Wear of two pit and fissure sealants in contact with primary teeth

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ABSTRACT

Objectives: Wear simulations may provide an indication of the clinical performance of pit-and-fissure sealants when associated with primary teeth as counterbody, restricting the involved variables. The aim of this study was to evaluate wear of dental materials used as pit-and-fissure sealants in contact with primary teeth. **Materials and Methods:** A resinous sealant (Fluroshield®) and a resin-modified glass ionomer cement (Vitremer®) were selected in a post-plate design, using as counterbody primary tooth pins (4 × 4 × 2 mm) at 3 and 10 N vertical load, 1 Hz frequency, 900 wear cycles in artificial saliva ($n = 15$). Attrition coefficient values were obtained and the material and primary tooth volumes were analyzed. Data were analyzed statistically by ANOVA and Duncan's test ($P < 0.05$). **Results:** Fluroshield® presented the highest attrition coefficient values for the 3 N but these values decreased significantly for the 10 N load. The means for volume loss (3 mm) of the different samples after the wear test were not statistically different for the materials. The volume loss values for the primary teeth were statistically different and there was an increase in volume loss with the increase of the load applied in the wear tests. **Conclusions:** Differences were also observed with regard to the surface deformation characteristics. The wear rates of primary tooth enamel vary according to the type of material and the load applied during mastication.

Key words: Pit and fissure sealant, preventive material, primary teeth, two-body wear

INTRODUCTION

Corrosive wear or biomechanical degradation results from the combined action of mechanical and chemical forces and is associated with the removal of residual layers that form on the material surface due to a reaction to an aggressive medium.[1] However, no problems have been reported with regard to preventive materials that come in contact with human primary teeth. Nonetheless, the mechanical characteristics of primary tooth enamel and the relationship between these characteristics and the chemical structure play important roles in studies of wear, toothpaste development and tooth restoration and prevention.

Tooth enamel is more resistant to wear than dentin. Wear occurs mainly on the occlusal surface of the tooth crown.[2] Excessive wear can reduce masticatory function, influence a child's facial growth, or result in oral disorders such as increased tooth sensitivity and temporomandibular joint disorder (TMD), among others.[3] Currently, a wide variety of dental materials are available with different compositions, indications, and physicochemical properties. This commercially available range of products often hinders the selection of a suitable material for a given clinical situation. Among these materials, pit and fissure sealants have been highlighted as effective preventive methods against the formation of carious lesions.

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The dental literature describes additional forms of chronic destructive processes that can lead to irrevocable losses of tooth structure,[4,5] including caries, trauma, and the corrosive–erosive actions of food and beverages.[6,7] Some researchers[8,9] have used an *in vitro* model to compare the erosive potential of different beverages on human teeth and have found that the microhardness of the tooth surface was reduced after immersion in low pH beverages. Occasionally, the use of pit and fissure sealants can help to reduce this problem.

The wear behaviors of pit and fissure sealants have been continuously improved over the years; however, limited wear resistance is still regarded as one of the greatest issues of pit and fissure sealants. Wear has been described as a consequence of the interaction between moving surfaces that are in contact with one another and the consequent gradual material removal.[10] Wear of the material and the tooth itself is the result of a complex process that depends primarily on the abrasive nature of food, the material properties, thickness, and hardness of the enamel and the chewing behaviors and neuromuscular forces.[10,11] Thus, friction occurs as a result of direct contact between the antagonist tooth and restorative or preventive material during chewing, swallowing, or occlusal movements.[12-14]

Dental materials have been shown to exhibit different wear mechanisms while under wear conditions *in vitro*,[15] and none of these existing mechanisms can completely simulate the clinical wear process.[16] Therefore, there are types of tests and research that aim to simulate chewing conditions in order to reproduce situations in the oral cavity. It is important to analyze friction in order to ascertain the characteristics of the chewing process and use these for evaluations of the wear resistance of investigated dental materials.[17]

Numerous studies in the literature have evaluated sealant retention through tests of shear and tensile bond strength and microleakage after contamination.[18-21] However, tribocorrosion studies of these materials are scarce or nonexistent. Despite doubts about the abilities of *in vitro* tests to predict clinical material performance, such tests are nonetheless considered valuable in the development of new products and the control of certain properties, especially because the rapid evolution of resin restorative materials has hindered the long-term evaluation of such products. The aim of this *in vitro* study was therefore to investigate the two-body wear resistance of pit and fissure sealants. The null hypotheses tested in this study were that there would be significant differences in quantitative wear and differences in micromorphology of the worn surfaces among the pit and fissure sealants investigated.

MATERIALS AND METHODS

Specimen preparation

Counterbody (antagonist)

Extracted and/or exfoliated healthy human primary molars that were donated by the Teeth Bank of the School of Dentistry of Ribeirão Preto, São Paulo University and approved by the Research Ethics Committee were selected for use as the counterbody. The teeth were stored in distilled water at 4°C to prevent dehydration prior to preparation. The teeth were subsequently fixed individually in a sectioning machine (Minitom, Struers A/S, Copenhagen, Denmark) and 2 mm thick sections of the proximal surfaces (mesial and distal) were obtained with a diamond saw that was used under refrigeration to avoid fractures, overheating of the structure, dehydration, and changes to the microstructure and chemical composition of the teeth.

When present, the roots were sectioned 2 mm below the cement–enamel junction using a water-cooled diamond saw (Minitom, Struers A/S, Copenhagen, Denmark). Next, the crowns were fixed with wax in Plexiglass® plates. Pieces of the teeth were removed using a double-faced diamond disk (KG Sorensen, 7015, Barueri, SP, Brazil) mounted on a low-speed hand piece under tap water irrigation to expose the testing surface. The fragments with standard dimensions of 2 mm in thickness were created. Afterwards, the fragments were individually fixed with wax in a cylindrical Plexiglass® abutment using a parallelometer to ensure that the enamel surface was kept perpendicular to the horizontal plane. The final 120 fragments had standard dimensions of 4 mm height × 4 mm width × 2 mm thickness. To ensure that the surfaces of the exposed teeth were free from scratches and deformations, the specimens were polished prior to indenting. To achieve these results, the surface material was removed by means of successively finer sizes of abrasive particles, and to ensure that the enamel surface was not modified by the polishing process, measures nanohardness was obtained before and after the procedures of planning and polishing; no differences in the values of counterbody has been observed. The grinding and polishing procedure was based on the work of Mahoney *et al*.[22]

Test specimen

Freshly extracted healthy human third molars and freshly extracted were used to prepare the specimens. These molars were obtained from the FORP-USP Teeth Bank. The teeth were kept in a 0.4% sodium azide solution after examination with the aid of a dental probe under a stereoscopic microscope with ×10 magnification.

The roots were sectioned 2 mm below the cementoenamel junction. Thereafter, the occlusal surfaces of the teeth were flattened and polished with 500 and 1000 grade sandpaper and subsequently polished with 9 and 1 µm diamond paste.[22] The teeth were washed in distilled water and stored at room temperature.

After 24 h, the teeth were removed from the water and cleaned with a pumice stone and water for 20 s. The teeth were then washed with high-pressure water jets for 20 s to remove pumice stone residues and dried for 20 s. The crowns were then fixed with an epoxy resin to a mold base so that the surfaces to be used in the sample preparation were parallel to the support plate during the wear test.

Preventive materials were applied to the occlusal surfaces of the teeth; these included a pit and fissure sealant (Fluroshield-Dentsply/Caulk, Milford, DE, USA; $n = 15$) and a glass-ionomer cement that was modified with composite resin to seal pits and fissures (Vitremer-3M/ESPE, St. Paul, MN, USA; $n = 15$).

Areas on the occlusal tooth surfaces were bonded with a 37% phosphoric acid gel, which was applied to the primary teeth for 30 s and to the permanent teeth for 15 s. The areas were rinsed with water jets for 20 s and dried with a moisture and grease-free air spray for 20 s to obtain uniform whiteness without shine and with a chalky appearance.

A Teflon® device was placed on the occlusal area and fixed with adhesive to control the material limits on the occlusal tooth surfaces. The Teflon® device was then filled with Fluroshield® sealant from a syringe and light cured for 20 s with a halogen light source at intensities that ranged between 400 and 470 mW/cm^2. The Vitremer® glass ionomer cement was light cured with a halogen light source, and manipulation was performed at a ratio of 1:3. The glaze (finishing gloss) was then applied and light cured for 20 s, according to the manufacturer's instructions.

After the materials were cured, the Teflon® tubes were removed and the samples were stored in distilled water at 37°C for 48 h, followed by automatic thermal cycling through alternating baths at temperatures of 5°C to 55°C. The immersion time per bath was 30 s at 5 s intervals, and a total of 500 cycles were completed. After thermal cycling, the teeth were rinsed in distilled water and kept in an oven at 37°C for 14 h. At the end of this period, they were removed, dried with air spray, and then prepared for tribochemical testing.

Tribological testing

The two-body tribological test was performed *in vitro* in a pin–plate configuration with alternative sliding movements of the tooth sample/dental material of 3.785 cm^2 in area along a total track length of 4 mm (stroke) and a fixed antagonist (pinned human tooth; 4 mm^2). The tribological values were recorded with a tribometer (TE 67 Tribometer, Plint, Tribology Products, UK). Tribological loads of 3 and 10 N at a frequency of 1 Hz were used as the parameters for all wear tests, and 900 cycles were performed per test. The tests were performed by immersion into artificial saliva solution (lubricant) as recommended by Fusayama (AS); this solution consisted of NaCl (400 mg/L), KCl (400 mg/L), $CaCl_2 \cdot H_2O$ (795 mg/L), $NaH_2PO_4.H_2O$ (690 mg/L), $NaS.9H_2O$ (5 mg/L), and urea (1000 mg/L) (Sigma Chemical Company, St. Louis, MO, USA) in distilled water (pH 5.5).

The tribological test began 1 min after positioning of the antagonist against the surface of the tooth/dental material. The acquisition rate was equal to 0.1 s, and the entire tribological experiment was performed at a controlled room temperature of 25°C.

After the tribological tests, the lost volumes were calculated (µ m^3) and the surfaces of each sample before and after the tribological tests were examined by scanning electron microscopy (SEM; JSM-610F, JEOL, Tokyo, Japan), and analyzed by X-ray diffraction (XRD - Siemens D5005 Diffractometer Cu Kα monochromatic radiation) and an energy dispersive spectrometer (EDS; Noran Instruments Voyager, Inc., Middletown, WI, USA).

Statistical analysis

The experimental data were statistically analyzed with ANOVA (parametric) to assess the influence of wear on the material behaviors. The Duncan test ($P < 0.05$) was used for multiple comparisons. Statistical analysis was performed with SPSS software for Windows, version 12.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

The use of primary or permanent teeth as a base did not affect the friction coefficients of either material because the material did not come into contact with the antagonist pin. Table 1 shows the means and standard deviations of the friction coefficients obtained from the wear tests of the materials used as pit and fissure sealants.

There were significant differences between the materials with regard to the sealant friction coefficients. When a 3 N load was applied, the Fluroshield® sealant displayed higher friction coefficient values that were significantly different from the values for Vitremer®. When the load was increased to 10 N, the coefficient values decreased significantly, indicating improved counterbody surface adaptation to the material.

The Vitremer® material showed the same characteristics as the Fluroshield® sealant in that the application of an increased load statistically reduced the friction coefficient. However, with a 3 N load, the values for Vitremer® were lower than those for Fluroshield®, and when the applied load was increased, the friction coefficient reduction for Vitremer® was less than that of Fluroshield®. The values in both cases were significantly different.

The means and standard deviation of the lost volumes (mm^3) of the different samples after the wear test are shown in Table 2, and the resulting values of lost volume by the antagonists (primary teeth) are shown in Table 3. There were no statistically significant differences in the lost volume values of the materials used in the study. However, the values found for the primary tooth volumes showed statistically significant differences, indicating an increase in lost volume values that was directly related to increased loads in the wear tests. Samples that were tested against Fluroshield® displayed higher wear values.

Representative samples of each material were analyzed by SEM. Differences in the surface deformation characteristics were observed in the wear and non-wear areas for both Fluroshield® and Vitremer. Both materials showed surface degradation in the wear area with particle losses, filler particles in the projected surface areas, and wear-related stress [Figure 1].

The resin sealant showed a more homogeneous distribution of filler particles in contrast to the nonhomogeneous distribution of the ionomer sealant.

Table 1: Means and standard deviations of the friction coefficients after wear tests of the preventive materials used as pit and fisure sealants

Experimental groups		Occlusal surfaces of the teeth	
Load applied	Preventive material	Permanent	Primary
3 N	Fluroshield	0,98 (0,04) a	0,99 (0,09) a
	Vitremer	0,85 (0,09) b	0,86 (0,07) b
10 N	Fluroshield	0,45 (0,12) c	0,46 (0,06) c
	Vitremer	0,56 (0,03) d	0,55 (0,07) d

Values followed by the same letters are statistically similar (ANOVA with post-hoc testing and Dunca correction, $P < 0.001$)

Table 2: The means and standard deviation of the lost volumes (mm^3) of the pit and fisure sealants after the wear test

Experimental groups		Occlusal surfaces of the teeth	
Load applied	Preventive material	Permanent	Primary
3 N	Fluroshield	0,005 (0,0021) a	0,004 (0,0007) a
	Vitremer	0,006 (0,0031) a	0,004 (0,0010) a
10 N	Fluroshield	0,003 (0,0006) a	0,005 (0,0022) a
	Vitremer	0,005 (0,0012) a	0,005 (0,0009) a

Values followed by the same letters are statistically similar (ANOVA with post-hoc testing and Dunca correction, $P < 0.05$)

Table 3: The means and standard deviation of the lost volumes (mm3) of the antagonists (primary teeth) after the wear test

Experimental groups		Antagonists Primary teeth
Load applied	Preventive material	
3N	Fluroshield	0,0013 (0,0012) ab
	Vitremer	0,0011 (0,0012) a
10N	Fluroshield	0,0039 (0,0031) b
	Vitremer	0,0022 (0,0004) b

Values followed by the same letters are statistically similar (ANOVA with post-hoc testing and Dunca correction, $P < 0.001$)

The structure of the resin sealant had fewer filler particle losses and wear traces [Figure 1] than the ionomer sealant, which displayed more filler particle losses and wear traces around the wear track.

Representative SEM images reveal the microstructure of the primary and permanent enamel. In [Figure 2], SEM analysis shows cracks on the tooth surface and detached 'platelet' particles. In additional, EDS examinations of the tooth surface indicate that the 'platelet' particles in the base are composed of elements obtained from the debris as a result of material transfer from the opposite specimens.

The XRD analysis results demonstrate that, after tribochemical testing, the materials continued to exhibit their initial characteristics in the samples tested

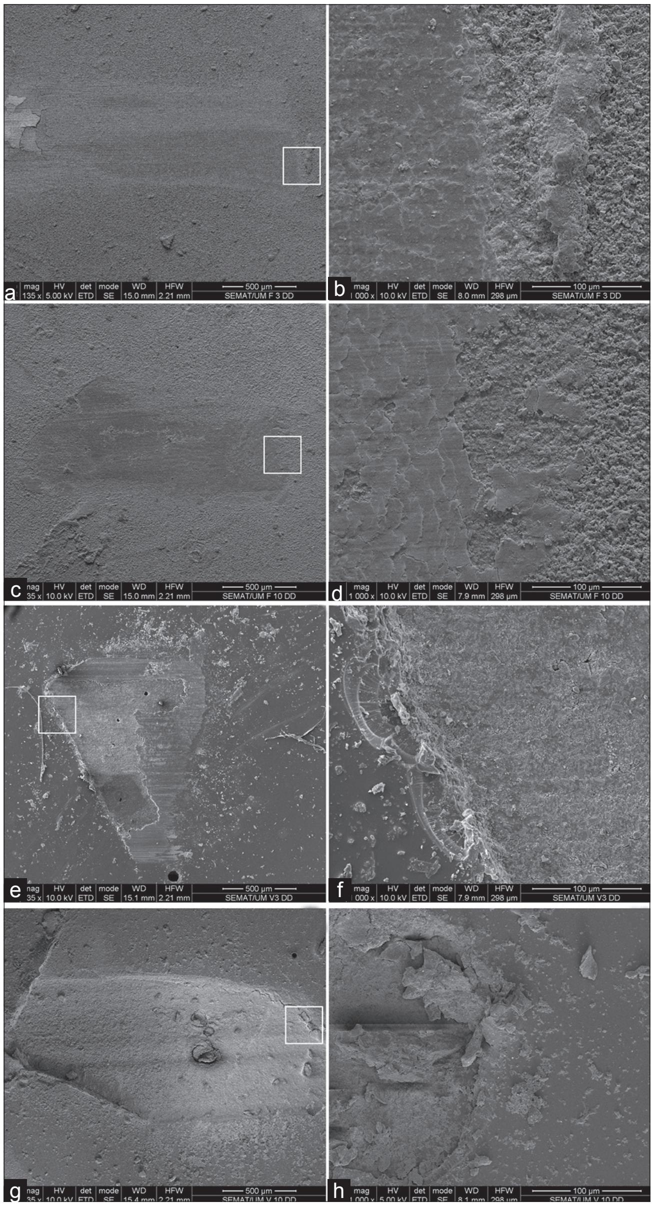

Figure 1: Representative scanning electron micrographs of the wear track-Fluroshield-3N (a), Fluroshield-10N (c), Vitrimer-3N (e) and Vitremer-10N (g) and at border of worn surface-Fluroshield-3N (b), Fluroshield-10N (d), Vitrimer-3N (f) and Vitremer-10N (h) (interface worn surface/polished surface)

with 3 and 10 N loads, with no significant differences in the materials after contact with the primary tooth.

DISCUSSION

Biomechanical degradation results from the combined actions of chemical and mechanical forces and is associated with the removal of layers that form on material surfaces due to a reaction to the medium.[1] Wear is an ongoing process that occurs during the lifetime of a restoration, and the characteristic degradation of a restoration is related to its clinical performance. While resin-based materials undergo the cleavage of polymer chains to form oligomers and monomers, glass ionomers display complex absorption, outward ion transportation, and disintegration processes.[23]

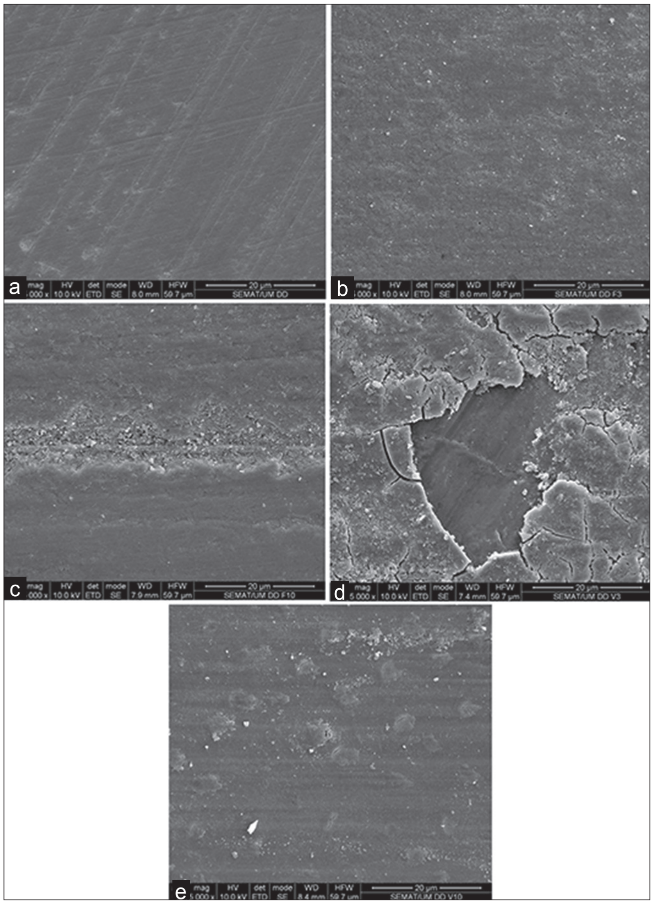

Figure 2: Representative scanning electron micrographs of superficial wear. (a) Primary teeth baseline; (b) primary teeth after wear with Fluroshield-3N; (c) primary teeth after wear with Fluorshield-10N; (d) primary teeth after wear with Vitremer-3N, and (e) primary teeth after wear with Vitremer-10N

A pin–plate configuration was used to simulate 2-body wear by simulating clinical situations with regard to the dental material degradation behaviors because clinical studies have reported that the analysis of tooth and restorative dental material wear is of paramount importance.[10-24] Thus, the use of human teeth as antagonists for *in vitro* evaluations of wear resistance has been reported by many researchers,[13,25,26] as were the masticatory forces used during wear tests. Masticatory forces can reach values between 3 and 150 N,[27] and the values of 3 and 10 N were considered because they are the approximation and adaptation loads between the occlusal surfaces, after these masticatory forces have been adjusted for testing.

Wear resistance can be attributed to many factors, such as size, hardness, the surface percentage occupied by filler particles, and the interaction between the matrix and the particles,[28] as well as the degree of polymer resin matrix conversion[29] caused by the applied force and the sliding distance.[10] Filler particles in resin materials play a key role in wear resistance because changes in their composition can promote wear and an increased resistance to degradation.[30,31]

Initially, the interactions between the studied materials and the primary teeth with the applied loads promoted degradation through mechanical and chemical wear. According to Sarkar,[1] chemical wear is initiated by the absorption of water that diffuses into the matrix, filler interfaces, pores, and other areas. The biodegradation rates of the different materials therefore depend on their hydrolytic stability.

The null hypotheses tested in this study were that there would be significant differences in quantitative wear and differences in micromorphology of the worn surfaces among the pit and fissure sealants investigated have to be accepted, Vitremer® had lower friction coefficient values but greater surface deformation when compared to Fluroshield®. The lower friction coefficient values are most likely attributed to the material composition and structure. Vitremer® comprises glass filler particles of a relatively large average size.[32] Furthermore, the polyacrylate matrix is more fragile than the dimethacrylate matrix used in other materials.[33] Additionally, there is a smaller bond between the inorganic filler particles and the organic matrix in resin-modified glass ionomers when compared to resin and/or composites in which filler particles contain smaller sized particles and bond more effectively with the organic phase.[33]

During the tribological tests, the materials in contact can promote transformations such as subsurface fissures due to fatigue and the consequent displacement of the matrix/filler, as well as surface exposure.[34] Moreover, loose particles can act as a third body during the wear process. Thus, the size and hardness of the displaced particles can promote greater or lesser wear and losses of volume. Thus, for the glass ionomer, which has larger particles and low bond strength between the organic and inorganic phases, the particle displacement and wear tracks were higher than for the Fluroshield [Figure 1], due to the presence of a rougher surface than the resin material. This corroborates a study by Kon *et al*.[35] in which a direct relationship was observed between higher wear volume and higher maximum wear depth relative to greater occlusal forces, thus, suggesting that the bond between the filler particles and the matrix is more susceptible to destruction under higher antagonist loads.

The volume loss values did not differ between the two types of studied materials. However, the SEM images showed that the glass-ionomer surfaces were more altered. Mair *et al*.[10] reported that glass-ionomer filler particles can transmit forces into the material and thus promote fissures within the organic matrix. With time, these particles are removed from the cracked organic matrix and might be added to the counterbody or embedded in the tribolayers that surround the wear track.

The friction coefficient results indicate a difference between Fluroshield® and Vitremer®. According to the results of this study, the friction coefficient provided by the Fluroshield® resin sealant was higher than that of the ionomer sealant when subjected to load of 3 N. This result was expected because resins display a higher combination of filler loading, reduced space between the inorganic filler particles, and a strong bond with the organic matrix.[36] The higher filler loading with smaller particle size promotes a reduction in the interstitial space that effectively protects the softer matrix, reduces the incidence of filler exfoliation, and improves the wear resistance of the material.[37] However, as the load is increased (10 N), the friction coefficient values decrease, most likely due to a better adaptation of the material surfaces to the primary teeth. Thus, it may be inferred that resin materials generally display smaller particle sizes that promote a better adaptation of the surface to an increased applied load.

The available composites offer improvements in wear resistance due to the use of different particle sizes in their composition; these result in a reduced incidence of filling matrix exfoliation during abrasion.[38,39] It is very difficult to attribute the wear patterns of the different materials to a simple variant. In this regard, Söderholm and Richards[40] have shown that the volume of inorganic material influences the wear resistance of composites. However, Cunha *et al*.[32] did not observe a significant difference between resins with different inorganic filler matrices.

The Fluroshield® resin sealant showed uniform patterns and soft features on the worn surfaces. However, in some areas there were decreases in volume and losses of the material, although these were not significantly different from the ionomer sealant. Despite the fact that Fluroshield® was not significantly different from the ionomer sealant, the wear potential indicates that it might be more susceptible to degradation under different loads.

The wear behaviors of human enamel in response to cyclical forces are substantially different from those in response to constant contact. The type of force influences the wear process.[41] Xu *et al*.[42] observed that the effects of the load type also contributed to the tribochemical process, and major problems have been found in unidirectional tribometers, in which the wear rate is 10 times lower than in devices that perform bidirectional movement. However, bite force increases at the end of chewing.[42] As a result, the wear suffered by the tooth varies during a single masticatory cycle.

In this study, the polishing and standardization of primary teeth counterbodys were carefully performed, although the primary molars displayed complete root resorption, which could indicate that the aprismatic layer had been removed by natural tooth functions.

Tables 2 and 3 show the positive correlation between dental material wear and primary tooth enamel. One of the factors that might be associated with tooth wear when used as a counterbody is the inorganic particle size of the restorative materials because these can be displaced from the surface and abrade the tooth enamel.[32] The results for Vitremer®, which produces large particles, are consistent with other studies that have shown a relationship between the inorganic material particle size and antagonist tooth wear, and as the force is increased, contact with these particles also increases, followed by increased enamel wear.

The Fluroshield® resin sealant produced greater wear on primary tooth enamel when compared to the ionomer sealant, although this difference was not significant regardless of the load. This result could be related to the bond between the primary tooth enamel and the resin sealant surface, which is corroborated by the higher friction coefficient values.

It can be concluded that the primary tooth enamel wear rate varies according to the type of pit and fissure sealant used as well as the applied load. Based on the results of this *in vitro* study, professional clinicians should consider wear properties when selecting materials for the prevention of dental caries, while considering the lifetime of the primary tooth in the mouth cavity.

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