Submitted: 27 July, 2022 Accepted: 29 September, 2022 Published: 03 January, 2023 DOI:10.22514/jocpd.2022.031

Journal of Clinical Pediatric Dentistry

ORIGINAL RESEARCH

Effect of some industrialized acidic beverages on the roughness of pit and fissure sealants: an *in vitro* study

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Abstract

This study evaluated *in vitro* the roughness of the pit and fissure sealants (PFS) after immersion in some industrialized acidic beverages. 120 discs (5 mm diameter and 2 mm thick) of 4 commercial brands (3M, Ivoclar, Ultradent, and VOCO) were immersed in 1.5 mL of 3 different industrialized acid beverages (soft drink, apple juice, and fermented milk) and incubated at 37 ºC for 15 and 30 days. Surface roughness (Ra and Rz) was measured at the beginning (0), 15 (1), and 30 days (2) after immersion, using a profilometer, under the standard ISO 4287-1997. Data were analyzed with one-way analysis of variance (One-way ANOVA) and repeated measures analysis of variance (Repeated measures ANOVA) test ($p < 0.05$). Ultradent and VOCO had the higher baseline surface roughness values, while 3M presented the lower baseline values ($p >$ 0.05). After 15 and 30 days of immersion, the 3M group still showed the minimum values of surface roughness ($p < 0.05$). In addition, the maximum roughness values were seen in group UC (Ultradent/Coca-Cola) ($p < 0.05$). The surface roughness of the PFS increased according to the period of immersion in some industrialized acidic beverages. This increase was specific to each commercial brand. Therefore, the 3M PFS presented the best performance before and after immersion in the beverages.

Keywords

Pit and fissure sealants; Industrialized acidic beverages; Surface roughness; Dental materials

1. Introduction

Untreated caries represents a significant public health challenge worldwide. It is the most prevalent condition in permanent teeth, affecting 2.4 billion people (35%), and the tenth one in primary teeth, affecting 621 million children (9%) [1]. The most significant risk areas of dental caries are the pits and fissures. These areas have a complex morphology that complicates dental hygiene and enhances biofilm accumulation [2].

The World Health Organization establishes that dental caries can be prevented by avoiding the intake of free sugars in the diet and carrying out preventive interventions [3]. In this sense, sealing pits and fissures of primary and permanent teeth has been considered an effective method for preventing and arresting caries [4], by forming a physical barrier in those deep zones [2]. Additionally, the American Academy of Pediatric Dentistry points out that this procedure can be part of a comprehensive approach to managing dental caries [5].

In 1955, Buonocore introduced the acid-etch technique, which led ten years later to the introduction of pit and fissure sealants, developed by Cueto and Buonocore, for preventive purposes [6]. Since then, PFS have evolved from self-curing to light-curing; from unfilled to filled, with or without color or fluoride-releasing [7]. Furthermore, resin-based PFS are classified into four generations according to their content and polymerization method. First-generation sealants are cyanoacrylates activated by a 365 nm ultraviolet light source. Second-generation resin sealants are composed of bisphenol A-glycidyl methacrylate (Bis-GMA) or urethane dimethacrylate-based products. Third-generation sealants contain a di-ketone initiator and a reducing agent to initiate polymerization and are visible light-activated. Fourth-generation sealants have fluoride-releasing resin-based products [2].

Some characteristics of the PFS, such as the surface texture, are critical for their clinical success. However, the PFS surface roughness is unknown since the manufacturer does not describe it. Nevertheless, its analysis, coupled with the study of other physical-mechanical properties, would allow a more appropriate selection of these materials for clinical use.

On the other hand, some properties of dental materials are influenced by the oral environment since, like the teeth, they are subject to physical stresses, temperature, or pH changes. Those variations result from food and beverage consumption, among other conditions, and cause alterations to the material's surface and may not contribute to its clinical success over time

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[8].

In recent decades the consumption of industrialized fruit juices, soft, sports, and energy drinks has increased worldwide [9]. This is a consequence of lifestyle changes, especially for children with primary and permanent teeth. Furthermore, these drinks have an acidic pH and a cariogenic content of sugars [10, 11], which is detrimental to oral health and affects both the teeth and dental materials used for preventive or restorative purposes.

In Preventive Dentistry, studying the effects of the consumption of different beverages on the roughness of the PFS is essential since a roughness increase could lead to early degradation of the restoration and subsequent clinical failure [12] and compromise the effectiveness of the PFS. However, in the current literature, there is scarce research regarding the effect of industrialized acidic beverages on PFS roughness. For this reason, the results of this work could contribute to the enrichment of the literature that allows better clinical decisions with a preventive approach.

Therefore, the present work evaluated *in vitro* the roughness of PFS before and after their exposure to some industrialized acidic beverages (soft drinks, fruit juice, and fermented milk). We hypothesize (H_0) that the surface roughness of PFS at each experimental stage was comparable between all brands. We tested H_0 against the alternative hypothesis (H_a) for a difference.

2. Materials and Method

2.1 Materials selection

PFS from the following four commercial brands were selected for evaluation: 3M ESPE (Clinpro^{TM}; 3M ESPE, Saint Paul, MN, USA), Ivoclar Vivadent (Helioseal F Plus; Ivoclar Vivadent, Schaan, Liechtenstein), Ultradent Products (Ultra-Seal XT^{TM} Hydro^{TM}; Ultradent Products, South Jordan, UT, USA) and VOCO (Grandio® Seal; VOCO, Cuxhaven, Germany). The materials' characteristics and composition are shown in Table 1. Additionally, an overall diagram of the experimental methods and their sequence is provided in Fig. 1.

2.2 Specimen preparation

Specimens of each material were prepared using a 5 mm diameter and 2 mm thick teflon mold [13], according to the manufacturer's instructions. The mold was filled with the PFS material without overflowing and was covered with a glass slide applying a slight hand pressure to extrude excess material. Then, it was photopolymerized for 20 s using a LED curing unit (Elipar™ DeepCure-L, 3M, Saint Paul, MN, USA) at a light intensity of 1470 mW/cm^2 with the light guide tip in direct contact with the upper glass slide. The light intensity of the LED curing unit was checked every eight samples with the light intensity meter included in the lamp's base. Each specimen was removed from the mold, and the irregularities from the periphery were lapped with abrasive strips (1000-grit; Sof-Lex™ Finishing Strips, 3M ESPE, Saint Paul, MN, USA). The specimen was placed in a labeled 2 mL plastic tube (Eppendorf® Safe-lock microcentrifuge tubes; Merck, Darmstadt, Germany) with 1.5 mL deionized water. It was stored at 37 °C for 24 h to complete the polymerization. Finally, samples were rinsed and dried with compressed air for 10 s. (Fig. 2)

2.3 Experimental groups

A total of one hundred and twenty discs comprised the sample. Thirty discs were assigned to a group for each PFS commercial brand. Groups were further randomly allocated into three subgroups (n = 10) according to the different industrialized acid beverages used for immersion (soft drink, apple juice, and fermented milk), as described in Tables 2 and 3.

2.4 Immersion in acidic drinks

The specimens were placed into labeled Eppendorf tubes containing 1.5 mL of the different industrialized acid beverages and stored in the incubator at 37 °C for fifteen and thirty days [14]. A digital pH meter (PH140, Conductronic, Puebla, Mexico) was used to measure the pH of each experimental drink. The vials were sealed to prevent evaporation, and the beverage content was renewed every 24 h to avoid fungal contamination.

2.5 Surfaces roughness analysis

The surface roughness (SR) of each sample was assessed with a profilometer (Surftest SJ-301, Mitutoyo, Tokyo, Japan) during three stages: at baseline ($Roughness_0$) and subsequently, after 15 days ($Roughness_1$) and 30 days ($Roughness_2$) of immersion in acidic industrialized beverages.

Before the evaluation, samples were rinsed with tap water and dried with compressed air for 10 s. The same operator carried the measurements perpendicularly to the disc surface. The stylus was placed in a horizontal direction, over three consecutive cycles, with the 2 μm radius diamond tip and a cut-off value of 0.08 mm (λc), a length of 0.5 mm, a velocity of 0.25 mm/s, and a Gaussian Filter. The following roughness parameters were assessed: Ra (the average distance from the profile to the mean line over the length of assessment) and Rz (the peak-to-valley values of five equal measures within the profile) under ISO 4287-1997 [15]. Finally, the average values were calculated for each sample, and then by group.

2.6 Statistical analysis

The results were statistically analyzed using a software package (SPSS. 25.0; IBM, Armonk NY, USA). The data distribution was evaluated by the Shapiro-Wilk test. Differences between materials' roughness were assessed using the One-way ANOVA test. To compare the surface roughness changes through the three experimental stages, a Repeated measures ANOVA test was performed. Tamhane's T2 post hoc test was employed when differences were found because Levene's test of homogeneity of variances showed unequal variances. Differences in the significance level were established, starting at a p-value of < 0.05.

120 discs (5 mm diameter and 2 mm thick) of pit and fissure sealants

3M	**I**	**U**	**V**
n = 30	n = 30	n = 30	n = 30
Cola n = 10	Cola n = 10	Cola n = 10	Cola n = 10
Apple Juice n = 10	Apple Juice n = 10	Apple Juice n = 10	Apple Juice n = 10
Fermented milk n = 10	Fermented milk n = 10	Fermented milk n = 10	Fermented milk n = 10

Roughness 0
n = 120 (n = 30 p/g)

Immersion in industrialized acidic beverages (15 days)

Roughness 1
n = 120 (n = 30 p/g)

Immersion in industrialized acidic beverages (30 days)

Roughness 2
n = 120 (n = 30 p/g)

FIGURE 1. Experimental design diagram.

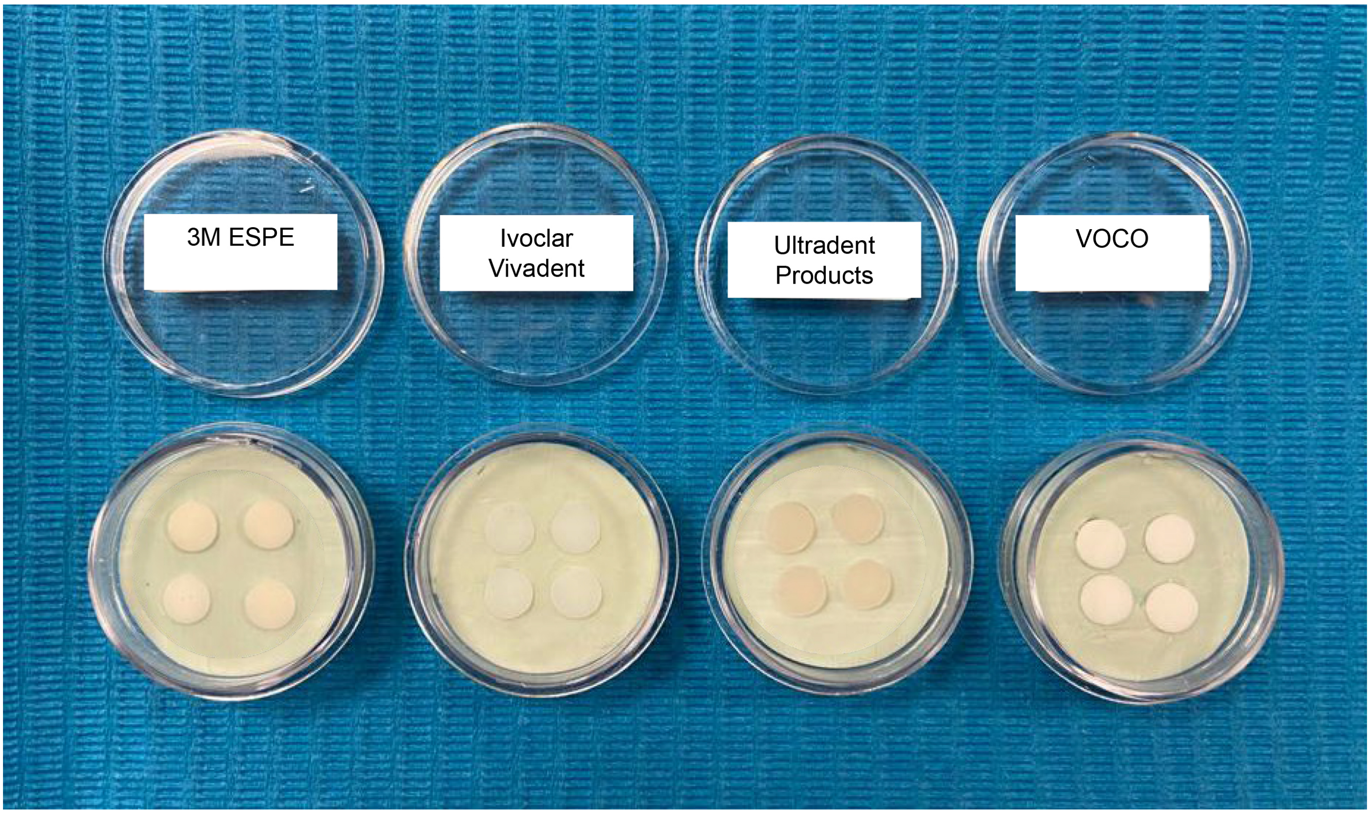

FIGURE 2. Disks of PFS.

TABLE 1. Characteristics and composition of the PFS.

Materials	Manufacturer	Organic matrix	Filler load %
Clinpro^{TM}	3M ESPE, Saint Paul, MN, USA	Bis-GMA, TEGDMA	0.0%
Helioseal F Plus	Ivoclar Vivadent, Schaan, Liechtenstein	UDMA, 2-Methacryloyloxy-ethyl phosphate	40.5%
UltraSeal XT^{TM} Hydro^{TM}	Ultradent Products, South Jordan, UT, USA	TEGDMA, DUDMA	53.0%
Grandio® Seal	VOCO, Cuxhaven, Germany	Bis-GMA, TEGDMA	70.0%

Abbreviations: Bis-GMA: bisphenol A-glycidyl methacrylate; TEGDMA: Triethylene glycol dimethacrylate; UDMA: Urethane dimethacrylate; DUDMA: Diurethane dimethacrylate.

TABLE 2. Study groups Immersion in acidic drinks.

Industrialized acid beverages	3M n = 30	Ivoclar n = 30	Ultradent n = 30	VOCO n = 30
Cola n = 10	3MC	IC	UC	VC
Apple juice n = 10	3MJ	IJ	UJ	VJ
Fermented milk n = 10	3MY	IY	UY	VY

Abbreviations: 3MC: 3M-Cola; 3MJ: 3M-Apple juice; 3MY: 3M-Fermented milk; IC: Ivoclar-Cola; IJ: Ivoclar-Apple juice; IY: Ivoclar-Fermented milk; UC: Ultradent-Cola; UJ: Ultradent-Apple juice; UY: Ultradent-Fermented milk; VC: VOCO-Cola; VJ: VOCO-Apple juice; VY: VOCO-Fermented milk.

TABLE 3. Composition of industrialized acid beverages used.

Tested agents (brand name/producer)	Composition	pH of beverages
Coca-Cola (The Coca-Cola, Atlanta, GA, USA)	Water, sugar, carbonic acid, color e150d, acidifier phosphoric acid, natural flavor, aroma caffeine	2.59
Apple juice (Grupo Jumex, Mexico City, Mexico)	Water, apple juice from concentrate, high fructose corn syrup, citric acid, malic acid, caramel color.	3.33
Fermented milk (Yakult Honsha, Tokyo, Japan)	Water, skimmed milk, glucose-fructose syrup, sugar, maltodextrin, flavorings, Lactobacillus casei Shirota.	3.76

3. Results

Table 4 presents the results obtained for the Ra and Rz roughness parameters. The basal roughness (0) by group of each material evaluated showed no statistically significant differences for both parameters ($p > 0.05$); Ultradent and VOCO had the highest values both for Ra_0 (U and V = 0.020 ± 0.003 μm) as well as for Rz_0 (U = 0.120 ± 0.013 μm; V = 0.118 ± 0.010 μm). On the contrary, 3M presented the lowest values in both parameters (Ra_0 = 0.005 ± 0.001; Rz_0 = 0.030 ± 0.003) ($p >$ 0.05).

After 15 and 30 days of immersion, the group 3M still showed the minimum values of surface roughness (Ra_1 = 0.006 ± 0.001; Rz_1 = 0.036 ± 0.004 and Ra_2 = 0.007 ± 0.001; Rz_2 = 0.044 ± 0.006), with no significant differences between the type of beverage ($p > 0.05$). In addition, the maximum roughness values were seen in group UC (Ra_1 = 0.029 ± 0.003; Rz_1 = 0.172 ± 0.021 and Ra_2 = 0.030 ± 0.003; Rz_2 = 0.177 ± 0.014).

Table 5 shows the general average and standard deviation (regardless of the industrialized acidic beverage used) for Ra and Rz parameters (μm) by material evaluated at different experimental stages. The 3M group obtained the lowest roughness values among groups at baseline and at the end of each immersion period (Ra_0 = 0.005 ± 0.001, Ra_1 = 0.006 ± 0.001 and Ra_2 = 0.007 ± 0.001) (p = 0.001). Ultradent and VOCO groups showed the highest basal roughness (Ra_0 = 0.020 ± 0.003 and Ra_0 = 0.020 ± 0.002, respectively) (p = 0.001); however, Ultradent showed the highest roughness values after immersion in industrialized acidic beverages (Ra_1 = 0.026 ± 0.004 and Ra_2 = 0.028 ± 0.002) (p = 0.001). All groups presented significant increases in their roughness surface throughout the experiment ($p < 0.05$).

TABLE 4. Mean and standard deviation of roughness parameters Ra and Rz (μm) of pit and fissure sealants at 0, 15, and 30 days of immersion in some industrialized acidic beverages.

Parameter	Groups		Surface roughness					
			0 days (R_0)		15 days (R_1)		30 days (R_2)	
Ra	3M	3MC	0.005 ± 0.001	A,a	0.006 ± 0.001	A,b	0.007 ± 0.001	A,c
		3MJ	0.005 ± 0.001	A,a	0.006 ± 0.001	A,b	0.007 ± 0.001	A,c
		3MY	0.005 ± 0.001	A,a	0.006 ± 0.001	A,b	0.007 ± 0.001	A,c
	I	IC	0.009 ± 0.001	A,a	0.015 ± 0.001	A,b	0.016 ± 0.001	A,c
		IJ	0.009 ± 0.001	A,a	0.020 ± 0.001	B,b	0.022 ± 0.002	B,c
		IY	0.009 ± 0.002	A,a	0.022 ± 0.002	C,b	0.024 ± 0.002	C,c
	U	UC	0.020 ± 0.003	A,a	0.029 ± 0.003	A,b	0.030 ± 0.003	A,c
		UJ	0.019 ± 0.003	A,a	0.024 ± 0.002	B,b	0.027 ± 0.001	B,c
		UY	0.020 ± 0.002	A,a	0.025 ± 0.002	C,b	0.028 ± 0.001	C,c
	V	VC	0.020 ± 0.003	A,a	0.023 ± 0.002	A,b	0.025 ± 0.002	A,c
		VJ	0.019 ± 0.001	A,a	0.021 ± 0.002	B,b	0.022 ± 0.002	B,c
		VY	0.020 ± 0.002	A,a	0.023 ± 0.002	A,b	0.024 ± 0.002	A,c
Rz	3M	3MC	0.030 ± 0.003	A,a	0.038 ± 0.007	A,b	0.047 ± 0.006	A,c
		3MJ	0.031 ± 0.004	A,a	0.038 ± 0.007	A,b	0.044 ± 0.006	A,c
		3MY	0.031 ± 0.004	A,a	0.036 ± 0.004	A,b	0.044 ± 0.006	A,c
	I	IC	0.053 ± 0.011	A,a	0.088 ± 0.008	A,b	0.096 ± 0.006	A,c
		IJ	0.057 ± 0.006	A,a	0.121 ± 0.014	B,b	0.134 ± 0.012	B,c
		IY	0.059 ± 0.011	A,a	0.130 ± 0.012	C,b	0.145 ± 0.013	C,c
	U	UC	0.120 ± 0.013	A,a	0.172 ± 0.021	A,b	0.177 ± 0.014	A,c
		UJ	0.118 ± 0.010	A,a	0.139 ± 0.008	B,b	0.168 ± 0.006	B,c
		UY	0.119 ± 0.012	A,a	0.148 ± 0.022	C,b	0.165 ± 0.007	C,c
	V	VC	0.118 ± 0.010	A,a	0.135 ± 0.013	A,b	0.147 ± 0.013	A,c
		VJ	0.117 ± 0.008	A,a	0.124 ± 0.009	B,b	0.131 ± 0.012	B,c
		VY	0.117 ± 0.010	A,a	0.136 ± 0.013	A,b	0.144 ± 0.014	A,c

Capital letters in a column represent the comparison between roughness values (Ra or Rz) of the same material immersed in different industrialized acidic beverages. Lowercase letters in a row compare parameters at different immersion stages. Identical letters indicate that there are no statistical differences $p < 0.05$.
3MC: 3M-Cola; 3MJ: 3M-Apple juice; 3MY: 3M-Fermented milk; IC: Ivoclar-Cola; IJ: Ivoclar-Apple juice; IY: Ivoclar-Fermented milk; UC: Ultradent-Cola; UJ: Ultradent-Apple juice; UY: Ultradent-Fermented milk; VC: VOCO-Cola; VJ: VOCO-Apple juice; VY: VOCO-Fermented milk.

4. Discussion

In the present study, the roughness of subsequent PFS immersions in industrialized acidic beverages was evaluated to know its effects on the materials after its consumption. A higher increase in the SR of the PFS was observed in the most prolonged immersion period (30 days).

The current literature points out that the dissolution of elements and the erosion of restorative materials' non-soluble components occur in the oral environment. Numerous factors, including low pH, acidic foods consumption, and saliva ionic composition (as well as the materials' physical and mechanical characteristics), are important conditions that may influence the quality and the quantity of the substances released from a restorative material [16].

This study was carried out considering the previous conditions to evaluate the SR of fourth-generation PFS (capable of releasing fluorine) [2] after immersing them for varied periods in three commonly consumed beverages: a soft drink, apple juice, and fermented milk. The Food and Drugs Administration (FDA) Guidelines recommend using some of these acids in industrialized beverages (among others) as food simulators [17]. Some studies show that acid solutions (pH = 2.67–3.79) increase the surface roughness of resin-based materials [18, 19], due to the softening of the resin matrix, which allows the dislodgement and elution of filler particles (unstable glass particles) and thus the eventual formation of rough surfaces [20, 21]. The pH of each liquid was measured to ensure that it was below the critical value (5.5). The following results were recorded: soft drink (Coca-Cola—pH 2.59), fruit juice (apple juice—pH 3.33), and fermented milk (Yakult—pH 3.76).

According to the baseline results of the surface roughness,

TABLE 5. General average and standard deviation of the Ra and Rz parameters (μm) at 0, 15, and 30 days of PFS immersion in some industrialized acidic beverages.

Parameter	Group	Surface roughness					
		0 day (R_0)		15 days (R_1)		30 days (R_2)	
Ra	3M	0.005 ± 0.001	A,a	0.006 ± 0.001	A,b	0.007 ± 0.001	A,c
	I	0.009 ± 0.001	B,a	0.019 ± 0.003	B,b	0.021 ± 0.004	B,c
	U	0.020 ± 0.003	C,a	0.026 ± 0.004	C,b	0.028 ± 0.002	C,c
	V	0.020 ± 0.002	C,a	0.022 ± 0.002	D,b	0.024 ± 0.002	D,c
Rz	3M	0.031 ± 0.004	A,a	0.037 ± 0.006	A,b	0.045 ± 0.006	A,c
	I	0.056 ± 0.010	B,a	0.113 ± 0.021	B,b	0.125 ± 0.024	B,c
	U	0.119 ± 0.012	C,a	0.153 ± 0.023	C,b	0.170 ± 0.011	C,c
	V	0.117 ± 0.009	C,a	0.132 ± 0.013	D,b	0.141 ± 0.015	D,c

Statistical analysis for each roughness parameter (Ra or Rz): the capital letters in the columns represent the comparison between the materials on the same immersion stage. Lowercase letters in a row compare parameters at different immersion stages. Identical letters indicate that there are no statistical differences, $p < 0.05$.

all PFS tested were different. These differences could be related to their composition. Reports show that the percentage of surface area occupied by the filler particles and the size directly impact the surface roughness [22, 23]. The technical specifications mentioned that 3M PFS has 0% filling load by volume, while Ivoclar has 45%; Ultradent 53% and VOCO 70%; this could explain the results (lowest roughness values for 3M, followed by Ivoclar and highest for Ultradent and VOCO).

The results of this study revealed that the initial roughness could be a determining factor for the final roughness. Ideally, those values should be minimal, even well below the established threshold for patient comfort (0.50 μm), and that do not favor bacterial adhesion (0.20 μm) [23]. In this study, we observed that the roughness of the Ivoclar group, which presented the highest roughness increase percentage (RIP = 66–144% and 77–166% after 15 and 30 days of immersion, with variations according to the acidic industrialized beverage), was never above the roughness of VOCO PFS. On the other hand, VOCO and Ultradent sealants showed the highest initial roughness. Still, the former sealant showed the lowest roughness increase percentage (RIP = 10–15% and 15–25% after 15 and 30 days, respectively), even though it had the highest roughness values at all stages of the experiment.

The highest RIP observed in the Ivoclar group may be due to the presence of bis-2 (methacryloyloxy) ethyl phosphate in its chemical composition. This functional monomer can release ions, such as fluoride, after interacting with water or saliva from the oral environment [24]. Then, it is assumed that some mechanisms of fluoride release could alter the surface roughness [25], even in immersions where other aqueous mediums, such as the beverages in this study, are used. Furthermore, for this material, it has been reported that a surface loss can occur, which causes the exposure of holes formed by the trapping of bubbles of air during handling due to the larger diameter of the injector tip [26].

The less evident changes in the roughness values observed in the VOCO PFS could be explained by its high percentage of filler load (70%) and its aluminum and barium borosilicate glass content. The literature mentions that when those glasses are added at 30% or higher, this reduces the solubility of dental materials [27, 28]. As previously mentioned, PFS materials exhibited significant changes from baseline measurements and after exposure to industrialized acidic beverages; therefore, the null hypothesis was rejected.

Other findings of this study are related to the pH of the beverages. However, pH might not be the only factor that modifies the roughness of PFS materials since the changes in roughness did not follow a general pattern. On the contrary, specific roughness changes for each PFS material were observed. These results suggest that one chemical reaction occurs between the materials and the drinks. Consequently, the material composition, including the percentage and size of the inorganic filler particles and the organic matrix type of the PFS, affect the roughness variations. In the case of industrialized acid beverages, their components are a determining factor, but no information is available regarding their concentration in the product.

Therefore, this could explain why the most affected PFS after immersion at 15 and 30 days was Ivoclar, with more evident RIP when immersed in fermented milk and apple juice beverages. Similarly, this could explain why higher increases in surface roughness were observed for VOCO, and Ultradent PFS submerged in Coca-Cola.

In the specific case of industrialized acidic beverages, it has been reported that fermented milk can contribute to the dissolution of the structure of the materials, causing greater roughness due to structural loss [11]; because of the lactic acid produced by the lactobacilli present in Yakult beverage [29]. Additionally, roughness increase has been associated with apple juice due to the citric acid present in its composition. Citric acid is erosive and increases dental restorations' dissolution because of the common ion loss effect [30]. On the other hand, Coca-Cola incorporates various acids into its composition, such as carbonic, phosphoric, and orthophosphoric acids, to improve its properties [20, 31, 32]. Due to the presence of all these acids, cola drinks have an inherent acidity that leads to the erosion of various materials [33]. These results are in accordance with literature data which show that cola-based beverages have a higher erosive potential than orange juices (which contain citric acid) immediately after exposure [34, 35].

Furthermore, several authors observed an increase in the surface roughness of PFS and resin-based materials after immersion in some juices [34, 35]. Karda *et al.* [11] analyzed the erosive potential of commercially available beverages on tooth enamel and various restorative materials. A statistically significant difference was observed in the surface roughness average after immersion in the four groups evaluated. Frooti (mango juice) showed statistically lower values than Nimbooz (lemon juice) and Coca-Cola. There was no statistically significant difference between the results of Yakult and Frooti.

Despite the increase in the surface roughness of the PFS after immersion in industrialized acidic beverages, their values achieved did not exceed the surface roughness values presented by intact deciduous (0.21 $\pm$ 0.11) and permanent (0.25 $\pm$ 0.20) dental enamel [36]. Therefore, they could be imperceptible to the patient during their clinical performance if placed according to the manufacturer's instructions and the clinical protocols.

Recently, the combined use of infiltrative resin plus a fluid composite resin has been proposed as an effective method for sealing non-cavitated and deproteinized carious lesions [37]. Therefore, it is recommended to extend the evaluation of surface roughness to fluid composite and infiltrative resin.

One of the limitations of this study was that the oral cavity environment could not be precisely and wholly replicated *in vitro*. Therefore, additional *in vitro* research or clinical trials are required to emulate the various phenomena in the oral cavity more adequately and quantitative evaluation of material loss based on microscopic techniques.

5. Conclusions

The research findings of this study have provided evidence that the basal surface roughness of PFS varies according to the commercial brand and the time of exposure to certain industrialized acidic beverages.

The changes in the roughness of the PFS after immersion in industrialized acidic beverages would not favor bacterial adhesion to the PFS surfaces since the values obtained are below the considered favorable threshold for Ra (2 μm).

After immersion in some industrialized acidic beverages, the 3M sealant presented the most stable behavior in terms of surface roughness.

AUTHOR CONTRIBUTIONS

GBS and RCB—designed the research study. GBS—performed the research. LERV and UVE—analyzed the data. GBS, RCB, and BTC—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted following the Declaration of Helsinki and its later amendments or comparable ethical standards and approved by the Research Ethics Committee at the Dental Research and Advances Studies Center, School of Dentistry at the Autonomous University of the State of Mexico (CEICIEAO-2020-019), date of approval 19 March 2021.

ACKNOWLEDGMENT

To Engr. Emilio Ramírez Rodríguez for his support in editing the text.

FUNDING

This research was funded by the Autonomous University of Mexico State, grant number 6178/2020CIB.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Georgina Baca-Solano, Rosalía Contreras-Bulnes, Laura Emma Rodríguez-Vilchis, Bernardo Teutle-Coyotecatl, Ulises Velazquez-Enriquez. Effect of some industrialized acidic beverages on the roughness of pit and fissure sealants: an *in vitro* study. Journal of Clinical Pediatric Dentistry. 2023; 47(1): 36-43. doi: 10.22514/jocpd.2022.031.