ASDJ
AINSHAMS DENTAL
JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
September 2024 • Vol. 35

# Microleakage and Wear resistance of Beautisealant and Clinpro dental sealants: An In-vitro study

*Omnia Bebers*[1], *Mariem Osama Wassel*[2], *Mohammed Nasser*[3], *Ola Abd El Geleel*[4,5]

**Aim:** To compare two distinct types of pit and fissure sealants, namely the Giomer-based Beautisealant sealant and the Resin-based ClinproTM sealant, regarding their microleakage and wear resistance.
**Materials and methods:** The study comprised of 28 teeth collected from the department of Oral and Maxillofacial surgery, Ain Shams University. They were divided into two equal groups. One group received the Giomer based fissure sealant Beautisealant and the other group received the Resin based sealant ClinproTM. Thermocycling (500 times/5– 55 ◦C) followed by dye penetration test were done. Specimens were then buccolingually sectioned, examined under a stereomicroscope followed by assessment of microleakage. For wear resistance testing a total of 16 disk specimens were prepared, eight disks for each material. Thermocycling (500 times/5– 55 ◦C) and chewing simulator (75,000 times/49 N) were applied as the aging procedures. Scans were made before and after aging procedures. Wear resistance was quantitively measured by using the Geomagic software to superimpose specimen scans. Mann-Whitney U test showed statistically significant difference between both groups in terms of microleakage (p<0.001). Wear data were normally distributed and analyzed using independent t-test.
**Results:** Beautisealant specimens had significantly higher microleakage scores than ClinproTM (p<0.001). However, ClinproTM (251.90±65.09) (µm) had a significantly higher wear value than Beautisealant (70.44±21.01) (µm) (p<0.001).
**Conclusions:** Resin-based sealants seem to provide a better seal at the tooth-sealant interface. However, Giomer-based sealants seem to have better mechanical performance.
.

**Keywords:** Giomer, chewing simulator, Self-etch, Etch and rinse.

1. MSc student, Pediatric Dentistry and Dental Public Health Department, Faculty of Dentistry, Ain Shams University.
2. Professor of Pediatric Dentistry and Dental Public Health Faculty of Dentistry, Ain shams University.
3. Assistant Professor of Operative Dentistry, Faculty of Dentistry, Ain shams University.
4. Assistant professor, Pediatric Dentistry and Dental Public Health Department, Faculty of Dentistry, Ain-Shams University, Cairo, Egypt.
5. Assistant professor, Pediatric Dentistry and Dental Public Health Department, Faculty of Dentistry, British University in Egypt, Cairo, Egypt.

Corresponding author: Omnia Bebers, email: omniabebers@dent.asu.edu.eg

## Introduction

The effectiveness of fissure sealants in preventing caries in the pit and fissures of teeth has been well-established.[1] First permanent molars are the most caries-susceptible teeth during their first and second years of eruption. Enamel has not fully matured and coalesced during this time; moreover, maintaining good oral hygiene of the erupting teeth might be challenging due to the lack of awareness of the newly emerged teeth.[2] Fluoride effectiveness at this region is further reduced due to a lack of salivary access into the fissures.

Resin based sealants (RBS) are considered the material of choice as they have high retention rates and high wear resistance, provided that appropriate isolation can be achieved.[3] However, technique sensitivity is the primary drawback for RBS. On the other hand, Glass ionomer cements (GIC) form a chemical bond with dental tissue and release fluoride, which has an anticariogenic effect. However, they have lack toughness, exhibit early water sensitivity, have low abrasion resistance, and show varying retention rates.

To overcome this, Giomer-based fissure sealing material was introduced, which combines the enhanced retention and wear resistance of resin- based sealants with the fluoride releasing properties of glass-ionomer-based sealants.[4] Another important aspect contributing to the success of a sealant is its marginal integrity, which can be evaluated by assessing microleakage.

Microleakage refers to the infiltration of bacteria and oral fluids into the space between the restoration and tooth structure. Inadequate sealing may lead to the advancement of dental caries beneath the restoration.[5] The success rate of these sealants also relies on their capability to serve as a protective barrier between the oral environment and the fissures of occlusal surfaces.[6]

The mechanical movements and temperature fluctuations within the oral cavity can adversely impact the physical structure of those sealants and the success of applied treatments. Therefore, in-vitro evaluation of dental materials is often preferred to simulate oral cavity conditions.

Few studies investigated microleakage[7,26,27] of the investigated sealants: Beautisealant (SHOFU INC, Japan) and Clinpro™(3M ESPE, U.S.A.), and even fewer investigated their wear resistance.[8] As a result, the study's aim was to further assess and compare microleakage and wear resistance of two different fissure-sealant materials. The null hypothesis of this study is that there will be no difference between Giomer based sealant (Beautisealant) and resin-based sealant (Clinpro™) in terms of microleakage and wear resistance.

## Materials and methods

### Ethical considerations:

This study was exempted from ethical review by Ain Shams University Research Ethics Committee (FDASU-REC) as it was an in-vitro study that used extracted teeth collected from anonymous patients. The ethical approval number was FDASU-RecEM022203.

### Study design

The study was designed following an in-vitro experimental model.

### Materials

All the materials utilized in the study are listed in the following table (Table 1).

**Table 1:** Materials utilized in the study.

| Commercial name | Material | Composition | Manufacturer |
|---|---|---|---|
| 1- 3M™ Scotchbond ™ Universal Etchant. | 34% Phosphoric acid etching gel | Water, Phosphoric acid, Synthetic amorphous silica, fumed, crystalline-free, Polyethylene Glycol, Aluminum oxide | 3M Deutschland GmbH Dental Products, Neuss, Germany |
| 2- Clinpro™ Sealant. | Resin based, fluoride releasing pit and fissure sealant with a unique color-change feature. | Matrix: BIS-GMA /TEGDMA camphorquinone tertiary amine, iodonium salt. Silane-treated fumed silica (6wt%). Titanium dioxide Rose Bengal dye. Light cure initiator system: camphorquinone, a tertiary amine, and an iodonium salt. Unfilled matrix Fluoride: patented organic fluoride salt | 3M ESPE Dental Products, St Paul, MN, U.S.A |
| 3- Beautisealant Paste. | Giomer based Fluoride Releasing Pit and Fissure Sealant | Fluoroboroaluminosilicate glass UDMA TEGDMA Micro fumed silica | SHOFU INC., Kyoto, Japan |
| 4- Beautisealant Primer. | Self-etch Primer featuring dual adhesive monomers | Acetone, Distilled water, Carboxylic acid monomer, Phosphonic acid monomer | SHOFU INC. Kyoto, Japan |
| 5- Prophy paste. | Prophylaxis polishing paste | Oil free, fluoride free, universal grit prophylaxis paste | PSP Dental Company Ltd. UK |

**Microleakage testing:**

A total of twenty-eight sound human permanent molars were collected. The teeth were thoroughly debrided and cleaned using an ultrasonic scaler and a non-fluoridated pumice with a prophy cup mounted on a low-speed contra-angle handpiece. The teeth were then stored in distilled water, to prevent their dehydration, at room temperature. The distilled water was changed on weekly basis until experiment time.

Teeth specimens were serially numbered and then randomly distributed into two major groups of teeth (14 specimens each) according to type of sealant they received: Group 1 received Beautisealant (Shofu INC, Japan) fissure sealant, and group 2 received Clinpro™ (3M ESPE, U.S.A.) fissure sealant.

- **Beautisealant application**

Primer was applied on the fissures using a micro brush and was left undisturbed for 5 seconds, then Gentle air drying for 3 seconds was done, followed by a stronger stream of air until a thin and uniform bonding layer was obtained.[9] A suitable amount of Beautisealant (Shofu INC, Japan) fissure sealant was then injected directly in the center of the fissure and a sharp explorer was used to spread it gently ensuring that it is free of any voids. Any excess sealant material was removed using a dry micro brush. The sealant was light-cured using Mini Led (420-480 nm, 1250mW/cm²) (Acteon, France) with overlapping exposures for 20 seconds each.

- **Clinpro™ fissure sealant application**

Enamel was etched for 30 seconds using the 34% phosphoric acid etch, extending beyond the anticipated margin of the sealant**.** This was followed by 30 seconds of rinsing and then air dried till a frosty white appearance was achieved.[10] Clinpro™ (3M ESPE, U.S.A.) fissure sealant was then injected into the center of the fissure, and gently stirred using a sharp explorer to ensure that there were no entrapped air bubbles. Excess sealant material was removed using a dry micro brush, followed by light-curing with overlapping exposures for 20 seconds each, using Mini Led (420-480 nm, 1250mW/cm²) (Acteon, France). The light-curing tip was brought as close as possible the specimens' surface and was at a perpendicular angulation.[9]

To ensure the removal of the oxygen-inhibited layer, glycerin gel was applied followed by light curing. Subsequently, the surface was rubbed using an alcohol-moistened cotton pellet.[9]

Specimens were subjected to thermocycling at 500 cycles between temperature of 5°C and 55°C in controlled water bath with a dwell time of 30 seconds in each water bath and transfer time of 15 seconds.[11] A double layer of nail varnish was then applied, leaving a 1 mm window between the varnish and the sealant material. Following that, teeth specimens were embedded in chemical cured acrylic resin (Acrostone, Egypt) and immersed in 2%

methylene blue (SD Fine-Chem limited, Mumbai, India) at room temperature for 24 hours.[12] Following dye immersion the teeth were then washed under running water to remove the excess dye. Specimens were then buccolingually sectioned through the center of the tooth using an Isomet 4000 precision saw (Buehler, Germany) to provide two sections for each tooth. Sections were examined under stereomicroscope and photographs were taken using Microscope professional HD Camera (Mechanic, DX-230).[11] Assessment was done following dye penetration and sectioning.

Microleakage assessment process was conducted utilizing Ovrebo and Raadal criteria for evaluation of dye penetration: [13]

Score 0: No dye penetration.

Score 1: Dye penetration restricted to outer half of enamel–sealant interface.

Score 2: Dye penetration in inner half of enamel–sealant Interface.

Score 3: Dye penetration into underlying fissure.

**Wear resistance testing:**

- **Disk specimens preparation**

Sixteen disk specimens (eight of each sealant) were prepared by injecting the material into a costume made split Teflon mold with an internal diameter of 8 mm and internal height of 3 mm.[14] Following this, a Mylar strip was placed on top of the mold, followed by a glass plate. Gentle pressure was placed on the glass plate to remove any extruded excess. Each specimen was cured, using the MiniLED curing light (Acteon, France) with a wavelength range of 420-480 nm and light intensity of 1250 mW/cm² for 20 seconds.

Specimens were scanned using the 3-Dimensional scanner Sirona ineos X5 (Dentsply Sirona, USA) and an STL file was produced for each specimen as a reference for the surface before the aging process. Afterwards, the specimens were subjected to thermocycling in the thermocycling apparatus at 500 cycles between temperature of 5°C and 55°C in controlled water bath with a dwell time of 30 seconds in each water bath and transfer time of 15 seconds. After thermocycling, the specimens were mounted in the chewing simulator CS-4 (Willytec/SD Mechatronik GmbH, Feldkirchen-Westerham, Germany) and was set to 75,000 cycles to be equivalent to 6 months chewing conditions under the load of 49N. [10]

The specimens were then scanned again to obtain the STL file post aging. The STL files representing the samples before and after aging were imported into 3D inspection and metrology software (Geomagic control X 2020. 1.1). The STL files taken before the aging process were set as reference for the upcoming comparisons and the STL files post aging were set as measured data.[15] Then, the two files were superimposed using the transform alignment software tool and pick up points followed by best fit alignment algorithm.

Wear was then measured in root mean square (RMS) using the 3D compare software tool. The wear qualitative data was represented in color map after setting a specific tolerance ranging from 0.01 to -0.01 mm indicating perfect superimposition with no wear in green color and area of wear was represented in light to dark blue color.

**Statistical Analysis**

Numerical data were presented as mean, standard deviation (SD), median, and interquartile range (IQR) values. They were explored for normality by checking the data distribution and by using the Shapiro-Wilk test. Wear data were normally distributed and were analyzed using an independent t-test. Ordinal data were presented as frequency and percentage values and were analyzed using the Mann-Whitney U test. Correlations were analyzed using Spearman's rank-order correlation coefficient. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.3.2 for Windows.[16]

## Results

### 1- Microleakage

Mann-Whitney U test showed a statistically significant difference between both groups in terms of microleakage ($p<0.001$). Beautisealant specimens had significantly higher microleakage scores than Clinpro™ ($p<0.001$). Frequency and percentage of microleakage values in both groups are presented in figure (1). Sections with different microleakage scores under the stereomicroscope are shown in figure (2).

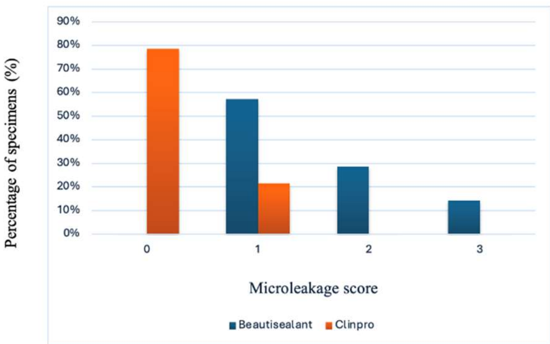


Figure 1: Clustered bar chart showing microleakage score for both groups.

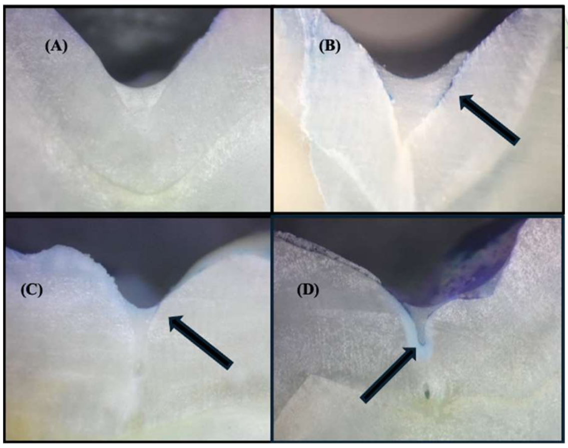


Figure 2: Evaluation of microleakage scores under stereomicroscope; (A) Score 0, (B) Score 1, (C) Score 2, (D) Score 3.

### 2- Wear resistance

Wear data were normally distributed and were analyzed using independent t-test. Clinpro (251.90±65.09) (µm) had a significantly higher wear value than Beautisealant (70.44±21.01) (µm) ($p<0.001$). Mean and Standard deviation (SD) and Interquartile range values (IQR) for amount of wear (µm) are presented in figure (3) and table (2), while figure (4) shows the superimposed pre and post-aging scans to compare the surface changes and assess the amount of wear.

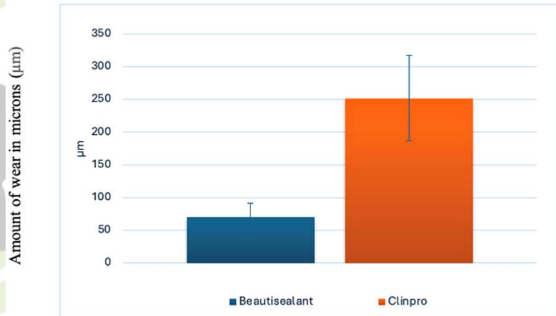


Figure 3: Bar chart showing average amount of wear (µm) for different groups.

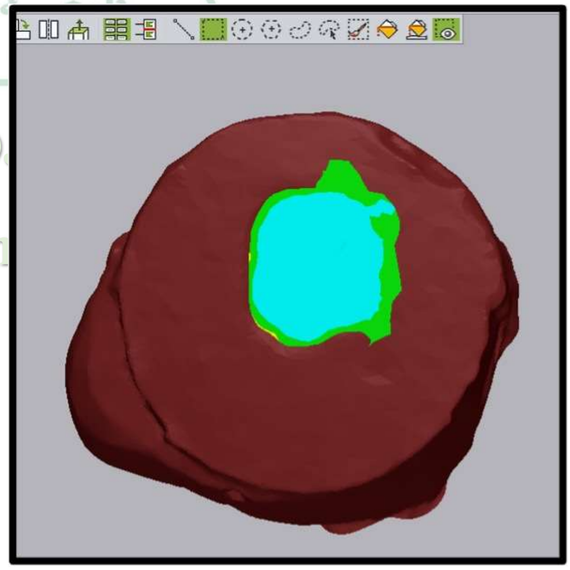

Figure 4: Superimposed pre and post-aging scans to compare the surface changes and assess the amount of wear.

Table 2: Intergroup comparison and summary statistics for the amount of wear (µm).

| Amount of wear (Mean±SD) (µm) | | Mean difference (95% CI) | t-value | p-value |
|---|---|---|---|---|
| Beautisealant | Clinpro | | | |
| 70.44±21.01 | 251.90±65.09 | -181.46 (-233.33:-129.60) | 7.50 | <0.001* |

CI Confidence interval, * Significant ($p<0.05$).

## Discussion

Pit and fissure sealants are an essential preventive strategy that can be used as a primary prevention measure to avoid dental caries or as a secondary prevention measure to halt disease progression.[17] The success rate of pits and fissures sealants is dependent on long-term retention and marginal adaptation to the tooth surface.[18] In instances where sealing is inadequate, microleakage can occur, potentially triggering the progression of caries lesions beneath the restoration, hence, microleakage was assessed in the present study.[5] Furthermore, wear resistance directly impacts the level of surface roughness, a factor that can contribute to plaque retention and consequently elevate the risk of dental caries.[10] Therefore, wear resistance was also assessed in our study.

Various methods can be used to assess in-vitro microleakage, such as dyes, chemical tracers, scanning electron microscopy, and neutron activation analysis. In this study, the dye penetration method was selected due to its simplicity, cost-effectiveness, and efficiency, eliminating the need for intricate laboratory equipment.[11]

The dye penetration approach uses contrasting dyes to stain sites of microleakage, followed by examination of the tooth-restoration interface for staining. The most used solutions include 0.5% basic fuchsin, 2% methylene blue, and 50% silver nitrate.[19] Methylene blue 2% was selected because of ease of availability and manipulation. The specimens were soaked in the dye for twenty-four hours which is a standard time span for dye to penetrate.[20]

The most frequently employed aging method is thermocycling, given its ability to reproduce the thermal cycles experienced in the oral environment. These cycles induce stresses through expansion and contraction, contributing to the weakening of materials.[21] While long-term thermocycling, up to 100,000 cycles, can reveal differences in the bond durability of various adhesives, reveal differences in the bond durability of various adhesives, the International Organization for Standardization (ISO) recommends a shorter thermocycling routine of 500 cycles[22] and so this was employed in our study, with temperatures between 5 ˚C and 55 ˚C and dwell time of 30 seconds as this is considered to be suitable to simulate short-term aging of dental materials.[23] A widely used method in dental research to simulate temperature changes that take place in the oral environment. [24]

The stereomicroscope, recognized as the gold standard for studying microleakage, was employed in this study. Multiple-surface scoring methods are preferred over single-surface methods as they provide a more accurate representation of leakage patterns.[25] Therefore, in the present study each specimen was cut into two sections and assessments were made based on those sections.

The results of the present study regarding the microleakage test revealed a significant difference between both groups. Beautisealant had a significantly higher score value than Clinpro ($p<0.001$).

The increased microleakage observed in Beautisealant may be linked to the limited demineralization potential of its self-etching primer, characterized by a mild pH of 2.3, as proposed by Ntaoutidou et al.[26]

The results of the present study were in line with those of Hatirli et al.,[27] who evaluated the microleakage of four different fissure sealants after cyclic aging, two of which were an unfilled RBS fissure sealant and a Giomer-based fissure sealant and reported that Giomer based fissure sealants applied after surface treatment with a self-etching primer exhibited higher microleakage than those of the RBS that used a phosphoric acid etch. Other studies also supported the hypothesis that surface pretreatment using phosphoric acid etching results in less microleakage than surface pretreatment with a self-etching primer.[22,28,29]

On the contrary our results were not in agreement with those of Hirayama et al.,[8] who reported that all the specimens sealed with the Giomer based sealant presented no dye penetration at all when examined. This variation could be attributed to the smaller sample size used in their study. Another reason could be the use of a different dye material, namely the acid fuchsin stain, to evaluate microleakage.

Our findings also contradicted those of Demirel et al.,[30] who found that the microleakage values for both GIC based sealant and Giomer based sealant were notably lower than those for the RBS. Nevertheless, this variance could be attributed to the more invasive technique (fissure preparation) utilized in their study.

Regarding the wear resistance testing in this study, laser scanning of the specimens followed by using the Geomagic® software as the matching software was employed as it is reputed to be the best technique for wear measurement.[31] Chewing simulators are used to replicate physiological masticatory loads and chewing movements, hence simulating aging within the oral cavity.[32] In the current study, the Mechatronik[1] chewing simulator was used. We opted for the two-body chewing simulator due to its precise control over load and movements, as well as the absence of a third body, which simplifies result interpretation.[33]

Literature shows that chewing forces are documented to range from 20 to 120N. Many researchers commonly utilize 5 Kg (49N), a value identified by Gibbs et al.[34] as the average chewing force during normal function. Therefore, in the present study 5 Kg (49N) was used. Regarding the antagonists, various materials, nonetheless, there is no consensus in the literature regarding the preferred material and shape of antagonists for in-vitro wear studies.[30] In the present study a ceramic ball 5 mm in diameter was used as the antagonist.

There was a significant difference between both groups. The wear value of the RBS Clinpro™ was significantly greater than that of the Giomer based sealant Beautisealant. This could be justified by the lack of fillers in the Clinpro™ fissure sealant while the Beautisealant contains Surface pre-reacted glass (S-PRG) fillers, hence enhancing their mechanical properties.[35]

Our results came in agreement with the conclusion in a review by Faria et al.,[31] that stated that unfilled sealants exhibited greater susceptibility to wear damage compared to filled sealants. On the contrary, Akcay et al.,[36] compared the aging effects on wear, surface roughness, and microhardness of four different fissure sealants. Results concluded a significant difference in the mean changes in wear or weight values, with the unfilled RBS demonstrating the least weight loss compared to the Giomer based sealant. Those findings could be due to the different assessment method utilized in their study as wear was assessed based on weight loss of the specimens after being subjected to chewing simulation. This technique might not be accurate as water sorption during thermocycling may affect the results.

Although this study bridged that gap regarding wear resistance among two different fissure sealants, it did have certain limitations. This study involved fully matured permanent molars, potentially influencing the level of microleakage due to the secondary maturation of enamel compared to young permanent teeth, which could impact the extent of etching or bonding to enamel. Furthermore, this study was conducted in laboratory conditions, hence the conditions don't accurately mimic the oral cavity.

On the other hand, this study also has the leverage of assessing wear by the matching software technique which provides more accurate results than other methods such as measuring wear by weight loss as water sorption of the materials affects the measurements. Overall, it can be concluded that resin-based sealants seem to offer a tighter seal at the tooth-sealant interface, while giomer-based sealants demonstrate superior mechanical performance.

The overall results of this study necessitated the rejection of the null hypothesis that there would be no difference found between Beautisealant and Clinpro in terms of both, microleakage and wear resistance.

## Conclusions

Within the limitations of this in-vitro study, the following conclusions can be drawn:

1. Resin-based sealants appear to offer a superior seal at the tooth-sealant interface.
2. Giomer-sealants seem to exhibit better mechanical performance.

## Acknowledgements

We extend our gratitude to Dr. Medhat Sameh Abdelaziz for his support with the Geomagic software.

## Funding

This research was not funded through any source.

## Conflict of interest

The authors declare no conflict of interest.

## References

1. Beauchamp J, Caufield PW, Crall JJ, Donly K, Feigal R, Gooch B, Ismail A, Kohn W, Siegal M, Simonsen R. Evidence-based clinical recommendations for the use of pit-and-fissure sealants: a report of the American Dental Association Council on Scientific Affairs. The Journal of the American Dental Association. 2008 Mar 1;139(3):257-68.
2. Turner EG, Dean JA. Development and Morphology of the Primary Teeth. McDonald and Avery's Dentistry for the Child and Adolescent-E-Book. 2015 Aug 10:80.
3. Kühnisch J, Bedir A, Lo YF, Kessler A, Lang T, Mansmann U, Heinrich-Weltzien R, Hickel R. Meta-analysis of the longevity of commonly used pit and fissure sealant materials. Dental Materials. 2020 May 1;36(5):e158-68.
4. Rusnac ME, Gasparik C, Irimie AI, Grecu AG, Mesaroş AŞ, Dudea D. Giomers in dentistry–at the boundary between dental composites and glass-ionomers. Medicine and Pharmacy Reports. 2019 Apr;92(2):123.
5. Singla A, Garg S, Jindal SK, Sogi HS, Sharma D. In vitro evaluation of marginal leakage using invasive and noninvasive technique of light cure glass ionomer and flowable polyacid modified composite resin used as pit and fissure sealant. Indian Journal of Dental Research. 2011 Mar 1;22(2):205-9.
6. Naaman R, El-Housseiny AA, Alamoudi N. The use of pit and fissure sealants—a literature review. Dentistry journal. 2017 Dec 11;5(4):34.
7. Özgür B, Kargın ST, Ölmez MS. Clinical evaluation of giomer-and resin-based fissure sealants on permanent molars affected by molar-incisor hypomineralization: a randomized clinical trial. BMC oral health. 2022 Jul 5;22(1):275.
8. MT RT, Ardu S, Daeniker L, Krejci I. Evaluation of marginal adaptation, seal and resistance against fatigue cracks of different pit and fissure sealants under laboratory load. American journal of dentistry. 2011 Dec 1;24(6):367-71.
9. Hirayama K, Hanada T, Hino R, Saito K, Kobayashi M, Arakaki M, Chiba Y, Nakamura N, Sakurai T, Iwamoto T, Fukumoto S. Material properties on enamel and fissure of surface pre-reacted glass-ionomer filler-containing dental sealant. pediatric dental journal. 2018 Aug 1;28(2):87-95.
10. Nahvi A, Razavian A, Abedi H, Charati JY. A comparison of microleakage in self-etch fissure sealants and conventional fissure sealants with total-etch or self-etch adhesive systems. European journal of dentistry. 2018 Apr;12(02):242-6.
11. Pardi V, Sinhoreti MA, Pereira AC, Ambrosano GM, Meneghim MD. In vitro evaluation of microleakage of different materials used as pit-and-

fissure sealants. Brazilian dental journal. 2006;17:49-52.
12. Hamed N, Ghallab O, Anwar MN. The Effect of Different Remineralizing Agents on Microleakage around Restored Demineralized Enamel: An In vitro Comparative Study. Ain Shams Dental Journal. 2023 Dec 1;32(4):26-36.
13. ÖVREBÖ RC, RAADAL M. Microleakage in fissures sealed with resin or glass ionomer cement. European Journal of Oral Sciences. 1990 Feb;98(1):66-9
14. Soliman, Naglaa Ibrahim Ezz El-Din, and Mona Fadel Mohamed. "IN VITRO EVALUATION OF WEAR RESISTANCE OF DIFFERENT FISSURE SEALANTS AFTER AGING PROCEDURES." Egyptian Dental Journal 63.2-April (Fixed Prosthodontics, Dental Materials, Conservative Dentistry & Endodontics) (2017): 1729-1737.
15. Alsahafi TA, Walter R, Nunes M, Sulaiman TA. Wear of Bulk-fill Composite Resins After Thermo-mechanical Loading. Operative Dentistry. 2023 May 23.
16. Team RC. R: A language and environment for statistical computing. R Foundation for Statistical Computing. (No Title). 2013.
17. Zhang C, Li Y, Zhang Z, Tian Y, Ding N, Ma Y. Improvement of pit-and-fissure sealant bonding to enamel with subpressure treatment. BioMed Research International. 2019 Mar 28;2019.
18. Vilchis RJ, Hotta Y, Yamamoto K. Examination of enamel-adhesive interface with focused ion beam and scanning electron microscopy. American Journal of Orthodontics and Dentofacial Orthopedics. 2007 May 1;131(5):646-50.
19. Yavuz I, Tumen EC, Kaya CA, Dogan MS, Gunay A, Unal M, Toptanci IR, Bahsi E. The reliability of microleakage studies using dog and bovine primary teeth instead of human primary teeth. European Journal of Paediatric Dentistry. 2013 Mar 1;14(1):42-6.
20. Govil S, Gupta V, Bhatt A. A comparative evaluation of micro-leakage of different tooth colored restorative materials. An in-vitro study.
21. El Mourad AM. Assessment of bonding effectiveness of adhesive materials to tooth structure using bond strength test methods: a review of literature. The open dentistry journal. 2018;12:664.
22. Van Meerbeek B, Peumans M, Poitevin A, Mine A, Van Ende A, Neves A, De Munck J. Relationship between bond-strength tests and clinical outcomes. Dental materials. 2010 Feb 1;26(2):e100-21.
23. Larsson C, Wennerberg A. The clinical success of zirconia-based crowns: a systematic review. International Journal of Prosthodontics. 2014 Jan 1;27(1).
24. Butail A, Dua P, Mangla R, Saini S, Chauhan A, Rana S. Evaluation of marginal microleakage and depth of penetration of different materials used as pit and fissure sealants: an in vitro study. International Journal of Clinical Pediatric Dentistry. 2020 Jan;13(1):38.
25. Mixson JM, Eick JD, Chappell RP, Tira DE, Moore DL. Comparison of two-surface and multiple-surface scoring methodologies for in vitro microleakage studies. Dental Materials. 1991 Jul 1;7(3):191-6.
26. Ntaoutidou S, Arhakis A, Tolidis K, Kotsanos N. Clinical evaluation of a surface pre-reacted glass (S-PRG) filler-containing dental sealant placed with a self-etching primer/adhesive. European Archives of Paediatric Dentistry. 2018 Dec;19:431-7.
27. Hatirli H, Yasa B, Yasa E. Microleakage and penetration depth of different fissure sealant materials after cyclic thermo-mechanic and brushing simulation. Dental materials journal. 2018 Jan 26;37(1):15-23.
28. Suryavanshi R, Choudhary HV, Tandon S, Singh N, Abdullah A. A stereomicroscopic evaluation of commercially available pit & fissure sealants for coronal microleakage. Journal of Advanced Medical and Dental Sciences Research. 2019 Aug 1;7(8):153-7.
29. Amend S, Frankenberger R, Boutsiouki C, Scharrelmann V, Winter J, Krämer N. Microleakage of pit and fissure sealings placed after enamel conditioning with phosphoric acid or with self-etching primers/adhesives. Clinical and Experimental Dental Research. 2021 Oct;7(5):763-71.
30. Demirel A, Işıl OA, Tulga ÖF, Orhan K. Three dimensional evaluation of marginal microleakage at the adhesive interface between different fissure sealants and enamel: Micro-CT analysis. Balkan Journal of Dental Medicine. 2022;26(1):7-14.
31. DeLong R. Intra-oral restorative materials wear: rethinking the current approaches: how to measure wear. Dental Materials. 2006 Aug 1;22(8):702-11.
32. Santos F, Branco A, Polido M, Serro AP, Figueiredo-Pina CG. Comparative study of the wear of the pair human teeth/Vita Enamic® vs commonly used dental ceramics through chewing simulation. Journal of the mechanical behavior of biomedical materials. 2018 Dec 1;88:251-60.
33. Matias1a P, Roulet2b JF, Abdulhameed2c N, Shen2d C. In vitro wear of 4 different universal composites. STOMATOLOGY EDU JOURNAL. 2016;39.
34. Gibbs CH, Mahan PE, Lundeen HC, Brehnan K, Walsh EK, Holbrook WB. Occlusal forces during chewing and swallowing as measured by sound

transmission. The Journal of prosthetic dentistry. 1981 Oct 1;46(4):443-9.

35. Faria M, Guedes A, Rompante P, Carvalho O, Silva F, Henriques B, Özcan M, Souza JC. Wear pathways of tooth occlusal fissure sealants: an integrative review. Biotribology. 2021 Sep 1;27:100190.
36. Akcay HC, Aktoren O. In vitro evaluation of wear resistance, microhardness and superficial roughness of different fissure sealants after aging. Journal of Clinical Pediatric Dentistry. 2024 Jan 1;48(1).