

# Surface properties of multilayered, acrylic resin artificial teeth after immersion in staining beverages

Karin Hermana NEPELENBROEK<sup>1</sup>, Eduardo KUROISHI<sup>1</sup>, Juliana HOTTA<sup>1</sup>, Vinicius Rizzo MARQUES<sup>1</sup>, Eduardo Buozzi MOFFA<sup>2</sup>, Simone SOARES<sup>1</sup>, Vanessa Migliorini URBAN<sup>3</sup>

1- Department of Prosthodontics, Bauru School of Dentistry, University of São Paulo, Bauru, SP, Brazil.

2- Department of Pediatric Dentistry, Orthodontics and Community Health, Bauru School of Dentistry, Bauru, SP, Brazil.

3- Department of Dentistry, State University of Ponta Grossa, Ponta Grossa, PR, Brazil.

**Corresponding address:** Karin Hermana Neppelenbroek - Departamento de Prótese - Faculdade de Odontologia de Bauru - Universidade de São Paulo - Al. Octávio Pinheiro Brisola, 9-75 - Bauru - SP - 17012-901 - Brazil - Phone: +55 14 3235 8245 - Fax: +55 14 3235 8277 - e-mail: khnepp@yahoo.com.br

**Submitted: February 19, 2015 - Modification: April 8, 2015 - Accepted: April 10, 2015**

## ABSTRACT

**O**bjective: To evaluate the effect of staining beverages (coffee, orange juice, and red wine) on the Vickers hardness and surface roughness of the base (BL) and enamel (EL) layers of improved artificial teeth (Vivodent and Trilux). Material and Methods: Specimens (n=8) were stored in distilled water at 37°C for 24 h and then submitted to the tests. Afterwards, specimens were immersed in one of the staining solutions or distilled water (control) at 37°C, and the tests were also performed after 15 and 30 days of immersion. Data were analyzed using 3-way ANOVA and Tukey's test ( $\alpha=0.05$ ). Results: Vivodent teeth exhibited a continuous decrease ( $p<0.0005$ ) in hardness of both layers for up to 30 days of immersion in all solutions. For Trilux teeth, similar results were found for the EL ( $p<0.004$ ), and the BL showed a decrease in hardness after 15 days of immersion ( $p<0.01$ ). At the end of 30 days, this reduction was not observed for coffee and water ( $p>0.15$ ), but red wine and orange juice continuously reduced hardness values ( $p<0.0004$ ). Red wine caused the most significant hardness changes, followed by orange juice, coffee, and water ( $p<0.006$ ). No significant differences in roughness were observed for both layers of the teeth during the immersion period, despite the beverage ( $p>0.06$ ). Conclusions: Hardness of the two brands of acrylic teeth was reduced by all staining beverages, mainly for red wine. Roughness of both layers of the teeth was not affected by long-term immersion in the beverages.

**Keywords:** Coloring agents. Hardness. Surface properties. Artificial tooth.

## INTRODUCTION

Several brands of artificial teeth are commercially available and differ in material, like vacuum-sintered porcelain, conventional acrylic resin, and modified resin<sup>9,15</sup>. Acrylic resin artificial teeth are widely used in oral rehabilitation since they have advantages over porcelain, such as greater fracture resistance, better absorption of masticatory forces, higher flexural impact strength, and easier occlusal adjustment, and they also present higher bond strength to denture base acrylic resin<sup>9,10</sup>. However, they present low resistance to abrasion and increased susceptibility to color change and biofilm

formation<sup>5,26</sup>, which can lead to occlusal unbalance and aesthetic problems<sup>26</sup>.

With the incorporation of cross-linking agents, there has been an increase in mechanical strength and a reduction in both water sorption and solubility of acrylic teeth<sup>17</sup>. Other structural improvements were achieved with the addition of copolymers or poly (methyl methacrylate) (PMMA) with an interpenetrating polymer network (IPN) and the manufacturing process using multilayering or double cross-linked (DCL) material layering techniques. Recently, in order to increase their wear resistance, acrylic teeth were modified with sustained life material (SLM), which combines

IPN technology with ultra-high molecular weight polyethylene, a synthetic polymer based on PMMA with DCL polymer and matrix, which reportedly is solvent resistant, or even with an inorganic microparticle filler polymerized into a polymer network (MRP: microfiller-reinforced polyacrylic)<sup>6</sup>. In order to promote a natural appearance of healthy teeth, anterior teeth have been modified by layers with a pearly effect to have a blue iridescence.

Some factors, such as masticatory load, occlusal coverage of antagonist teeth, and abrasive chemicals, have been reported to explain the wear mechanism of multilayered artificial teeth<sup>5,17,26</sup>. In this context, it is important to consider that the outer/enamel layer of these teeth is more susceptible to the effects of wear, assuming that the inherent masticatory cycle and occlusal adjustment procedures can lead to the exposure of the inner/base layers<sup>15</sup>.

During clinical use, acrylic artificial teeth are exposed to saliva, beverages, and cleaning agents, and such materials are prone to the absorption and adsorption processes<sup>12,26</sup>. Moreover, it has been shown that certain foods can promote discoloration, surface degradation, and changes in other properties of the artificial teeth<sup>4,8,26</sup>.

Surface properties of the layers of acrylic resin artificial teeth, such as hardness and roughness, have not been investigated<sup>15</sup>. Also, there are no reports about the potential effects of food dyes on the surface properties of the different layers of improved acrylic artificial teeth. Vickers indentation is used for evaluating the hardness and viscoelastic responses of polymers<sup>14</sup>, and some studies have used Vickers hardness to test denture base acrylic resin<sup>13</sup> and acrylic resin denture teeth<sup>10,20</sup>. The evaluation of roughness is important to ensure the clinical longevity of acrylic teeth since this property is directly or indirectly associated with various factors, such as staining resistance, microbial adherence, health of the oral tissues, and patient comfort<sup>23</sup>.

The present study evaluated the effect of potentially staining beverages on the Vickers hardness and surface roughness of the inner and outer layers of two brands of acrylic artificial teeth. The null hypothesis was considered that the surface properties of multilayered, acrylic resin artificial teeth would not be affected by liquid foods.

## MATERIAL AND METHODS

Thirty-two modified, acrylic artificial teeth (maxillary right central incisors, color A2) of two trademarks were used: SR Vivodent PE (PMMA; Ivoclar Vivadent, Schaan, VA, Liechtenstein) and Trilux, IPN resin (PMMA/ethylene glycol dimethylacrylate; Dental Vipi Ltda., Pirassununga,

SP, Brazil). The potentially staining beverages tested were soluble coffee (Nescafé Tradição; Nestlé Brasil Ltda., Araras, SP, Brazil), orange juice (Suco Del Valle Laranja; Coca Cola Indústrias Ltda., São Paulo, SP, Brazil), red wine (Cabernet Sauvignon; Santa Helena, Helene, Vina Santa Helena, Santiago, Chile), and distilled water (control).

Artificial incisors were fixed with red wax on a glass plate (Wilson; Polidental Ind. e Com. Ltda., São Paulo, SP, Brazil) and embedded with their mesial surface upwards in transparent acrylic resin (Vipi Cril; Dental Vipi Ltda., Pirassununga, SP, Brazil) in polyvinylchloride tubes (10x17 mm). After polymerization of the acrylic resin, PVC tubes were cut in the cervical-incisal direction using a precision cutting machine (ISOMET 100 Precision Saw; Buehler Ltd., Lake Buff, IL, USA) with a double-face diamond disc (XL 12205; Extec Corp., Enfield, CT, USA) at 300 rpm with the aim of exposing both the teeth layers (base - BL and enamel - EL). The specimens were subjected to a smoothing procedure with 320-grit silicon carbide sandpaper (Norton S.A., São Paulo, SP, Brazil) coupled to a metallographic polisher (Modelo APL-2; Arotec S.A. Ind. e Com., Cotia, SP, Brazil) under water cooling. Afterwards, the embedded teeth were removed from the PVC tube and were polished using 600-, 800-, 1000-, and 1200-grit silicon carbide papers, discs, and felt wheels impregnated with polishing paste (Opal L; Renfert GmbH, Hilzingen, BE, Germany). The specimens were then stored in dark containers of distilled water at 37°C (MA 0324; Marconi Equipamentos Laboratoriais Ltda., Piracicaba, SP, Brazil) for 24 h<sup>22</sup> and subsequently subjected to initial measurements of hardness and roughness.

The exposed and polished layers (BL and EL) of the specimens were marked with a scalpel blade on their incisal, middle, and cervical thirds. For each specimen, five indentations were made at the three sections on each layer, and the mean Vickers hardness (VHN) value was then calculated. The measurements were made (Shimadzu HMV-2000; Shimadzu Corp., Kyoto, TO, Japan) at a 100-g load for 15 s, and the data were obtained by software (Cams-Win; New Age Industries, Inc., Southampton, PA, USA).

The roughness was measured (Hommel Tester Basic T 1000; Hommelwerke GmbH, Schweningem, BE, Germany) with a cutoff of 0.8 mm and speed of 0.5 mm/s, adding up to a measurement path of 2.4 mm. Three measurements of surface roughness were performed on each section of both layers, and the mean value (Ra) represented each specimen.

After the initial readings, eight samples of each brand were randomly immersed in 200 mL of the staining beverages or distilled water<sup>28</sup>. During immersion, the specimens were suspended using

a device to avoid contact with the bottom of the containers. The specimens were stored at 37°C for 30 days<sup>11,16</sup>, and to prevent precipitation of particles from the beverages, the containers were shaken once a day and the solutions replaced weekly throughout the experimental period. The coffee solution was prepared according to the manufacturer's recommendations and used immediately after cooling. The surface analyses were performed again at 15 and 30 days of immersion in the beverages. Before the tests, each specimen was washed in distilled water and dried with absorbent paper<sup>4,11,28</sup>.

Both layers' hardness and roughness values were statistically analyzed by a repeated measure 3-way ANOVA ("teeth brand," "solution," and "time") followed by Tukey's test ( $\alpha=0.05$ ) since the same specimens were analyzed before and after immersion in different beverages and also after each storage period. *Post hoc* power analysis was also performed using statistical software (SPSS 19; SPSS Inc., IBM Company, Armonk, NY, USA).

## RESULTS

For the number of specimens used ( $n=8$ ), the study was adequately powered for all factors (over 98%,  $\alpha=0.05$ ) regarding hardness and roughness analyses for both layers (BL and EL).

For each brand of artificial, acrylic teeth used, no statistically significant difference was observed

between BL and EL hardness at day 0 ( $p>0.05$ ).

Table 1 shows a significant and progressive reduction in the hardness of both layers (BL and EL) over the 30-day evaluation period after immersion in all beverages for Vivodent teeth ( $p<0.0005$ ). Similar results were found after the immersion of EL specimens from Trilux teeth in all solutions ( $p<0.004$ ). For BL specimens of Trilux teeth, there was a significant and progressive decrease during 30 days of immersion in orange juice and red wine ( $p<0.0004$ ). When teeth were immersed in soluble coffee and distilled water, the hardness of BL decreased after 15 days ( $p<0.01$ ); however, no change was observed between 15 and 30 days of evaluation ( $p>0.15$ ) (Table 1).

For Vivodent teeth in both layers (BL and EL) at days 15 and 30, the red wine was the solution that most affected the hardness ( $p=0.0001$ ), followed respectively by orange juice and coffee, which showed no difference between each other ( $p>0.3766$ ). The results also demonstrated that the immersion in distilled water resulted in the lowest changes in hardness values ( $p<0.0001$ ). At the 15-day evaluation period, the water resulted in significantly minor changes in the hardness of both layers for Trilux teeth ( $p=0.0001$ ) compared to the other tested beverages that were statistically similar ( $p>0.8570$ ). For the BL and EL of Trilux teeth, the red wine caused the significantly greatest reduction in hardness at 30 days ( $p=0.0001$ ), followed, respectively, by orange juice ( $p<0.0001$ ), soluble

**Table 1-** Vickers Hardness (VHN) means $\pm$ standard deviations for the experimental groups

Artificial Teeth	Layer	Period	Beverages			
			Coffee	Juice	Wine	Water
Vivodent	BL	0 d	18.6 $\pm$ 0.46 <sup>Aa (a)</sup>	18.4 $\pm$ 0.24 <sup>Aa (a)</sup>	18.4 $\pm$ 0.43 <sup>Aa (a)</sup>	18.17 $\pm$ 0.41 <sup>Aa (a)</sup>
		15 d	17.1 $\pm$ 0.40 <sup>Bb (b)</sup>	16.75 $\pm$ 0.23 <sup>Bb (b)</sup>	15.55 $\pm$ 0.34 <sup>Bc (c)</sup>	17.56 $\pm$ 0.15 <sup>Ba (a)</sup>
		30 d	16.1 $\pm$ 0.33 <sup>Cb (c)</sup>	16.01 $\pm$ 0.30 <sup>Cb (c)</sup>	14.32 $\pm$ 0.48 <sup>Cc (e)</sup>	17.02 $\pm$ 0.28 <sup>Ca (b)</sup>
	EL	0 d	18.60 $\pm$ 0.73 <sup>Aa (a)</sup>	18.34 $\pm$ 0.53 <sup>Aa (a)</sup>	18.38 $\pm$ 0.40 <sup>Aa (a)</sup>	18.05 $\pm$ 0.39 <sup>Aa (a)</sup>
		15 d	17.06 $\pm$ 0.39 <sup>Bb (b,c)</sup>	16.68 $\pm$ 0.25 <sup>Bb (c)</sup>	15.45 $\pm$ 0.48 <sup>Bc (d)</sup>	17.50 $\pm$ 0.33 <sup>Ba (b)</sup>
		30 d	15.77 $\pm$ 0.35 <sup>Cb (c)</sup>	15.85 $\pm$ 0.32 <sup>Cb (c)</sup>	14.18 $\pm$ 0.52 <sup>Cc (e)</sup>	16.85 $\pm$ 0.28 <sup>Ca (b)</sup>
Trilux	BL	0 d	18.03 $\pm$ 0.5 <sup>Aa (a)</sup>	17.95 $\pm$ 0.45 <sup>Aa (a)</sup>	18.31 $\pm$ 0.35 <sup>Aa (a)</sup>	18.49 $\pm$ 0.46 <sup>Aa (a)</sup>
		15 d	17.04 $\pm$ 0.2 <sup>Bb (b)</sup>	17.07 $\pm$ 0.51 <sup>Bb (b)</sup>	16.85 $\pm$ 0.26 <sup>Bb (b)</sup>	17.91 $\pm$ 0.15 <sup>Ba (a)</sup>
		30 d	16.72 $\pm$ 0.09 <sup>Bb (b)</sup>	15.82 $\pm$ 0.24 <sup>Cc (c)</sup>	14.95 $\pm$ 0.23 <sup>Cd (d)</sup>	17.71 $\pm$ 0.29 <sup>Ba (a)</sup>
	EL	0 d	18.16 $\pm$ 0.23 <sup>Aa (a)</sup>	18.36 $\pm$ 0.40 <sup>Aa (a)</sup>	18.5 $\pm$ 0.37 <sup>Aa (a)</sup>	18.70 $\pm$ 0.23 <sup>Aa (a)</sup>
		15 d	17.25 $\pm$ 0.31 <sup>Bb (b)</sup>	17.28 $\pm$ 0.26 <sup>Bb (b)</sup>	17.2 $\pm$ 0.48 <sup>Bb (b,c)</sup>	18.15 $\pm$ 0.26 <sup>Ba (a)</sup>
		30 d	16.85 $\pm$ 0.34 <sup>Cb (b)</sup>	16.05 $\pm$ 0.19 <sup>Cc (c)</sup>	15.19 $\pm$ 0.34 <sup>Cd (d)</sup>	17.63 $\pm$ 0.29 <sup>Ca (a)</sup>

Vertically, for each layer of each artificial teeth, different uppercase letters indicate significant differences between the periods for the same solution ( $p<0.05$ ). Horizontally, for each layer of each artificial teeth, different lowercase letters indicate significant differences among solutions within the same period ( $p<0.05$ ). For each layer, different superscript letters in parenthesis indicate significant differences between teeth brands for the different solutions within the same period ( $p<0.05$ ).

coffee ( $p < 0.0005$ ), and distilled water ( $p < 0.0008$ ).

Table 1 shows that, for the BL, no significant difference was observed between the hardness of Vivodent and Trilux teeth prior to immersion (day 0) in beverages ( $p > 0.06$ ). The same result was observed in the teeth brands for the EL hardness at day 0 in all experimental groups ( $p > 0.2457$ ) (Table 1). At day 15, the red wine statistically resulted in major changes in the mean hardness of the BL experimental groups ( $p = 0.0001$ ), followed by Vivodent in juice, Trilux in wine, Trilux in coffee, Vivodent in coffee, and Trilux in juice, which showed no significant difference between each other ( $p > 0.4609$ ). The lowest changes in average BL hardness values for both teeth brands were observed with the immersion in water at the 15-day evaluation period ( $p = 0.0001$ ). At day 15, Vivodent teeth immersed in wine demonstrated the lowest hardness mean values of the EL experimental groups ( $p = 0.0001$ ), followed by Vivodent in juice, Vivodent in coffee, and Trilux in wine, which showed no significant difference between each other ( $p > 0.3766$ ). The EL hardness of Vivodent teeth in coffee and Trilux in wine was also not significantly different from that of Trilux in coffee, Trilux in juice, and Vivodent in water at day 15 ( $p > 0.3766$ ). In this period, the lowest changes in average EL hardness values for both teeth were observed for Trilux immersed in water ( $p = 0.0001$ ). Vivodent teeth immersed in wine demonstrated at day 30 the lowest hardness mean values of EL and

BL experimental groups ( $p = 0.0001$ ), followed by Trilux immersed in wine ( $p < 0.0269$ ) and Vivodent in coffee, Vivodent in juice, and Trilux in juice, which were statistically similar ( $p > 0.7378$ ). In sequence, significant minor changes in the EL and BL hardness were observed for specimens of Vivodent immersed in distilled water and those of Trilux immersed in coffee ( $p = 0.0001$ ), which had no difference between them at the 30-day evaluation period ( $p = 1.0000$ ). The hardness of Trilux teeth specimens immersed in distilled water demonstrated the highest hardness mean values between the EL and BL experimental groups ( $p = 0.0001$ ) (Table 1).

For each brand of artificial acrylic teeth, no significant differences were observed between the BL and EL roughness at day 0 ( $p > 0.05$ ).

Table 2 displays that immersion in different solutions did not significantly affect the EL ( $p > 0.0618$ ) and BL ( $p > 0.0759$ ) roughness for the two brands of teeth over the 30-day evaluation period. For each immersion period, no significant differences were observed between the roughness mean values of the tested solutions in BL ( $p > 0.1544$ ) and EL for both teeth ( $p > 0.4288$ ).

For Vivodent teeth, no significant difference was observed between the initial BL and EL roughness prior to immersion (day 0) in all tested beverages ( $p > 0.05$ ). Similar results were found for both layers of Trilux teeth before the immersion (day 0) in all solutions ( $p > 0.06$ ) (Table 2).

The average BL roughness of Trilux teeth was

**Table 2-** Surface roughness ( $\mu\text{m}$ ) $\pm$ standard deviations for the experimental groups

Artificial Teeth	Layer	Period	Beverages			
			Coffee	Juice	Wine	Water
Vivodent	BL	0 d	0.021 $\pm$ 0.005 <sup>Aa (b)</sup>	0.022 $\pm$ 0.006 <sup>Aa (b)</sup>	0.018 $\pm$ 0.002 <sup>Aa (b)</sup>	0.017 $\pm$ 0.002 <sup>Aa (a)</sup>
		15 d	0.018 $\pm$ 0.002 <sup>Aa (b)</sup>	0.018 $\pm$ 0.002 <sup>Aa (b)</sup>	0.017 $\pm$ 0.003 <sup>Aa (b)</sup>	0.017 $\pm$ 0.003 <sup>Aa (a)</sup>
		30 d	0.019 $\pm$ 0.002 <sup>Aa (b)</sup>	0.018 $\pm$ 0.002 <sup>Aa (b)</sup>	0.019 $\pm$ 0.002 <sup>Aa (b)</sup>	0.017 $\pm$ 0.002 <sup>Aa (a)</sup>
	EL	0 d	0.024 $\pm$ 0.009 <sup>Aa (b)</sup>	0.021 $\pm$ 0.004 <sup>Aa (b)</sup>	0.018 $\pm$ 0.003 <sup>Aa (b)</sup>	0.018 $\pm$ 0.002 <sup>Aa (b)</sup>
		15 d	0.021 $\pm$ 0.006 <sup>Aa (b)</sup>	0.019 $\pm$ 0.003 <sup>Aa (b)</sup>	0.018 $\pm$ 0.002 <sup>Aa (b)</sup>	0.019 $\pm$ 0.004 <sup>Aa (b)</sup>
		30 d	0.022 $\pm$ 0.006 <sup>Aa (b)</sup>	0.022 $\pm$ 0.004 <sup>Aa (b)</sup>	0.018 $\pm$ 0.003 <sup>Aa (b)</sup>	0.020 $\pm$ 0.003 <sup>Aa (b)</sup>
Trilux	BL	0 d	0.033 $\pm$ 0.008 <sup>Aa (a)</sup>	0.038 $\pm$ 0.010 <sup>Aa (a)</sup>	0.036 $\pm$ 0.007 <sup>Aa (a)</sup>	0.037 $\pm$ 0.006 <sup>Aa (a)</sup>
		15 d	0.035 $\pm$ 0.006 <sup>Aa (a)</sup>	0.041 $\pm$ 0.009 <sup>Aa (a)</sup>	0.036 $\pm$ 0.006 <sup>Aa (a)</sup>	0.032 $\pm$ 0.007 <sup>Aa (a)</sup>
		30 d	0.034 $\pm$ 0.008 <sup>Aa (a)</sup>	0.042 $\pm$ 0.011 <sup>Aa (a)</sup>	0.039 $\pm$ 0.008 <sup>Aa (a)</sup>	0.037 $\pm$ 0.007 <sup>Aa (a)</sup>
	EL	0 d	0.032 $\pm$ 0.010 <sup>Aa (a)</sup>	0.033 $\pm$ 0.007 <sup>Aa (a)</sup>	0.031 $\pm$ 0.008 <sup>Aa (a)</sup>	0.031 $\pm$ 0.005 <sup>Aa (a)</sup>
		15 d	0.034 $\pm$ 0.006 <sup>Aa (a)</sup>	0.037 $\pm$ 0.005 <sup>Aa (a)</sup>	0.036 $\pm$ 0.006 <sup>Aa (a)</sup>	0.033 $\pm$ 0.004 <sup>Aa (a)</sup>
		30 d	0.032 $\pm$ 0.007 <sup>Aa (a)</sup>	0.036 $\pm$ 0.009 <sup>Aa (a)</sup>	0.035 $\pm$ 0.007 <sup>Aa (a)</sup>	0.034 $\pm$ 0.006 <sup>Aa (a)</sup>

Vertically, for each layer of each artificial teeth, different uppercase letters indicate significant differences between the periods for the same solution ( $p < 0.05$ ). Horizontally, for each layer of each artificial teeth, different lowercase letters indicate significant differences among solutions within the same period ( $p < 0.05$ ). For each layer, different superscript letters in parenthesis indicate significant differences between teeth brands for the different solutions within the same period ( $p < 0.05$ ).

significantly higher than that of Vivodent teeth, regardless of the test solution and the time period evaluated ( $p < 0.0000$ ). Similarly to BL, the mean roughness values for the EL of Trilux teeth (Table 2) were significantly higher than those of Vivodent teeth for all tested beverages and time points evaluated ( $p < 0.0000$ ).

## DISCUSSION

This study evaluated the effects of staining beverages on the surface properties of different layers of two acrylic resin artificial teeth. The null hypothesis was partially accepted, given that beverages affected the hardness but did not interfere with the roughness of both types of multilayered artificial teeth.

According to the manufacturer, Vivodent teeth are composed of cross-linked PMMA chains with high molecular weight. Nevertheless, a significant and progressive reduction in hardness of both layers was observed after storing in all solutions, including water. The average hardness ranged from 18.60 VHN (day 0) to 14.18 VHN (day 30) (Table 1), with an average reduction of 24%.

According to the manufacturer, Trilux teeth are composed of cross-linked PMMA chains with high molecular weight, which are crossed within another three-dimensional network occupied by a second cross-linked polymer (IPN resin). Along with the increase in the molecular weight of linear polymeric chains, the possibility of double cross-linking (DCL), meaning the highest amount of cross-linking within the material and not the exact number or types of covalent chemical bonds present in the polymer network, proportionally grows. The two systems (DCL and IPN) coexist in these teeth, producing polymers with individual and inseparable polymeric chains, which may result in lower solubility and greater mechanical strength to these materials<sup>17</sup>. However, in this study, the hardness values of both layers of Trilux were decreased within 30 days of immersion in all solutions, with the exception of coffee and water, in which the hardness of BL remained constant after 15 days until the end of the experiment. The average hardness ranged from 18.70 VHN (day 0) to 14.95 VHN (day 30) (Table 1), with an average reduction of 20%, similar to that observed for Vivodent.

Although the distilled water caused the least change in the hardness of the layers of both teeth, it progressively decreased the mean values throughout the immersion time. These results are in agreement with those obtained by Pavarina, et al.<sup>20</sup> (2003) and Campanha, et al.<sup>3</sup> (2005). It is known that acrylic polymers absorb water<sup>1</sup>, which acts as a plasticizer, reducing the hardness by the formation of microcracks, resulting from the

absorption/adsorption process and by hydrolysis of ester bonds and gradual deterioration of its structure over time<sup>30</sup>. According to Braden<sup>1</sup> (1964), the absorption/adsorption of water by the polymers is governed by the diffusion coefficient and balance of concentration. The absorbed water can be found in two ways: "free," meaning it occupies free volume between the polymer chains or pores created during the polymerization, or "bound," attached to the polymer chain by hydrogen bonds, leading to the formation of primary and secondary hydration capsules around hydrophilic ionic terminations of the matrix resin<sup>30</sup>. The plasticizing effect and hydrolytic degradation could explain the reduction in hardness of the acrylic teeth after immersion in water observed in the present study.

The tested staining beverages caused further reduction in the hardness of both layers of the two acrylic artificial teeth. This suggests that in addition to the plasticizing effect of these aqueous solutions, other effects might be related to the greater reduction in hardness of the teeth. Both factors, the solution and material itself, can influence the absorption/adsorption process. It is known that the composition, pH, and polarity of the liquid, as well as the immersion time, are factors that can change the polymer solubility and cause surface degradation<sup>18</sup>. In this study, we used beverages with natural dyes: the coffee had caramel coloring, orange juice contained annatto, and the red wine contained anthocyanin from grapes. The presence of these dyes probably had an additional effect on the hardness of artificial teeth in comparison to water.

For both layers of the evaluated teeth, red wine caused the highest reduction in hardness values over 30 days of immersion. There are no reports available in the literature that evaluated the effect of the staining beverages tested in the present study on the hardness of artificial teeth. Thus, only indirect comparisons can be established. Satoh, et al.<sup>26</sup> (1993) demonstrated that artificial teeth with higher hardness (containing cross-linking agents) showed lower susceptibility to staining (red wine, coffee, and turmeric) than conventional acrylic resin teeth. It has been demonstrated that wine was the solution that promoted the greatest color change in resins when compared to other solutions, such as coffee, tea, and cola<sup>7,18,19,27</sup>. The polymer's surfaces are susceptible to alcohol degradation by softening<sup>19</sup> after prolonged immersion<sup>18</sup>. In addition, food liquids with acidic pH can damage the surface integrity of the material<sup>8</sup>. Red wine has a low pH (around 3.5), which may potentiate the effect of alcohol on the degradation of the polymer surface<sup>19,27</sup>. This can explain the major variation in the hardness of acrylic teeth immersed in wine compared to the other solutions. The decrease in hardness after the immersion of specimens in

orange juice can also be associated with its low pH, and the reduction was lower than after immersion in wine, probably because of its alcohol content.

According to Ruyter, et al.<sup>25</sup> (1987), the degree of polarity of a pigment agent determines the degree of penetration into the polymer. Less polar dyes, such as yellow presented in coffee<sup>29</sup>, can be absorbed more easily<sup>25</sup>. In this study, the hardness change caused by coffee was similar to that observed for juice and intermediate between water and wine. Other authors observed significant color change in acrylic resins<sup>2</sup> and acrylic artificial teeth<sup>16</sup> after prolonged immersion in coffee. The tannic acid presented in solutions like tea and coffee can also promote deleterious effects on the polymer surface<sup>2,7</sup>. Thus, the hardness reduction of the acrylic teeth after immersion in coffee can be attributed to the low polarity of the solution, its high affinity to the polymer, and the presence of yellow dye and tannic acid in its composition.

According to Guler, et al.<sup>7</sup> (2005), 24 h of immersion in coffee represents 30 days of daily consumption of this beverage. Thus, a 30-day immersion period would correspond to 2.5 years of coffee consumption. Using this average calculation and based on previous data about color stability of polymers<sup>4,11,16</sup>, a 30-day period of immersion was used in the present study. This period interfered with the results since, in general, the hardness of artificial teeth was gradually reduced. However, the initial average hardness of artificial teeth and the percentage of reduction after immersion in the beverages are comparable to those observed by Pavarina, et al.<sup>20</sup> (2003) after chemical disinfection and by Campanha, et al.<sup>3</sup> (2005) after microwave irradiation. Further studies should be conducted to assess whether this reduction is clinically relevant.

Loyaga-Rendon, et al.<sup>15</sup> (2007) showed that the Vickers hardness of the inner layers of reinforced artificial teeth of certain commercial brands was significantly lower than that of the outer layer, with a difference of up to 29.2 VHN between them. Conversely, in this research, it was not observed. This suggests that the surface properties of the evaluated teeth can be maintained if their internal layers are exposed by wear. However, to confirm this hypothesis, *in vitro* studies using dynamic wear tests and *in vivo* clinical studies are necessary.

The rougher the acrylic resin artificial tooth, the greater the possibility of accumulation of plaque, which leads to loss of brightness and surface degradation of the polymer<sup>24</sup>. Therefore, it is essential to polish the outer surface of the dentures and artificial teeth carefully after adjustment procedures. There are also no studies available in the literature that evaluated the effect of immersion in beverages on the roughness of acrylic teeth. Pisani, et al.<sup>21</sup> (2012) found that the roughness of

three different brands of acrylic denture teeth was increased after prolonged immersion in 2% *Ricinus communis* and reduced after immersion in distilled water and sodium hypochlorite. Conversely, in the present study, the surface roughness of the tested acrylic teeth was not changed after immersion in beverages, regardless of the assessed layer. These differences may be attributed to the different immersion solutions used in this study (staining beverages) and in the study of Pisani, et al.<sup>21</sup> (2012) (denture cleansers).

The present study suggests that commonly consumed staining beverages can decrease the hardness of improved acrylic artificial teeth without compromising their roughness. However, these results should be interpreted with caution since the artificial teeth can undergo other influences not assessed by the *in vitro* methodology used in this research. In clinical situations, dynamic conditions such as saliva, cleaning procedures, food consistency and feeding behavior, frequency of intake of staining and/or acidic foods, parafunctional habits, type of artificial teeth, antagonist teeth, and occlusal condition affect the surface properties of artificial teeth.

## CONCLUSION

Within the methodological limitations of this *in vitro* study and according to the results obtained, it was concluded that:

(1) Both layers of Vivodent teeth and the outer layer of Trilux teeth exhibited a continuous decrease in hardness for up to 30 days of immersion in all tested beverages. This was also observed for the inner layer of Trilux teeth after 15 days of immersion in the solutions.

(2) For both brands of multilayered, acrylic resin artificial teeth and on both layers, the red wine was the solution that caused the greatest reduction in Vickers hardness, followed by orange juice, coffee, and water.

(3) The roughness of the inner and outer layers of the two brands of acrylic teeth was not significantly affected by the tested beverages up to 30 days.

(4) For each brand of artificial teeth, no significant difference in Vickers hardness and roughness mean values was observed between the inner and outer layers prior to immersion in the staining beverages.

## ACKNOWLEDGEMENTS

This study was supported by FAPESP - São Paulo Research Foundation (grants 2009/02075-2 and 2010/07788-4). The authors wish to thank Dental Vipi and Ivoclar Vivadent for kindly providing the artificial teeth used in this study.

## REFERENCES

- 1- Braden M. The absorption of water by acrylic resins and other materials. *J Prosthet Dent*. 1964;14:307-16.
- 2- Buyukyilmaz S, Ruyter IE. Color stability of denture base polymers. *Int J Prosthodont*. 1994;7:372-82.
- 3- Campanha NH, Pavarina AC, Vergani CE, Machado AL. Effect of microwave sterilization and water storage on the Vickers hardness of acrylic resin denture teeth. *J Prosthet Dent*. 2005;93:483-7.
- 4- Ghahramanloo A, Madani AS, Sohrabi K, Sabzevari S. An evaluation of color stability of reinforced composite resin compared with dental porcelain in commonly consumed beverages. *J Calif Dent Assoc*. 2008;36:673-80.
- 5- Ghazal M, Albashaireh ZS, Kern M. Wear resistance of nanofilled composite resin and feldspathic ceramic artificial teeth. *J Prosthet Dent*. 2008;100:441-8.
- 6- Gregorius WC, Kattadiyil MT, Goodacre CJ, Roggenkamp CL, Powers JM, Paravina RD. Effects of ageing and staining on color of acrylic resin denture teeth. *J Dent*. 2012;40:e47-54.
- 7- Guler AU, Yilmaz F, Kulunk T, Guler E, Kurt S. Effects of different drinks on stainability of resin composite provisional restorative materials. *J Prosthet Dent*. 2005;94:118-24.
- 8- Gupta R, Parkash H, Shah N, Jam V. A spectrophotometric evaluation of color changes of various tooth colored veneering materials after exposure to commonly consumed beverages. *J Indian Prosthodont Soc*. 2005;5:72.
- 9- Hirano S, May KB, Wagner WC, Hacker CH. *In vitro* wear of resin denture teeth. *J Prosthet Dent*. 1998;79:152-5.
- 10- Kawano F, Ohguri T, Ichikawa T, Mizuno I, Hasegawa A. Shock absorbability and hardness of commercially available denture teeth. *Int J Prosthodont*. 2002;15:243-7.
- 11- Koksai T, Dikbas I. Color stability of different denture teeth materials against various staining agents. *Dent Mater J*. 2008;27:139-44.
- 12- Kurtulmus-Yilmaz S, Deniz ST. Evaluation of staining susceptibility of resin artificial teeth and stain removal efficacy of denture cleansers. *Acta Odontol Scand*. 2014;72:811-8.
- 13- Lai CP, Tsai MH, Chen M, Chang HS, Tay HH. Morphology and properties of denture acrylic resins cured by microwave energy and conventional water bath. *Dent Mater*. 2004;20:133-41.
- 14- Low I. Effects of load and time on the hardness of a viscoelastic polymer. *Mater Res Bull*. 1998;33:1753-8.
- 15- Loyaga-Rendon PG, Takahashi H, Hayakawa I, Iwasaki N. Compositional characteristics and hardness of acrylic and composite resin artificial teeth. *J Prosthet Dent*. 2007;98:141-9.
- 16- Mutlu-Sagesen L, Ergün G, Ozkan Y, Bek B. Color stability of different denture teeth materials: an *in vitro* study. *J Oral Sci*. 2001;43:193-205.
- 17- Ogle RE, David LJ, Ortman HR. Clinical wear study of a new tooth material: Part II. *J Prosthet Dent*. 1985;54:67-75.
- 18- Omata Y, Uno S, Nakaoki Y, Tanaka T, Sano H, Yoshida S, et al. Staining of hybrid composites with coffee, oolong tea, or red wine. *Dent Mater J*. 2006;25:125-31.
- 19- Patel SB, Gordan VV, Barrett AA, Shen C. The effect of surface finishing and storage solutions on the color stability of resin-based composites. *J Am Dent Assoc*. 2004;135:587-94.
- 20- Pavarina AC, Vergani CE, Machado AL, Giampaolo ET, Teraoka MT. The effect of disinfectant solutions on the hardness of acrylic resin denture teeth. *J Oral Rehabil*. 2003;30:749-52.
- 21- Pisani MX, Macedo AP, Paranhos HF, Silva CH. Effect of experimental *Ricinus communis* solution for denture cleaning on the properties of acrylic resin teeth. *Braz Dent J*. 2012;23:15-21.
- 22- Polyzois GL, Yannikakis SA, Zissis AJ, Demetriou PP. Color changes of denture base materials after disinfection and sterilization immersion. *Int J Prosthodont*. 1997;10:83-9.
- 23- Quiryneen M, Bollen CM. The influence of surface roughness and surface-free energy on supra- and subgingival plaque formation in man. A review of the literature. *J Clin Periodontol*. 1995;22:1-14.
- 24- Rahal JS, Mesquita MF, Henriques GE, Nóbilo MA. Surface roughness of acrylic resins submitted to mechanical and chemical polishing. *J Oral Rehabil*. 2004;31:1075-9.
- 25- Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. *Dent Mater*. 1987;3:246-51.
- 26- Satoh Y, Nagai E, Azaki M, Morikawa M, Ohyama T, Toyoma H, et al. Study on high-strength plastic teeth. Tooth discoloration. *J Nihon Univ Sch Dent*. 1993;35:192-9.
- 27- Sepúlveda-Navarro WF, Arana-Correa BE, Borges CP, Jorge JH, Urban VM, Campanha NH. Color stability of resins and nylon as denture base material in beverages. *J Prosthodont*. 2011;20:632-8.
- 28- Topcu FT, Sahinkesen G, Yamanel K, Erdemir U, Oktay EA, Ersahan S. Influence of different drinks on the colour stability of dental resin composites. *Eur J Dent*. 2009;3:50-6.
- 29- Um CM, Ruyter IE. Staining of resin-based veneering materials with coffee and tea. *Quintessence Int*. 1991;22:377-86.
- 30- Yiu CK, King NM, Pashley DH, Suh BI, Carvalho RM, Carrilho MR, et al. Effect of resin hydrophilicity and water storage on resin strength. *Biomaterials*. 2004;25:5789-96.