Effect of acidic beverages on surface roughness and color stability of artificial teeth and acrylic resin

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PURPOSE. The aim was to evaluate the effect of four acidic beverages on the roughness (Ra) and color change (ΔE_{ab}) of two brands of artificial teeth and a heat-polymerized acrylic resin (HPAR) for use in a prosthetic base. **MATERIALS AND METHODS.** All materials were divided into 5 groups, according to the used acidic beverage (artificial saliva - control, red wine, orange juice, coke-based, and lemon juice-based soft drink). The immersion process was divided into two stages: T1 - immersion in the acidic solutions for 10 minutes for 14 days; T2 - after T1, the samples were immersed in grape juice for 14 days. The Ra of the samples was evaluated in a rugosimeter and the ΔE_{ab} in a spectrophotometer, before and after the immersions. The analysis of variance of one (ΔE_{ab}) and two factors (Ra) and Tukey were performed (α=.05). **RESULTS.** There was a statistical difference for roughness after immersion (T1) for Trilux and Tritone teeth, regardless of the acid solution. For Trilux teeth, all acid solutions increased Ra (P<.05). For Tritone teeth, only the coke-based soft drink did not statistically change Ra. Grape juice (T2) altered Ra only of artificial teeth (P<.05). The color was changed for all materials, after T1 and T2. **CONCLUSION.** In general, the acidic solutions changed the Ra and ΔE_{ab} of HPAR and artificial teeth after T1. The grape juice altered the roughness only of the artificial teeth, promoting a clinically acceptable color change in the materials. ***[J Adv Prosthodont 2020;12:55-60]***

KEYWORDS: Acrylic resins; Artificial teeth; Color; Physical properties; Surface analysis

INTRODUCTION

Among the properties required for the materials used in complete denture prosthesis, those related to the surface, such as roughness, have great clinical importance, since they facilitate the accumulation of biofilm and staining.[1] A smooth surface is more resistant to contamination by microorganisms, besides facilitating the process of hygiene of these prostheses.[2,3]

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Received August 28, 2019 / Last Revision March 4, 2020 / Accepted March 12, 2020

One of the main requirements for a complete denture prosthesis to be considered satisfactory is the surface smoothness that is in contact with the oral mucosa.[3,4] Thus, polishing the base of the polymethylmethacrylate (PMMA) prosthesis and the maintenance of its smoothness contributes to patient comfort, esthetics, and minimal retention of microorganisms.[3,4] Any changes in its surface roughness will directly influence the microorganism's adhesion, since the presence of irregularities acts as a microbial shelter, increasing the probability of these microorganisms remaining on the surfaces, even after conventional cleaning procedures.[4-6]

Artificial teeth and the acrylic resin bases of complete dentures are constantly exposed to food and beverages and hence to the acidic pH and pigments of these solutions.[7,8] This frequent interaction compromises both the color and surface roughness of these materials, damaging the esthetic, physico-mechanical properties and durability of these prostheses.[9] Some beverages, such as soft drinks, artificial or natural fruit juices, and wines may be considered acidic since they have a pH of less than 5.[10] The low pH of these beverages can be responsible for the degradation of the artificial teeth and the acrylic base, inducing color changes, wear and surface irregularities, consequently reducing the prosthesis life.[11] The surface smoothness acts not only on the esthetic characteristics but also on the durability since the irregularities make it difficult for the cleaning procedure, promoting staining and eventually a decrease of the mechanical properties.[9] The use of potentially aggressive beverages should be identified, and the patient should be informed to avoid or reduce the frequency of their consumption, to extend the longevity of these prostheses.

Nowadays, there is the need for studies that evaluate the effect of acidic beverages on the materials used for the manufacture of complete denture prostheses. Thus, the aim of this study was to evaluate the effect of 4 commercially available acidic beverages (orange juice, red wine, coke- and lemon-based soft drink), on the alteration of the roughness and color stability of 2 commercial brands of artificial teeth and heat-polymerized acrylic resin (HPAR) for the prosthetic base. The superficial alteration was evaluated at two points: after immersion for 10 minutes daily for 14 days in acidic beverages and, after that period, after immersion in grape juice, for another 14 days. The null hypotheses were that the acidic solutions (orange juice, red wine, coke- and lemon-based soft drink) would alter the surface roughness and color stability of the denture base and the artificial teeth, and would contribute to the materials' subsequent staining, after being subjected to immersion in grape juice.

MATERIALS AND METHODS

The study was designed to evaluate the effect of acidic solutions on the alteration of roughness and color stability of materials for the fabrication of complete denture prosthesis. For this, 50 samples (n = 10) of heat-polymerized acrylic resin (HPAR) (VipiCril Plus, VIPI Produtos Odontológicos, Pirassununga, São Paulo, Brazil) were fabricated, and 100 artificial teeth (n = 10) from 2 different commercial brands (Trilux, model O32 - color: 1D and Tritone, model 3P - color: 66, Vipi, Pirassununga, São Paulo, Brazil) were used. The sample size was defined considering a 0.05 level of significance, 80% power, and a medium effect size. The results of the calculation showed that 150 samples (n = 10) were required for this study.

The 50 samples of HPAR (10 × 2.5 mm) were made according to the manufacturer's recommendations and, after polymerization, were polished in a semiautomatic universal polish machine (Arotec SA Ind. Com., Cotia, São Paulo, Brazil) with sequential metallographic sandpapers (# 400, # 600, # 800, and # 1200, Buehler, Lake Bluff, IL, USA) and finished with a felt disc and a blue colloidal silica solution (MasterMet and MicroCloth, Buehler, Lake Bluff, IL, USA). The samples were ultrasonically cleaned (Ultrasonic Cleane, Unique, Indaiatuba, SP, Brazil) for 20 minutes in distilled water, to remove possible debris on the surface of the resin.[5] No procedure on artificial teeth was performed prior to immersion in the solutions.

Samples of HPAR and the artificial teeth were divided into 5 groups, according to the used acidic beverage (Table 1). All samples from each group were immersed for 10 minutes daily for 14 days in their respective solution, simulating their ingestion.[7] During the remainder of the period, the samples were washed and kept in a bacteriological oven at 36 ± 1ºC in artificial saliva.[7] The acid solutions packages were opened daily in order not to interfere in the pH. The pH of the beverages was measured before each immersion using a bench pH meter (HANNA Instruments pH 21, São Paulo, Brazil). The pH values of the beverages are shown in Table 1.

The surface roughness (Ra) of the samples (n = 10) was measured using a rugosimeter (Surftest SJ-401, Mitutoyo

Table 1. Distribution of groups, composition, trade name/manufacturer and pH of the immersion solutions

Groups - Immersion solutions	Composition	Fabricant	pH
AS - Artificial saliva (Control)	KCl (0.4 g L^{-1}), NaCl (0.4 g L^{-1}), $CaCl_2\_2H_2O$ (0.906 g L^{-1}), $NaH_2PO_4\_2H_2O$ (0.690 g L^{-1}), $Na_2S\_9H_2O$ (0.005 g L^{-1}), and urea (1 g L^{-1})	Fórmula ativa Araçatuba/SP, Brazil	6.5
OJ - Orange juice	Water, orange juice concentrate, apple juice concentrate, vitamin C, citric acid acidulant, carboxymethylcellulose stabilizer and natural orange flavoring.	Sufresh, Wow Nutrition, Brazil	3.52
RW - Red wine	Cabernet Sauvignon e Merlot grapes, ethyl alcohol: 12.5% vol.	Salton Flowers Cabernet Sauvignon Merlot, Vinícula Salton, Bento Gonçalves/RS, Brazil	3.57
CO - Coke-based soft drink	Carbonated water, sugar, cola nut extract, yellow dye IV, acidulant INS 338, and natural flavors.	Coca-cola, Coca-Cola Brasil, Sorocaba/SP, Brazil	2.49
LE - Lemon-based soft drink	Carbonated water, lemon juice, citric acid acidulant, natural flavoring, sodium cyclamate sweeteners (72 mg) and sodium saccharin (11 mg) per 100 mL, preservatives sodium benzoate and potassium sorbate, sodium citrate stabilizer.	Sprite, Coca-Cola Brasil, Sorocaba/SP, Brazil	3.24

Corp, Kawasaki, Japan). The results were analyzed at 3 different periods (T0 - before the immersion process, T1 - after immersion in acidic solutions for 14 days, T2 - after T1, the samples were immersed in grape juice for another 14 days). In all periods, 3 readings were taken in each sample (initially being positioned on the specimen surface center, and subsequently to the right and left of the first reading). In the artificial teeth, the readings were performed transversely along the long axis of the teeth. The length of each reading was 2.4 mm, with a cut-off of 0.8 mm.[6,12] The reading speed was 0.5 mm/s.[6,12] The roughness value was obtained through the arithmetic mean and given in micrometers.[6,12]

All samples were subjected to the color stability test in the same 3 periods (T0, T1, and T2) through a visible ultraviolet reflection spectrophotometer (UV-2450, Shimadzu, Japan). The CIELab system was used for the evaluation of color stability, as established by the International Commission of I'Eclairage - CIE (International Commission on Illumination). The CIELab system calculates the color variation between 2 points using the formula: $\Delta E_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$.

The data of surface roughness (Ra) and color stability (ΔE_{ab}) were subjected to the Shapiro-Wilk method to test normality ($P > .05$) and the Levene test to confirm the variance of homogeneity for all dependent variables ($P > .05$). The analysis of variance (ANOVA) of 2 factors (period × solution) for repeated measurements in the roughness test and 1 factor (solution) for repeated measurements in the color stability test was performed. The Tukey test was used as post-hoc ($\alpha = .05$; IBM SPSS 20.0, IBM, Armonk, NY, USA).

RESULTS

The 2-ANOVA roughness analysis showed a statistically significant difference only for the period factor for HPAR ($P = .004$) and Trilux ($P = .001$). For Tritone, a significant difference for all the analyzed factors and the interaction among them was found ($P < .002$).

In Table 2, regarding HPAR, a statistical difference was observed for the AS group in the initial period ($P < .043$) compared to T1. After immersion in acid solutions (T1), the highest values of roughness were found for AS and RW groups, without statistical significance regarding the other acidic solutions. For T2, after immersion in grape juice, the highest values of roughness were found for AS and OJ groups, also without statistical significance. For Trilux teeth, the lowest values were found in the initial period, presenting statistical difference to the other periods ($P < .001$). The highest values were obtained after immersion in grape juice (T2) for all groups, regardless of the previous immersion solution. Concerning Tritone, the lowest values were found for the period after immersion in acidic solutions (T1) and the highest values were found after immersion in grape juice (T2), with OJ and RW being the highest obtained values (Table 2).

Regarding ΔE_{ab}, there was no significant difference for the solution factor for the HPAR samples in the 2 analysis periods (T1: $P = .256$ and T2: $P = .355$). In the Trilux teeth, there was a significant difference for the solution factor ($P < .001$) after immersion in the acidic solutions (T1), whereas there was no significant difference for the solution factor ($P = .446$) after immersion in the grape juice (T2). In the 1-ANOVA factor for the Tritone material, it was verified that there was no significant difference for the solution factor in the 2 analysis periods (T1: $P = .093$ and T2: $P = .324$).

In Table 3, it can be observed that there was no significant statistical difference among the groups, for both periods of analysis in the HPAR material. Regarding Trilux teeth, after immersion in acidic solutions (T1), there was difference ($P < .001$) among groups only in the RW, presenting the highest value (6.64). In the Tritone teeth, it can be verified that there was no significant statistical difference among the groups in each period, with the highest values found after immersion in acid solutions (T1) ($P < .001$).

Table 2. Mean and standard deviation of the roughness (μm) of the evaluated materials, before and after each immersion period

Group	HPAR			Trilux			Tritone		
	Initial (T0)	After acid solution (T1)	After grape juice (T2)	Initial (T0)	After acid solution (T1)	After grape juice (T2)	Initial (T0)	After acid solution (T1)	After grape juice (T2)
AS	0.04 (0.01)[Ab]	0.1 (0.07)[Aa]	0.07 (0.02)[Aab]	0.04 (0.01)[Ac]	1.75 (0.15)[Ab]	1.97 (0.16)[Aa]	1.81 (0.23)[Aa]	1.73 (0.18)[Aa]	1.97 (0.39)[Ba]
OJ	0.04 (0.01)[Aa]	0.04 (0.01)[Aa]	0.07 (0.02)[Aa]	0.04 (0.01)[Ab]	1.78 (0.2)[Aa]	1.92 (0.1)[Aa]	1.93 (0.25)[Ab]	1.69 (0.19)[Ac]	2.43 (0.55)[Aa]
RW	0.04 (0.01)[Aa]	0.07 (0.02)[Aa]	0.05 (0.01)[Aa]	0.04 (0.01)[Ab]	1.72 (0.1)[Aa]	1.83 (0.23)[Aa]	1.95 (0.32)[Ab]	1.65 (0.13)[Ac]	2.43 (0.57)[Aa]
CO	0.04 (0.01)[Aa]	0.04 (0.01)[Aa]	0.05 (0.01)[Aa]	0.04 (0.01)[Ac]	1.66 (0.16)[Ab]	1.88 (0.17)[Aa]	1.77 (0.28)[Aa]	1.63 (0.18)[Aa]	1.79 (0.1)[Ba]
LE	0.04 (0.01)[Aa]	0.05 (0.01)[Aa]	0.06 (0.01)[Aa]	0.04 (0.01)[Ac]	1.73 (0.21)[Ab]	1.96 (0.18)[Aa]	1.85 (0.16)[Aa]	1.62 (0.11)[Ab]	1.85 (0.25)[Bab]

Columns followed by the same uppercase letter (comparison between groups) and lowercase (between periods) of each material did not differ at the 5% level of significance ($P < .05$) by the Tukey test. HPAR – heat-polymerized acrylic resin, AS – artificial saliva, OJ – orange juice, RW – red wine, CO – cola-based soft drink, LE – lemon-based soft drink.

Table 3. Mean and standard deviation of the color change (ΔE_{ab}) in the evaluated materials after each immersion period

Groups	HPAR		Trilux		Tritone	
	After acid solution	After grape juice	After acid solution	After grape juice	After acid solution	After grape juice
AS	11.24 (1.20)^A	2.37 (0.53)^A	1.54 (1.09)^B	1.51 (0.44)^A	32.73 (1.12)^A	1.18 (0.34)^A
OJ	11.54 (1.86)^A	1.85 (1.02)^A	2.49 (1.5)^B	1.88 (1.26)^A	34 (1.08)^A	1.22 (0.58)^A
RW	11.28 (2.47)^A	1.74 (0.87)^A	6.64 (3.99)^A	2.07 (0.73)^A	33.27 (1.38)^A	1.58 (1.28)^A
CO	9.69 (1.89)^A	2.01 (1.09)^A	3.23 (1.04)^B	1.7 (0.58)^A	33.54 (2.02)^A	1.02 (0.30)^A
LE	10.98 (2.19)^A	1.63 (0.59)^A	1.87 (0.95)^B	1.54 (0.57)^A	34.45 (1.36)^A	1.56 (0.64)^A

Columns followed by the same uppercase letter (comparison between groups) of each material did not differ at the 5% level of significance ($P < .05$) by the Tukey test.
HPAR – heat-polymerized acrylic resin, AS – artificial saliva, OJ – orange juice, RW – red wine, CO – coke-based soft drink, LE – lemon-based soft drink.

DISCUSSION

The hypothesis that the acidic solutions would alter the surface roughness and color stability of the materials evaluated in this study was accepted for the artificial teeth and was rejected for the denture base, since no alteration in roughness was found, although there was an alteration in color stability for this material. The hypothesis that the acidic solutions would promote subsequent staining of the materials after being immersed in grape juice was also rejected, since there was no difference in the ΔE_{ab} values of the groups of acid solutions and the control group (artificial saliva).

Artificial teeth and the acrylic base of the prostheses are subject to constant exposure to food and beverages and, consequently, to the effects of their acids and pigments, as well as the action of cleaning and disinfecting products.[13] This frequent interaction compromises the properties of these materials, reflecting on esthetic damages and reduced duration.[6,7] Furthermore, the acidic environment promoted by acid food and beverages is correlated with dentin[14] and enamel[15] injury. Moreover, the degradation of restorative and prosthodontic materials has been also reported.[16-18] These factors should be carefully considered for prevention promotion, by emphasizing more about the importance of patient's dietary education.

The surface roughness is an important property to evaluate the surface integrity of the materials, determining the polishing capacity and the wear rate.[19] The roughness also influences optical properties and microbial adhesion, causing an increase of the surface area, favoring the mechanical retention of pigments and biofilm.[6,11] In the present study, roughness results after immersion in the coke-based soft drink were found statistically equal to the initial for the Tritone teeth. However, it is important to note that, in the initial period, the Tritone teeth was rougher (mean of 1.86 µm). Despite the low pH, this beverage does not seem to harm the resin surface of the Tritone teeth. As reported in other studies, the erosive potential of acidic beverages does not depend only on its pH but also on the chelation properties of the acidic beverages and the frequency and duration of its ingestion.[20]

Artificial saliva also had the potential to increase HPAR and Trilux teeth roughness. Thus, it is evident that other factors besides the pH of the solutions may interfere with the properties of the materials, like the composition, the polarity of the liquid, and the immersion time in the acidic beverages. These factors can alter the polymer solubility, promoting surface degradation.[21] These changes in the properties of the polymeric materials embedded in organic acids have been attributed to the polymer softening, caused by the diluents leaching. The softening of the resin matrix can also promote the filling particle displacement, contributing to the formation of a rough surface.[22] Thus, the roughness maintenance is important to ensure the materials' clinical longevity, being associated with extrinsic pigmentation, staining, microbial adherence, oral tissue health, and patient comfort.[11,12]

There was a color change in all analyzed materials that was considered clinically acceptable ($\Delta E_{ab} > 3.3$).[23,24] The low pH of beverages could promote changes in color, mainly in the luminosity, due to the wear and irregularities created in the artificial teeth, reducing the prosthesis's duration.[7] In this study, the acidic beverages promoted color change clinically unacceptable in the HPAR samples. This fact can be explained by the lower degree of the monomer's conversion obtained through the conventional polymerization technique, recommended by the manufacturer, and by the presence of porosities on the material surface.[25] The volatilization of the methacrylate subjected to high temperatures during the polymerization process predisposes the formation of porosities and/or irregularities on the resin's surface.[23,25] Also, PMMA in aqueous media is susceptible to the sorption of substances in the interior (absorption) and its superficial deposition (adsorption), changing its properties such as color.[26,27] The liquid absorption or adsorption by the polymers depends on their chemical composition, surface characteristics, roughness, polarity, amount of residual monomer and porosities, due to overheating or insufficient pressure during the polymerization.

For the Trilux teeth, the acidic solution that most altered the color was red wine in the initial period, whereas for the other solutions, the color change was considered clinically acceptable. According to the manufacturer, the Trilux teeth are composed of high molecular weight PMMA resin (IPN resin - Interpenetrated Polymer Network), forming a tridimensional network. With the increase in the molecular weight of linear polymer chains, the possibility of double crosslinking confers a greater number of covalent chemical bonds producing polymers with inseparable polymer chains, resulting in lower solubility and higher mechanical strength of these teeth.[11] Besides these factors, the Trilux teeth are composed of triple pressing. The application of different layers improves esthetics and allows greater color stability due to a better polymerization. The opposite was observed for Tritone teeth, where higher values of color change were found. Possibly, the composition and method of polymerization of these teeth culminated with an inferior color property when compared to the Trilux teeth, although they are manufactured by the same company.

This study has some limitations that need to be addressed, such as the inability to reproduce the clinical performance of these materials, since it is impossible to mimic all the conditions found in the clinical environment. Also, it is difficult to reproduce the interval that the beverages remain in contact with artificial teeth and acrylic resin before swallowing. Other types of analysis (i.e. hardness, sorption, solubility, flexural strength) should be performed to better justify the obtained results, in order to better understand the effects of the solutions on the surface of each material evaluated in this study. Also, the effect of oral hygiene products (toothpaste, mouthwashes) should be evaluated in future studies to attempt to reproduce the effect of the combination of an acid environment and cleaning agents on the properties of these materials.

Correlating the values of color change and roughness of the materials evaluated in this study, it was possible to observe that the acidic beverages was able to change their properties. Thus, the patient should be informed about the effects of consumption of these acidic beverages to avoid or reduce the frequency of their use, in order to ensure the clinical longevity of their prostheses.

CONCLUSION

Based on the results of this study, it can be concluded that the acidic beverages alter the roughness and color stability of the HPAR and artificial teeth after daily immersion of 10 minutes for 14 days. Grape juice altered the roughness only of the artificial teeth and promoted a clinically acceptable color change in the materials after immersion for 14 days.

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