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Research article

Influence of incorporation of nanostructured silver vanadate decorated with silver nanoparticles on roughness, microhardness, and color change of pit and fissure sealants

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ABSTRACT

Objective: The aim of this study was to evaluate the roughness, hardness, and color change of pit and fissure sealants of two commercial brands (Fluroshield ™ and Ultraseal XT ™) incorporated with nanostructured silver vanadate nanomaterial decorated with silver nanoparticles (β-$AgVO_3$) in concentrations (0% - control, 2.5% and 5%).

Material and methods: Two commercial brands Fluroshield TM and Ultraseal XT ™ were used to make the samples with dimensions of 6 × 6 × 4 mm. The control group was made according to the manufacturer's instructions and in the groups with the addition of β-$AgVO_3$, the nanomaterial was added proportionally by mass at percentages of 2.5% and 5%. Roughness properties were evaluated using a 3D Laser Confocal Microscope ($n = 10$), Knoop microhardness by Micro-durometer ($n = 10$), and color change by Portable Color Spectrophotometer on the CIEDE2000 system ($n = 10$). Data were evaluated by one-way ANOVA with Bonferroni adjustment and Tukey's mean comparison test at a 5% significance level.

Results: Ultraseal XT ™ sealant roughness showed a significant difference between concentrations with the highest mean for the 5% group ($P = 0.010$). Regarding the hardness, both sealants showed no significant difference between the groups. Fluroshield ™ sealant showed a significant difference in $\Delta E00$ between the control-2.5% 24.93 (3.49) and control-5% 28.41 (2.58).

Conclusion: It may be concluded that the incorporation of β-$AgVO_3$ influenced the increase in roughness for Ultraseal XT ™ pit and fissure sealant, did not interfere with the microhardness of both sealants, and promoted a change in the color of Fluroshield ™ sealant within clinically acceptable limits.

1. Introduction

The poor hygiene associated with a high carbohydrate diet promotes a favorable scenario for the development of tooth decay, which, although it has been reduced over the years, is still the most prevalent chronic disease in the world [1–3]. The occlusal surface

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[1] In memoriam.

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of the posterior teeth is the most affected by caries, mainly due to dental morphology (shape, depth, and narrowing of the fissures), which facilitates the accumulation of biofilm and prevents self-cleaning by food, tongue, and cheeks, and also hampers the mechanical hygiene and the action of fluorides compared to smooth surfaces [2–5].

Non-invasive treatments including fluoride varnish, fluoride toothpaste, and pit and fissure sealant treatment have been suggested as effective measures for preventing caries disease [6]. Fluoride varnish and toothpaste are applied to all teeth in the oral cavity, while sealants are selectively applied to posterior teeth with complex anatomy. Sealants are recommended for patients at high risk for caries as they function as a physical barrier that interrupts or inhibits the entry of bacteria and nutrients, resulting in a decrease of around 90% of posterior caries after one year of application and approximately 50% after five years [2–4,6–11]. Behroozian et al. used Feigal's criterion [12] to evaluate the treatment failure rate by analyzing three factors: marginal adaptation, marginal discoloration, and anatomical shape of permanent first molars treated with pit and fissure sealants. After 12 months, they observed that the success rate was 74.3% and with this, the authors emphasized that pit sealants are a valid therapy for the prevention of tooth decay [12,13].

To achieve treatment efficacy, some care must be taken, such as application technique, which must be careful to avoid humidity, because the presence of saliva can prevent the penetration of resinous fluid into the microporosities, decrease shear strength, and increase microleakage, these being the main causes of failure and failure of preventive treatment [5,11,13–15].

Maintaining the integrity of pit and fissure sealants on the tooth surface is critical to treatment success. The primary cause of loss of integrity is material wear, especially when applied to the occlusal surface [16,17]. The wear resistance can be evaluated by mechanical tests, among them microhardness, which can provide a good indication of wear resistance, in addition, pit and fissure sealants wear out over time and therefore need to be reapplied, which increases the cost of treatment [16,18–20]. Microleakage is one of the main disadvantages of pit and fissure sealants and can be caused by defects in the mechanical properties and oral environmental challenges, such as the chewing cycle, temperature changes, and pH [14,21]. Microleakage may allow cariogenic substances to enter, reducing the retention rate and resulting in caries initiation under sealed surfaces [21,22]. Because of the deficiencies of conventional sealants, it is better to work on improving their physical and mechanical problems, especially in children with a higher risk of caries [21,23].

In this context, investigations have been carried out in order to improve pit and fissure sealants by incorporating materials into their composition [1,24–28]. The study proposed by Silva et al. was to add amorphous calcium phosphate to the sealant to provide better remineralization of the compromised dental elements [27]. Shanmugaavel et al. and Garcia et al. in their studies, incorporated the antimicrobials poly hexamethylene guanidine hydrochloride (PHMGA) and chlorhexidine, respectively, in order to reduce the number of microorganisms at the sealant-tooth interface, and the results were promising with the reduction in the number of microorganisms near the material [1,28].

Following this line of materials incorporation, nanostructured silver vanadate decorated with silver nanoparticles (β-AgVO$_3$), was developed and patented by the research group and its application and effectiveness have been investigated in dental materials such as acrylic resin [29,30], resin cement [31], endodontic sealers [32,33], porcelain [34–36] and soft liners [37]. β-AgVO$_3$ stabilizes the silver nanoparticles (AgNPs) by reducing particle agglomeration due to deposition on the vanadium nanowires, which allows the maintenance of a larger contact area and continuous release of silver ions (Ag+), which acts in the antimicrobial action [38,39]. The synergy between AgNPs and vanadium (4V+) favors increased antimicrobial activity by altering cell membrane integrity through oxidative stress and ROS formation [29,30,40]. Studies [32,34,37,41] have revealed antimicrobial efficacy against gram-positive and gram-negative bacteria, including *Staphylococcus aureus* and *Streptococcus mutans*. Besides antimicrobial capacity, the incorporation of β-AgVO$_3$ can improve or not alter the mechanical properties of dental materials, such as acrylic resins, endodontic cement, soft liner, and dental ceramics [32,34,37,41].

The use of nanotechnology has enabled the advancement of dentistry through the innovation of modified dental materials with the possibility of acquiring better properties and antimicrobial activity, as well as being able to promote intelligent materials that can respond to specific stimuli and overcome the limitations of current materials [21,42–44]. Given the effective application of nanomaterial β-AgVO$_3$ in other dental materials and the possibility of improving pit and fissure sealants, this study aimed to evaluate the roughness, microhardness, and color change of pit and fissure sealants incorporated with different percentages of nanostructured silver vanadate decorated with silver nanoparticles (β-AgVO$_3$). It presents a null hypothesis that the incorporation of the nanomaterial will not promote changes to the sealant.

2. Material and methods

2.1. Synthesis of nanostructured silver vanadate

Nanostructured silver vanadate was synthesized via a precipitation reaction between silver nitrate (AgNO3, Merck 99.8%) and ammonium vanadate (NH4VO3, Merck 99%). Initially, 0.9736 g of NH4VO3 and 1.3569 g of AgNO3 were solubilized in 200 mL of distilled water, respectively. The solutions were stirred separately on a heated surface at 65 °C for 10 min. Next, the silver nitrate solution was added dropwise with the use of a burette to the ammonium vanadate solution under constant stirring at 65 °C. The precipitate obtained was washed with distilled water and absolute alcohol several times, then filtered and dried in a vacuum oven for 10 h [38]. Nanostructured silver vanadate is obtained, with particles of size 100 nm and the silver particles that decorate the vanadium nanowires with a size in the range of 1–10 nm [38,39].

2.2. Fabrication of the specimens

Two commercial brands of resin sealants were used, Fluroshield (Dentsply) ™ and Ultraseal XT (Ultradent) ™ (Table 1). The sealants were divided into three groups, control and those modified with the incorporation of 2.5% and 5% of β-$AgVO_3$.

The sealants were applied in a Teflon matrix in the dimensions 6 × 6 × 4 mm to prepare the specimens and photoactivated with an Optilux 501 curing unit (Kerr; Orange, CA, USA) for 20 s at 800 mW/cm^2 of energy. The control group was made according to the manufacturer's instructions. For the groups containing β-$AgVO_3$, the sealants were placed on glass plates on the rough side and weighed. Using a precision balance, the β-$AgVO_3$ was added proportionally to the incorporated concentration of 2.5% and 5%. To promote the homogenization of the sealants with β-$AgVO_3$ the materials were mixed until a homogeneous mass was obtained and placed in the matrix. After insertion into the Teflon matrix, light-curing was carried out for 20 s [31]. After their confection, the samples (Fig. 1) were polished with water sandpaper of different grits 100, 320, 640, 1000, 1200, 1500 and 2000. The sample size calculation tests were carried out by Power Test using the RStudio software, version 2023.09.0 + 463 (R Foundation for Statistical Computing, Vienna, Austria).

2.3. *Roughness*

A 3D Laser Confocal Microscope (LEXT 4000; Olympus, Hamburg, Germany) was used to evaluate the surface roughness of the sealants before and after laser irradiation. This test evaluates Ra, Rz, and Sa. The parameter Ra, or arithmetic mean roughness, is the average of the absolute values of the surface deviations from the mean line. Rz, or maximum profile height, measures the vertical distance between the highest peak and the lowest valley over a sampling length. Sa, or arithmetic mean of the absolute values of the surface deviations, is another parameter that represents the average surface roughness and was used in this study [46,47]. Scans will be performed at 10 × magnification and 1024 × 1024 pixels resolution. Two measurements per sample were performed in different and random positions with n = 10 for each analysis group.

2.4. *Microhardness*

A microdurometer (Shimadzu HMV-2, Japan) was used for the evaluation of Knoop hardness (KHN). The surface of the samples (n = 10) was marked with a diamond indenter with a load of 25 g and a time of 15 s at least 1 mm from the edge of each upper and lower surface. The microhardness value of each sample consisted of the arithmetic mean of five markings. After removing the load, the diagonals of the notch were measured with an optical microscope. The microhardness value was defined as the ratio between the indentation load and the residual impression area [31].

2.5. *Color change*

The measurement of the color change of the specimens (n = 10) of each group was performed using a Portable Color Spectrophotometer - Model SP 62S (Spherical Geometry Spectrophotometer, D/8°, XRITE Incorporated, USA, 11/2012), with 3 measurements for each, with white background, in order to verify if the different percentages of the nanomaterial (2.5% and 5%) differ from the control group. This was done using the CIEDE2000 system that allows the evaluation of color attributes, identifying inconsistencies, and communicating its results numerically and accurately. The L*C*h system uses the same diagram as the L*a*b* color space but with cylindrical coordinates instead of rectangular coordinates. The ΔE00 was calculated according to the formula [48,49]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L*}{K_L S_L}\right)^2 + \left(\frac{\Delta C*}{K_C S_C}\right)^2 + \left(\frac{\Delta H*}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C*}{K_C S_C}\right)\left(\frac{\Delta H*}{K_H S_H}\right)}$$

where ΔL indicates the difference in luminosity, ΔC the difference in chroma and ΔH' the difference in hue. The RT interaction function takes into account the interaction between the chroma and hue differences in the blue region. To adjust the total color difference, weighting functions are applied: SL (for luminosity), SC (for chroma), and SH (for hue), which help to take into account the differences in color space. KL, KC, and KH are empirical terms that correct or weight the metric differences calculated by the formula

Table 1
Commercial brands, classification, and characteristics of the pit and fissure sealants used.

Pit and fissure sealant (Manufacturer)	Classification	Characteristics	Composition
Fluroshield (Dentsply) ™	Light Cure Light cure for 20 s.	Fluoride release Viscosity Durability	NCO Monomer, Nupol Bis GMA, TEGDMA, Penta, N-methyl Diethylamine, BHT, 2_n Methacrylate, Camphorquinone, Cervit T 1000, Silanized Barium, Sodium Fluoride, Cabosil TS 720 and Titanox 3328.
Ultraseal XT (Ultradent) ™	Light Cure Light cure for 20 s.	Radiopaque Fluoride release Viscosity Wear resistance	>10%–≤25% TEGDMA, >2.5%–≤10% DUDMA, >2.5%–≤10% aluminum oxide, ≤2.5% HEMA, ≤2.5% amine methacrylate, ≤2.5% organophosphine oxide, 0.1% sodium monofluorophosphate [45]

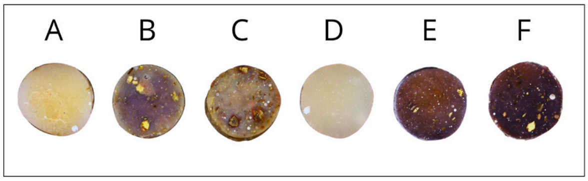


Fig. 1. Image of the samples of Ultraseal XT ™ and Fluroshield ™ sealant at 5%, 2.5%, and control concentrations, taken by a camera. Legend: A Control group Ultraseal XT ™; B- 2.5% de β-AgVO$_3$ Ultraseal XT ™; C- 5% β-AgVO$_3$ Ultraseal XT ™; D- Control group Fluroshield ™, E- 2.5% β-AgVO$_3$ Fluroshield ™; F- 5% β-AgVO$_3$ Fluroshield ™.

[50]. Color changes with $\Delta E00 < 3.3$ were considered clinically acceptable in this study [51–53].

2.6. *Statistical analysis*

For statistical analysis, the distribution and homogeneity of the data were verified and thus, for the analysis of color change and microhardness, one-way ANOVA variance analysis with Bonferroni adjustment was used ($\alpha = 0.05$) and for roughness, ANOVA and Tukey tests were used for comparison between concentrations within the same group of sealants. Mann-Whitney's *U* test was applied to evaluate the difference between sealants. A significance level of 5% was adopted [54].

3. Results

3.1. *Roughness*

For surface roughness was observed that Ultraseal XT ™ sealant showed a significant difference between concentrations ($P = 0.010$) with the highest mean for the 5% β-AgVO$_3$ group compared to 2.5% β-AgVO$_3$ ($P = 0.006$) and control ($P = 0.002$). For the Fluroshield ™ sealant, no significant difference was observed between concentrations ($P = 0.458$). In the comparison between sealants, there was a significant difference for the control ($P = 0.007$) and 2.5% β-AgVO$_3$ ($P = 0.028$) groups, with higher roughness for Fluroshield ™; for the 5% β-AgVO$_3$ group there was no difference between sealants ($P = 0.218$) (Graph 1).

The images (Figs. 2–7) were obtained by laser confocal microscopy for the different groups. The control group of Fluroshield ™ (Fig. 2) displayed a uniformly polished surface. In contrast, the 2.5% β-AgVO$_3$ Fluroshield ™ group (Fig. 3) exhibited surface alterations with crater-like structures of β-AgVO$_3$, causing a loss of homogeneity relative to the control group. The 5% β-AgVO$_3$ Fluroshield ™ group (Fig. 4) demonstrated heterogeneity in regions with visible agglomerated β-AgVO$_3$ particles. Surface observations indicate that the matrix surrounding the agglomerates remains unaffected.

The control group using the Ultraseal XT™ sealant (Fig. 5) shows a surface appearance distinct from the Fluroshield™ control, with crater-like regions and differing surface homogeneity. When 2.5% β-AgVO$_3$ Ultraseal XT™ (Fig. 6) is applied, no surface agglomerates

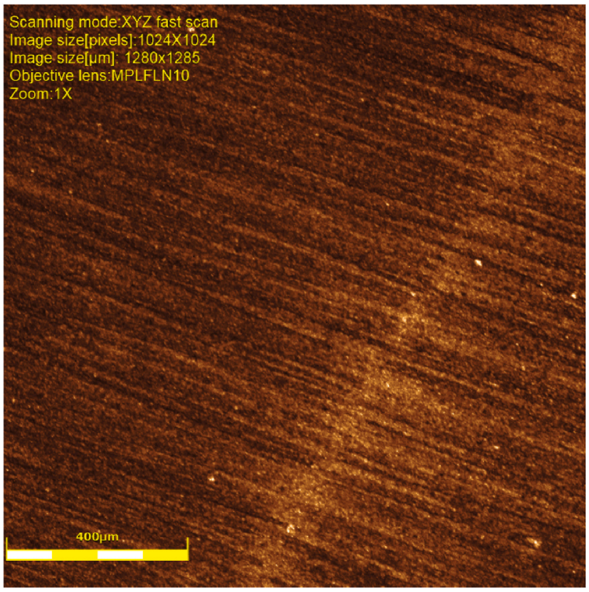


Fig. 2. Laser confocal microscope of the Fluroshield ™ control.

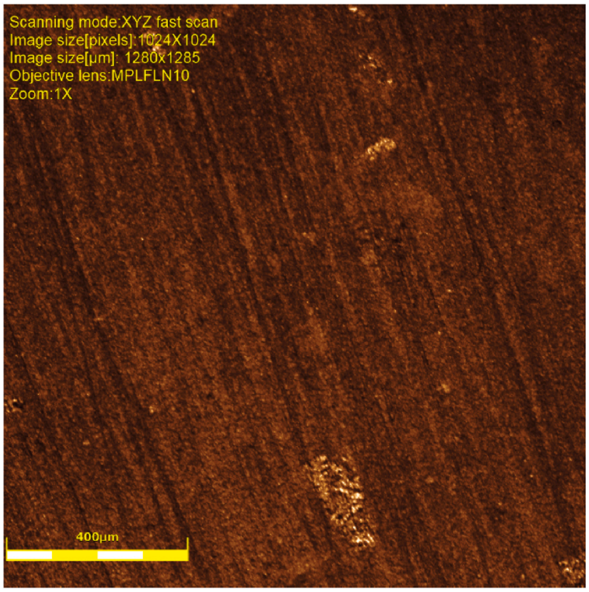


Fig. 3. Laser confocal microscope of the Fluroshield ™ 2.5% of β-$AgVO_3$.

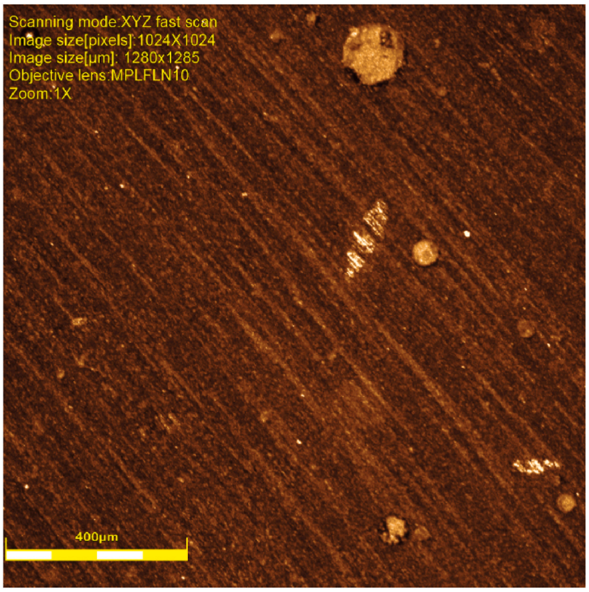


Fig. 4. Laser confocal microscope of the Fluroshield ™ 5% of β-$AgVO_3$.

are detected, suggesting the sealant matrix exhibits greater encapsulation. This is similarly observed in the Ultraseal XT™ 5% β-$AgVO_3$ group (Fig. 7). These results support the roughness data presented earlier, as a result of the increased encapsulation of β-$AgVO_3$ within the Ultraseal XT™ sealant.

3.2. Microhardness

Regarding hardness, no significant difference was observed between the concentrations for each type of sealant, ($P > 0{,}05$) and Fluroshield ™ ($P > 0{,}05$), that is, the incorporation of nanomaterial did not promote changes in the hardness of the different groups. However, when comparing the sealants, a difference was observed, with Ultraseal XT ™ showing statistically different mean microhardness values than Fluroshield ™ in the control group, 2.5% β-$AgVO_3$ 5% β-$AgVO_3$ ($P < 0.001$; $P = 0.014$; $P < 0.001$) (Graph 2).

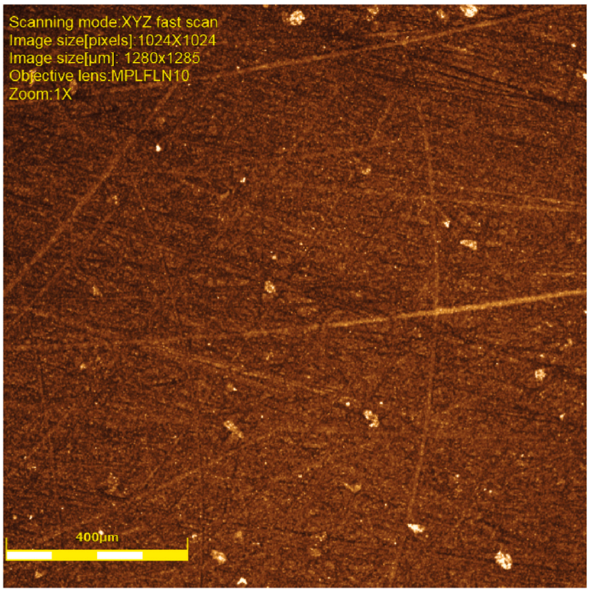


Fig. 5. Laser confocal microscope of the Ultraseal XT ™ control.

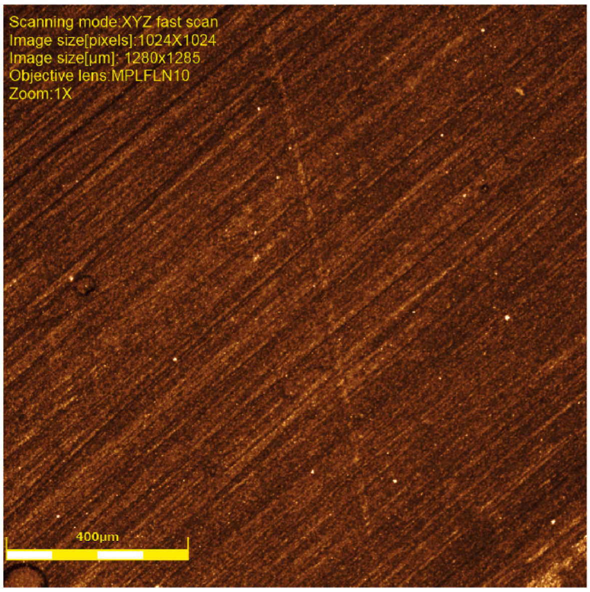


Fig. 6. Laser confocal microscope of the Ultraseal XT ™ 2.5% of β-$AgVO_3$.

3.3. Color change

For Ultraseal XT ™ sealant no significant difference in ΔE00 was observed between control-2.5% β-$AgVO_3$ and control-5% β-$AgVO_3$ ($P = 0.790$) groups. For the Fluroshield ™ sealant, a significant difference in ΔE00 was observed between control-2.5% β-$AgVO_3$ and control-5% β-$AgVO_3$ groups ($P = 0.004$). When comparing sealants, there was a significant difference between brands ($P < 0.001$), with lower mean ΔE00 scores for Ultraseal XT ™ in both the control-2.5% β-$AgVO_3$ and control-5% β-$AgVO_3$ groups (Table 2).

4. Discussion

The modification of pit and fissure sealants to promote better physicochemical and mechanical properties and antimicrobial activity aims to find a material that better combines structure-property correlation and its clinical application. In this study, the null hypothesis that the incorporation of β-$AgVO_3$ nanomaterial does not promote changes in the properties of the evaluated pit and fissure

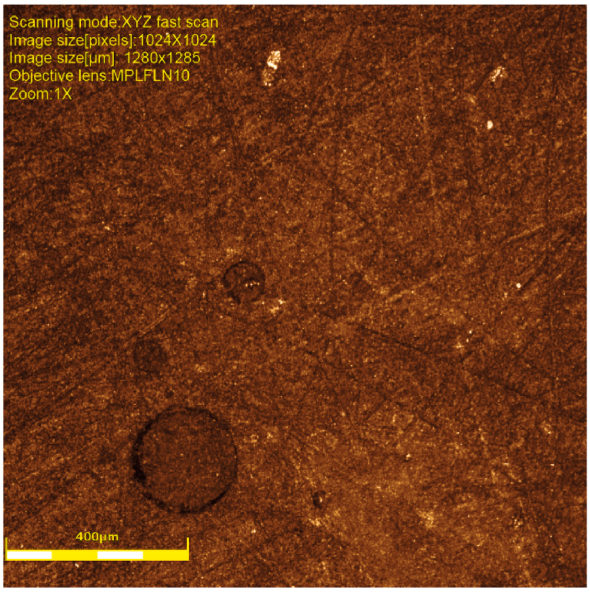
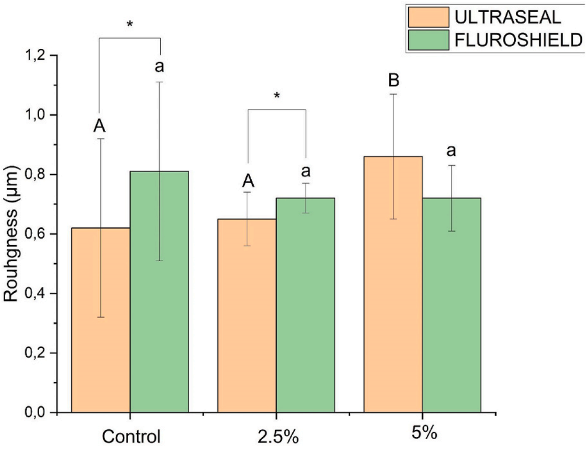


Fig. 7. Laser confocal microscope of the Ultraseal XT ™ 5% of β-AgVO$_3$.

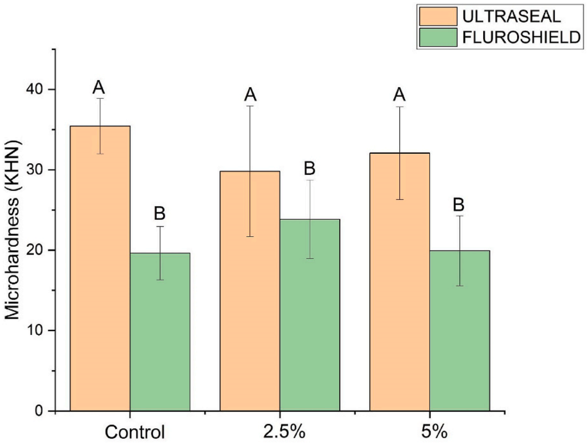


Graph 1. Graph with mean and standard deviation (SD) of roughness for the different sealants and concentrations.
Legend: One-way ANOVA, Tukey test ($P > 0.05$). Different capital letters indicate statistical differences for Ultraseal ™. Different lowercase letters indicate statistical differences for Fluroshield ™. * Indicates difference between brands.

sealants was rejected.

The β-AgVO$_3$ was effectively incorporated and showed results compatible with acceptable clinical parameters for analyzing antimicrobial activity, compression, hardness, and roughness for acrylic resins, radiopacity and pH for endodontic cement, and promotion of antimicrobial activity for dental implants [33,40]. Thus, the incorporation of β-AgVO$_3$ in different dental materials, pit and fissure sealants are a class of materials that can benefit from the incorporation of the nanomaterial by promoting antimicrobial activity and improving mechanical properties that are still deficient and can hinder the preventive treatment of dental caries.

When a material is modified, its properties can be altered and in this study, the roughness, hardness, and color change of sealants prepared with β-AgVO$_3$ were evaluated. It was observed that the incorporation of nanomaterials resulted in increased roughness for the 5% Ultraseal XT ™ group. This phenomenon can be explained by the non-uniform distribution of nanomaterial particles in the organic matrix, which promotes the formation of agglomerates and leads to the creation of surface irregularities. This result is consistent with the findings of Ferreira et al. and Vidal et al. who reported increased surface roughness in the 10% group of β-AgVO$_3$ incorporated into dental ceramics [34,35]. Increased roughness is frequently associated with the formation of biofilms and gingival inflammation, and it should be carefully monitored due to its potential to cause treatment failure [48]. In their study, Hesaraki et al. pointed out that the incorporation of nanoparticles results in a gradual increase in surface roughness, and despite proper nanoparticle dispersion in the polymer, nano-agglomerates may still be observed [52,55]. A difference was observed between the groups when comparing Ultraseal



Graph 2. Graph of the mean and standard deviation (SD) of microhardness for the different sealants and concentrations. Legend: One-way ANOVA, Tukey test ($P > 0,05$). Different letters indicate statistical differences between the brands.

Table 2
Mean and standard deviation (SD) of the comparison between the control group and the 2.5% and 5% concentrations of β-AgVO3 in color change.

Groups	ΔE00	p-value
Ultraseal XT control-2.5%	13.92 (2.25)A	$P = 0.790$
Ultraseal XT control-5%	13.62 (1.33)A	$P = 0.790$
Fluroshield control-2.5%	24.93 (3.49)B	$P = 0.004$
Fluroshield control-5%	28.41 (2.58)B	$P = 0.004$

Legend: One-way ANOVA, Tukey test ($P > 0.05$). * Indicates difference between brands.

XT™ and Fluroshield™, with Fluroshield™ presenting a rougher surface even when compared to the control groups. This may be explained by the difference in formulation between the materials since roughness can be influenced by the size and distribution of the filler particles and the polymerization contraction of the different polymer particles.

No significant differences in hardness were observed among the various modified sealant compositions, i.e. the incorporation of different percentages of β-$AgVO_3$ did not alter the hardness of the sealants, as can be seen in Graph 2, where the groups with added nanomaterial showed a hardness statistically similar to the control group, since β-$AgVO_3$ acts as a reinforcing structure for the sealants. The findings align with Monteiro et al. which noted no changes in sealant hardness when incorporating 1,3,5-triacrylonyl hexahydro-1,3,5-triazine (TAT) and α-tricalcium phosphate (α-TCP) in the composition. However, they found significant improvements in other properties, including increased tensile strength [56]. Hamilton et al. found that adding chitosan to the composition of pit and fissure sealants resulted in a significant increase in hardness. This could be attributed to the interfacial bonding between the matrix and the chitosan fibers [51].

Color stability, or the ability of a material to maintain its original color, can be influenced by factors such as the nature of the material, water absorption, and extrinsic influences like food and beverage coloring. Studies [52,53] have demonstrated that the incorporation of β-$AgVO_3$, a yellowish nanomaterial, into pit and fissure sealants can lead to significant alterations in coloration, potentially impacting its application. This is an important consideration given the current emphasis on esthetics in dentistry [48,52,53]. Results of color change revealed that the Fluroshield ™ brand demonstrated a significant difference when contrasted with the Ultraseal XT ™ brand. A smooth surface enhances light reflection, thereby resulting in brightness, a property measured by spectrophotometers and colorimeters. Hence, one probable reason for the color change observed in Fluroshield ™ sealant treated with β-$AgVO_3$ could be the rough surface that diminishes the light reflection capacity as read by the spectrophotometer [48,57].

The alteration in the Fluroshield™ sealant upon the inclusion of the nanomaterial, when compared to the control group, could be attributed to its interaction with a particular component of the material's chemical composition. Color change evaluation is typically employed to examine the correlation between the duration of material use inside the oral cavity and internal discoloration. Certain analyses may still impact the results of this study, specifically those concerned with evaluating the effects of time of use, exposure to acids, food coloring, and other cavity-related factors that could cause alterations to β-$AgVO_3$-modified sealants [57]. Nonetheless, it is important to note that a noticeable color change occurs when $\Delta E00 > 1$, and acceptable ΔE00 values are restricted to $\Delta E00 < 3.3$ [51–53]. Therefore, the modified sealants tested in this study fall within the range of acceptable clinical values [48,52].

This study has limitations regarding the dispersal of β-$AgVO_3$ particles in fissure sealants. An alternative incorporation method is recommended. Additionally, an evaluation of the nanomaterial's potential antimicrobial activity, which could play a vital role in caries prevention, was absent. Further evaluation is also necessary for physical-mechanical properties such as degree of conversion, adhesion to dental structures, and changes in the color of extracted teeth. Further research is required to address these limitations. Nonetheless, the implementation of nanostructured silver vanadate adorned with silver nanoparticles exhibits prospective usefulness in pit and fissure sealants for preventing caries disease. However, additional in vitro assessments are required to assess the modified material's antimicrobial effectiveness, ion discharge, cytotoxicity, shear strength, and other physicochemical and mechanical traits, to determine its practicality.

5. Conclusion

We can infer from the data found in this study that the addition of 2.5% and 5% β-$AgVO_3$ in pit and fissure sealants:

- Promoted changes in the roughness of Ultraseal XT ™ sealant;
- Did not promote changes in the microhardness of Ultraseal XT ™ and Fluroshield ™ sealants.
- Altered the color of Fluroshield ™ sealant, but within clinically acceptable limits.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Izabela Ferreira: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Oswaldo Luiz Alves:** Validation, Resources, Methodology. **Marco Antônio Schiavon:** Validation, Software, Resources, Methodology. **Andréa Cândido dos Reis:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] I.M. Garcia, S.B. Rodrigues, V.C.B. Leitune, F.M. Collares, Antibacterial, chemical and physical properties of sealants with polyhexamethylene guanidine hydrochloride, Braz. Oral Res. 33 (2019 Mar 18) e019, https://doi.org/10.1590/1807-3107bor-2019.vol33.0019.

[2] J.T. Wright, M.P. Tampi, L. Graham, C. Estrich, J.J. Crall, M. Fontana, E.J. Gillette, B.B. Nový, V. Dhar, K. Donly, E.R. Hewlett, R.B. Quinonez, J. Chaffin, M. Crespin, T. Iafolla, M.D. Siegal, A. Carrasco-Labra, Sealants for preventing and arresting pit-and-fissure occlusal caries in primary and permanent molars, Pediatr. Dent. 38 (4) (2016) 282–308, https://doi.org/10.1016/j.adaj.2016.06.003. Erratum in: Pediatr Dent. 2017 Mar 15;39(2):100.

[3] B.C. Borges, E.J. Souza-Júnior, A. Catelan, J.R. Lovadino, P.H. Dos Santos, L.A. Paulillo, F.H. Aguiar, Influence of extended light exposure time on the degree of conversion and plasticization of materials used as pit and fissure sealants, J. Investig. Clin. Dent. 1 (2) (2010 Nov) 151–155, https://doi.org/10.1111/j.2041-1626.2010.00015.x.

[4] M.L. Junger, S.O. Griffin, S. Lesaja, L. Espinoza, Awareness among US adults of dental sealants for caries prevention, Prev. Chronic Dis. 16 (2019 Mar 14) E29, https://doi.org/10.5888/pcd16.180398.

[5] K.R. Kantovitz, F.M. Pascon, F.H. Nociti Jr., C.P. Tabchoury, R.M. Puppin-Rontani, Inhibition of enamel mineral loss by fissure sealant: an in situ study, J. Dent. 41 (1) (2013 Jan) 42–50, https://doi.org/10.1016/j.jdent.2012.09.015.

[6] R.C. Soares, S.V. da Rosa, S.T. Moysés, J.S. Rocha, P.V.C. Bettega, R.I. Werneck, S.J. Moysés, Methods for prevention of early childhood caries: overview of systematic reviews, Int. J. Paediatr. Dent. 31 (3) (2021) 394–421, https://doi.org/10.1111/ipd.12766.

[7] B. Özgür, S.T. Kargın, M.S. Ölmez, Clinical evaluation of giomer- and resin-based fissure sealants on permanent molars affected by molar-incisor hypomineralization: a randomized clinical trial, BMC Oral. Health 22 (1) (2022) 275, https://doi.org/10.1186/s12903-022-02298-9.

[8] J. Kharouba, A.A. Gonoratsky, T. Brosh, M. Masri, R. Iraqi, S. Blumer, Effect of different etching times on pit-and-fissure sealant micro-shear bond strength to the enamel of primary teeth, Children (Basel, Switzerland) 10 (3) (2023) 461, https://doi.org/10.3390/children10030461.

[9] H. Alharthy, H.M. Elkhodary, A. Nahdreen, A. Al Tuwirqi, K. Baghlaf, Comparative evaluation of retention and cariostatic effect of hydrophilic and hydrophobic resin-based sealants: a systematic review and meta-analysis, Niger. J. Clin. Pract. 25 (6) (2022) 861–884, https://doi.org/10.4103/njcp.njcp_1863_21.

[10] N.M. Dos Santos, S.C. Leal, D.B. Gouvea, C.S. Sarti, J. Toniolo, M. Neves, J.A. Rodrigues, Sealing of cavitated occlusal carious lesions in the dentine of deciduous molars: a two-year randomised controlled clinical trial, Clin. Oral Invest. 26 (1) (2022) 1017–1024, https://doi.org/10.1007/s00784-021-04085-2.

[11] Y.T. Hu, F. Yu, X.Y. Tang, W.Z. Wu, P. Zhang, Z.H. Hu, J.H. Chen, X.D. Xing, Y.H. Xiao, The antibacterial effect and physical performance of pit and fissure sealants based on an antibacterial core-shell nanocomposite, J. Mech. Behav. Biomed. Mater. 117 (2021 May) 104414, https://doi.org/10.1016/j.jmbbm.2021.104414.

[12] R.J. Feigal, Sealants and preventive restorations: review of effectiveness and clinical changes for improvement, Pediatr. Dent. 20 (2) (1998) 85–92. PMID: 9566011.

[13] A. Behroozian, Z. Aghazadeh, Z.K. Sadrabad, M. Aghazadeh, V. Alizadeh, Z. Esmaili, M. Pirzadeh Ashraf, Evaluation of the success rate of pit and fissure sealants on first molars: 12 months follow-up study, Int. J. Dent. Hyg. (2021 Dec 13), https://doi.org/10.1111/idh.12566.

[14] S.M. Fiorati-Aguiar, M.P. Lucisano, L.A.B.D. Silva, R.A.B.D. Silva, A.C.C. Spadaro, M.C. Borsatto, P. Nelson-Filho, Mechanical, chemical and antimicrobial properties of a bisphenol A-free pit-and-fissure sealant, Am. J. Dent. 31 (6) (2018 Dec) 279–284. PMID: 30658372.

[15] K.M.S. Moreira, K.R. Kantovitz, J.P.D. Aguiar, A.F.S. Borges, F.M. Pascon, R.M. Puppin-Rontani, Impact of the intermediary layer on sealant retention: a randomized 24-month clinical trial, Clin. Oral Invest. 21 (5) (2017 Jun) 1435–1443, https://doi.org/10.1007/s00784-016-1890-4.

[16] M. Faria, P. Rompante, B. Henriques, et al., Degradation of tooth occlusal fissure and pit sealants by wear and corrosion pathways: a short review, J. Bio. Tribo. Corros. 7 (2021) 111, https://doi.org/10.1007/s40735-021-00547-y.

[17] H. Ramesh, R. Ashok, M. Rajan, L. Balaji, A. Ganesh, Retention of pit and fissure sealants versus flowable composites in permanent teeth: a systematic review, Heliyon 6 (9) (2020) e04964, https://doi.org/10.1016/j.heliyon.2020.e04964.

[18] S. Beun, C. Bailly, J. Devaux, G. Leloup, Physical, mechanical and rheological characterization of resin-based pit and fissure sealants compared to flowable resin composites, Dent. Mater. 28 (4) (2012 Apr) 349–359, https://doi.org/10.1016/j.dental.2011.11.001.

[19] Selvakumar Kritika, B. Jothimani, Vidhya Sampath, Sanjeev Kavitha, Mahalaxmi Sekar, B. Venkatachalapathy, S. Sureshkumar, Incorporation of hydrophobic nanochitosan improves wear resistance of dental sealants, Int. J. Polym. Mater. Polym. Biomater. 70 (5) (2021) 309–317, https://doi.org/10.1080/00914037.2020.1713782.

[20] M. Memarpour, A. Abedinzade, A. Rafiee, A. Hashemian, Penetration ability and microhardness of infiltrant resin and two pit and fissure sealants in primary teeth with early enamel lesions, Sci. Rep. 12 (1) (2022) 4652, https://doi.org/10.1038/s41598-022-08725-9.

[21] H. Li, Y. Huang, X. Zhou, C. Zhu, Q. Han, H. Wang, H.H.K. Xu, B. Ren, L. Cheng, Intelligent pH-responsive dental sealants to prevent long-term microleakage, Dent. Mater. 37 (10) (2021 Oct) 1529–1541, https://doi.org/10.1016/j.dental.2021.08.002.

[22] T. Prabahar, N. Chowdhary, K.N. Konkappa, R.R. Vundela, S. Balamurugan, Evaluation of microleakage of different types of pit and fissure sealants: an in vitro comparative study, Int. J. Clin. Pediatr. Dent. 15 (5) (2022) 535–540, https://doi.org/10.5005/jp-journals-10005-2436.

[23] C.J. Oulis, E.D. Berdouses, Fissure sealant retention and caries development after resealing on first permanent molars of children with low, moderate and high caries risk, Eur. Arch. Paediatr. Dent. 10 (4) (2009 Dec) 211–217, https://doi.org/10.1007/BF03262684.

[24] X. Fei, Y. Li, M.D. Weir, B.H. Baras, H. Wang, S. Wang, J. Sun, M.A.S. Melo, J. Ruan, H.H.K. Xu, Novel pit and fissure sealant containing nano-CaF2 and dimethylaminohexadecyl methacrylate with double benefits of fluoride release and antibacterial function, Dent. Mater. 36 (9) (2020 Sep) 1241–1253, https://doi.org/10.1016/j.dental.2020.05.010.

[25] I. Ferreira, T.T. de Oliveira, A.C. dos Reis, Antimicrobial activity in pit and fissure sealants: a systematic review, Clin. Lab. Res. Dent. (2022. Jan) 1–10, https://doi.org/10.11606/issn.2357-8041.clrd.2022.192671.

[26] M.S. Ibrahim, A.A. Balhaddad, I.M. Garcia, E. Hefni, F.M. Collares, F.C. Martinho, M.D. Weir, H.H.K. Xu, M.A.S. Melo, Tooth sealing formulation with bacteria-killing surface and on-demand ion release/recharge inhibits early childhood caries key pathogens, J. Biomed. Mater. Res. B Appl. Biomater. 108 (8) (2020 Nov) 3217–3227, https://doi.org/10.1002/jbm.b.34659.

[27] K.G. Silva, D. Pedrini, A.C. Delbem, L. Ferreira, M. Cannon, In situ evaluation of the remineralizing capacity of pit and fissure sealants containing amorphous calcium phosphate and/or fluoride, Acta Odontol. Scand. 68 (1) (2010 Jan) 11–18, https://doi.org/10.3109/00016350903260264.

[28] A.K. Shanmugaavel, S. Asokan, J.B. John, P.G. Priya, J.G. Devi, Effect of one percent chlorhexidine addition on the antibacterial activity and mechanical properties of sealants: an in vitro study, Int. J. Clin. Pediatr. Dent. 8 (3) (2015 Sep-Dec) 196–201, https://doi.org/10.5005/jp-journals-10005-1312.

[29] D.T. de Castro, M.L. Valente, J.A. Agnelli, C.H. Lovato da Silva, E. Watanabe, R.L. Siqueira, O.L. Alves, R.D. Holtz, A.C. dos Reis, In vitro study of the antibacterial properties and impact strength of dental acrylic resins modified with a nanomaterial, J. Prosthet. Dent 115 (2) (2016 Feb) 238–246, https://doi.org/10.1016/j.prosdent.2015.09.003.

[30] D.T. de Castro, M.L. Valente, C.H. da Silva, E. Watanabe, R.L. Siqueira, M.A. Schiavon, O.L. Alves, A.C. Dos Reis, Evaluation of antibiofilm and mechanical properties of new nanocomposites based on acrylic resins and silver vanadate nanoparticles, Arch. Oral Biol. 67 (2016 Jul) 46–53, https://doi.org/10.1016/j.archoralbio.2016.03.002.

[31] S. Kreve, A.L. Botelho, M. Lima da Costa Valente, L. Bachmann, M.A. Schiavon, A.C. Dos Reis, Incorporation of a β-AgVO3 semiconductor in resin cement: evaluation of mechanical properties and antibacterial efficacy, J. Adhesive Dent. 24 (1) (2022) 155–164, https://doi.org/10.3290/j.jad.b2916423.

[32] A.B. Vilela Teixeira, C. de Carvalho Honorato Silva, O.L. Alves, A. Cândido Dos Reis, Endodontic sealers modified with silver vanadate: antibacterial, compositional, and setting time evaluation, BioMed Res. Int. 2019 (2019 May 9) 4676354, https://doi.org/10.1155/2019/4676354.

[33] A.B.V. Teixeira, C.L. Vidal, D.T. de Castro, C. de Oliveira-Santos, M.A. Schiavon, A.C. Dos Reis, Incorporating antimicrobial nanomaterial and its effect on the antimicrobial activity, flow and radiopacity of endodontic sealers, Eur. Endod. J. 2 (1) (2017 Jul 6) 1–6, https://doi.org/10.14744/eej.2017.16029.

[34] I. Ferreira, C.L. Vidal, A.L. Botelho, P.S. Ferreira, M.L.D.C. Valente, M.A. Schiavon, O.L. Alves, A.C. Dos Reis, Effect of nanomaterial incorporation on the mechanical and microbiological properties of dental porcelain, J. Prosthet. Dent 123 (3) (2020 Mar) 529.e1–529.e5, https://doi.org/10.1016/j.prosdent.2019.10.012.

[35] C.L. Vidal, I. Ferreira, P.S. Ferreira, M.L.C. Valente, A.B.V. Teixeira, A.C. Reis, Incorporation of hybrid nanomaterial in dental porcelains: antimicrobial, chemical, and mechanical properties, Antibiotics (Basel) 10 (2) (2021 Jan 20) 98, https://doi.org/10.3390/antibiotics10020098.

[36] L.M. Uehara, I. Ferreira, A.L. Botelho, M.L.D.C. Valente, A.C.D. Reis, Influence of β-AgVO3 nanomaterial incorporation on mechanical and microbiological properties of dental porcelain, Dent. Mater. 38 (6) (2022) e174–e180, https://doi.org/10.1016/j.dental.2022.04.022.

[37] S. Kreve, V.C. Oliveira, L. Bachmann, O.L. Alves, A.C.D. Reis, Influence of AgVO3 incorporation on antimicrobial properties, hardness, roughness and adhesion of a soft denture liner, Sci. Rep. 9 (1) (2019 Aug 15) 11889, https://doi.org/10.1038/s41598-019-48228-8.

[38] R.D. Holtz, A.G. Souza Filho, M. Brocchi, D. Martins, N. Durán, O.L. Alves, Development of nanostructured silver vanadates decorated with silver nanoparticles as a novel antibacterial agent, Nanotechnology 21 (18) (2010 May 7) 185102, https://doi.org/10.1088/0957-4484/21/18/185102.

[39] R.D. Holtz, B.A. Lima, A.G. Souza Filho, M. Brocchi, O.L. Alves, Nanostructured silver vanadate as a promising antibacterial additive to water-based paints, Nanomedicine 8 (6) (2012 Aug) 935–940, https://doi.org/10.1016/j.nano.2011.11.012.

[40] M.R. de Campos, A.L. Botelho, A.C. Dos Reis, Nanostructured silver vanadate decorated with silver particles and their applicability in dental materials: a scope review, Heliyon 7 (6) (2021 May 28) e07168, https://doi.org/10.1016/j.heliyon.2021.e07168.

[41] D.T. de Castro, S. Kreve, V.C. Oliveira, O.L. Alves, A.C. Dos Reis, Development of an impression material with antimicrobial properties for dental application, J. Prosthodont. 28 (8) (2019 Oct) 906–912, https://doi.org/10.1111/jopr.13100.

[42] E. Ferrando-Magraner, C. Bellot-Arcís, V. Paredes-Gallardo, J.M. Almerich-Silla, V. García-Sanz, M. Fernández-Alonso, J.M. Montiel-Company, Antibacterial properties of nanoparticles in dental restorative materials. A systematic review and meta-analysis, Medicina (Kaunas) 56 (2) (2020 Jan 29) 55, https://doi.org/10.3390/medicina56020055.

[43] E.K. Salas-López, M. Pierdant-Pérez, J.F. Hernández-Sierra, F. Ruíz, P. Mandeville, A.J. Pozos-Guillén, Effect of silver nanoparticle-added pit and fissure sealant in the prevention of dental caries in children, J. Clin. Pediatr. Dent 41 (1) (2017) 48–52, https://doi.org/10.17796/1053-4628-41.1.48.

[44] P. Rahmath Meeral, J. Prabakar, M.A. Indiran, J. Ganesh, S. Rajesh Kumar, Silver nanoparticles incorporated hydrophilic pit and fissure sealant- its preparation, characterization and assessment of shear bond strength, J. Popul. Ther. Clin. Pharmacol. 30 (6) (2023) 102–109, https://doi.org/10.47750/jptcp.2023.30.06.014.

[45] S. Amend, R. Frankenberger, S. Lücker, N. Krämer, Caries-inhibiting effect of microencapsulated active components in pit and fissure sealants, Operat. Dent. 47 (4) (2022 Jul 1) E174–E187, https://doi.org/10.2341/20-048-L.

[46] N.A. Hamzah, N.A.A. Razak, M.S.A. Karim, et al., Validation of roughness parameters for defining surface roughness of prosthetic polyethylene Pe-Lite liner, Sci. Rep. 12 (2022) 2636, https://doi.org/10.1038/s41598-022-05173-3.

[47] K. Palová, T. Kelemenová, M. Kelemen, Measuring procedures for evaluating the surface roughness of machined parts, Appl. Sci. 13 (2023) 9385, https://doi.org/10.3390/app13169385.

[48] A. Nikolaidis, T. Vouzara, E. Koulaouzidou, Pit and fissure nanocomposite sealants reinforced with organically modified montmorillonite: a study of their mechanical properties, surface roughness and color stability, Dent. Mater. J. 39 (5) (2020 Sep 29) 773–783, https://doi.org/10.4012/dmj.2019-214.

[49] O. Sahin, A. Koroglu, D.Ö. Dede, B. Yilmaz, Effect of surface sealant agents on the surface roughness and color stability of denture base materials, J. Prosthet. Dent 116 (4) (2016) 610–616, https://doi.org/10.1016/j.prosdent.2016.03.007.

[50] S. Suliman, T.A. Sulaiman, V.G. Olafsson, A.J. Delgado, T.E. Donovan, H.O. Heymann, Effect of time on tooth dehydration and rehydration, J. Esthetic Restor. Dent. 31 (2) (2019) 118–123, https://doi.org/10.1111/jerd.12461.

[51] M.F. Hamilton, A.D. Otte, R.L. Gregory, R. Pinal, A. Ferreira-Zandoná, M.C. Bottino, Physicomechanical and antibacterial properties of experimental resin-based dental sealants modified with nylon-6 and chitosan nanofibers, J. Biomed. Mater. Res. B Appl. Biomater. 103 (8) (2015 Nov) 1560–1568, https://doi.org/10.1002/jbm.b.33342.

[52] E. Karaman, D. Tuncer, E. Firat, O.S. Ozdemir, S. Karahan, Influence of different staining beverages on color stability, surface roughness and microhardness of silorane and methacrylate-based composite resins, J. Contemp. Dent. Pract. 15 (3) (2014 May 1) 319–325, https://doi.org/10.5005/jp-journals-10024-1536.

[53] P. Shetty, T.P. Purayil, K. Ginjupalli, K.C. Pentapati, Effect of polishing technique and immersion in beverages on color stability of nanoceramic composites, J. Oral. Biol. Craniofac. Res. 11 (1) (2021) 53–56, https://doi.org/10.1016/j.jobcr.2020.11.011.

[54] C.M. Vrbin, Parametric or nonparametric statistical tests: considerations when choosing the most appropriate option for your data, Cytopathology 33 (6) (2022) 663–667, https://doi.org/10.1111/cyt.13174.

[55] S. Hesaraki, M. Karimi, N. Nezafati, The synergistic effects of SrF2 nanoparticles, YSZ nanoparticles, and poly-ε-l-lysin on physicomechanical, ion release, and antibacterial-cellular behavior of the flowable dental composites, Mater. Sci. Eng., C 109 (2020 Apr) 110592, https://doi.org/10.1016/j.msec.2019.110592.

[56] J.C. Monteiro, M. Stürmer, I.M. Garcia, M.A. Melo, S. Sauro, V.C.B. Leitune, F.M. Collares, Dental sealant empowered by 1,3,5-tri acryloyl hexahydro-1,3,5-triazine and α-tricalcium phosphate for anti-caries application, Polymers 12 (4) (2020 Apr 12) 895, https://doi.org/10.3390/polym12040895.

[57] E.H. Ozera, F.M. Pascon, A.B. Correr, R.M. Puppin-Rontani, A.R. Castilho, L. Correr-Sobrinho, A.B. Paula, Color stability and gloss of esthetic restorative materials after chemical challenges, Braz. Dent. J. 30 (1) (2019 Jan-Feb) 52–57, https://doi.org/10.1590/0103-6440201902263.