. biofilm formed on polyamide and polymethyl methacrylate resins. *J Prosthet Dent* 2011;105:51–8.
- [20] Nikawa H, Hamada T, Yamashiro H, Kumagai H. A review of *in vitro* and *in vivo* methods to evaluate the efficacy of denture cleansers. *Int J Prosthodont* 1999;12:153–9.
- [21] Nikawa H, Iwanaga H, Hamada T, Yuhta S. Effect of denture cleansers on direct soft denture lining materials. *J Prosthet Dent* 1994;72:657–62.
- [22] Yonehara M, Matsui T, Kihara K, Ison H, Kijima A, Sugibayashi T. Experimental relationships between surface roughness, glossiness and color of chromatic colored metals. *Mater Trans* 2004;45:1027–32.
- [23] Spasojevic P, StamenKovic D, Pjanovic R, Boskovic-Vragolovic N, Dolic J, Grujic S, et al. Diffusion and solubility of commercial poly (methyl methacrylate) denture base material modified with itaconate and d-n-butyl itaconate during water absorption/desorption cycles. *Polym Int* 2012; 61:1272–8.
- [24] Polyzois GL, Zissis AG, Yannikakis SA. The effect of glutaraldehyde and microwave disinfection on some properties of acrylic denture resins. *Int J Prosthodont* 1995;8:150–4.
- [25] Hamouda IM, Ahmed SA. Effect of microwave disinfection on mechanical properties of denture base acrylic resin. *J Mech Biomed Mater* 2010;3:480–7.
- [26] Sartori EA, Schmidt CB, Walber LF, Shinkai RS. Effect of microwave disinfection on denture base adaptation and resin surface roughness. *Braz Dent J* 2006;17:195–200.
- [27] Ribeiro DG, Pavarina AC, Dovigo LN, Spolidorio DMP, Giampaolo ET, Vergani CE. Denture disinfection by microwave irradiation: a randomized clinical study. *J Dent* 2009;37: 666–72.
- [28] Senna PM, da Silva WJ, Faot F, Del Bel Curry AA. Microwave disinfection: cumulative effect of different power levels on physical properties of denture base resins. *J Prosthodont* 2011;20:606–12.
- [29] Senna PM, Sotto-Mattior BS, da Silva WJ, Del Bel Curry AA. Adding denture cleanser to microwave disinfection regimen to reduce the irradiation time and the exposure of dentures to high temperatures. *Gerodontology* 2012;30:26–31.
- [30] Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. *J Prosthet Dent* 2007;97:200–8.
- [31] Hersek N, Canay S, Uzun G, Yildiz F. Color stability of denture base acrylic resins in three food colorants. *J Prosthet Dent* 1999;81:375–9.
- [32] Polyzois G, Niarchou A, Ntala P, Pantopoulos A, Frangou M. The effect of immersion cleansers on gloss, colour and sorption of acetal denture base materials. *Gerodontology* 2013;30: 150–6.
- [33] Hong G, Murata H, Li Y, Sadamori S, Hamada T. Influence of denture cleansers on the color stability of three types of denture base acrylic resin. *J Prosthet Dent* 2009;101:205–13.
- [34] Bollen CM, Lambrechts P, Quirymen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. *Dent Mater* 1997;13:258–69.
- [35] Ereifej NS, Oweis YG, Eliades G. The effect of polishing technique on 3-D surface roughness and gloss of dental restorative resin composites. *Oper Dent* 2013;38:E1–E12.

- [36] Cohen DK. Clossary of surface texture parameters. Livonia: Michigan Metrology LLC; 2009.
- [37] Paranhos HF, Peracini A, Pisani MX, Oliveira VC, de Souza RF, Silva-Lovato CH. Color stability, surface roughness and flexural strength of an acrylic resin submitted to simulated overnight immersion in denture cleansers. *Braz Dent J* 2013;24:152–6.
- [38] Cook MP, Thomas K. Evaluation of gloss meters for measurement of molded plastics. *Polym Test* 1990;9: 233–44.
- [39] Malaga K, Bengtsson T. The Nordic Method: performance tests for protective sacrificial coatings on mineral surfaces. Hydrophobe V, 5th International conference on water repellent treatment of building materials. Aedificatio Publishers, Freiburg, Germany; 2008. p 169–80.
- [40] Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. *J Mater Sci Mater Med* 2007;18:155–63.