RESEARCH PAPER

Comparative Evaluation of Microleakage, Penetration Depth of Hydrophilic and a Contemporary Hydrophobic Pit and Fissure Sealant- An In Vitro Study

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ABSTRACT

Introduction:

Effective pit and fissure sealing depends largely on proper surface preparation and appropriate material selection. Sealant application remains a well-established preventive strategy for inhibiting the initiation and progression of dental caries, particularly on occlusal surfaces that are highly susceptible to plaque accumulation.

Aim:

To compare the microleakage and penetration depth of hydrophilic and hydrophobic pit and fissure sealants following acid etching under dry and moist surface conditions.

Materials and Methods:

Sixty freshly extracted primary molars were selected and divided into two groups based on sealant type: hydrophilic (Group A) and hydrophobic (Group B). Each group was further subdivided according to surface condition into dry (A1 and B1) and moist (A2 and B2) subgroups, with two teeth in each subgroup. In the dry groups (A1 and B1), the occlusal surfaces were cleaned, dried using a three-way syringe, etched with 37% phosphoric acid, and the sealant was applied and light-cured. In the moist groups (A2 and B2), the etched surfaces were contaminated with 0.1 mL of fresh human saliva for 20 seconds and gently dried using a cotton pellet before sealant application. All samples were subjected to 500 thermocycles and subsequently sectioned to evaluate microleakage and penetration depth. The sections were examined under a light microscope and analyzed using image analysis software (SigmaScan).

Results:

The results indicated that hydrophobic sealants demonstrated greater penetration depth into pits and fissures compared with hydrophilic sealants under both dry and moist surface conditions. However, hydrophilic sealants exhibited comparatively lower microleakage, particularly under moist conditions.

Conclusion:

Within the limitations of this in vitro study, the hydrophilic pit and fissure sealant showed reduced penetration depth but better tolerance to saliva contamination and lower microleakage compared with conventional hydrophobic sealants. These findings suggest that hydrophilic sealants may be advantageous in clinical situations where moisture control is difficult. However, further in vitro and in vivo studies with larger sample sizes are required to comprehensively evaluate their effectiveness, particularly in primary molars.

Keywords: Pit and fissure sealant, Hydrophilic sealant, Hydrophobic sealant, Microleakage, Penetration depth, Primary molars

How to cite this article: Bhavesh S, Ramesh R. Comparative Evaluation of Microleakage, Penetration Depth of Hydrophilic and a Contemporary Hydrophobic Pit and Fissure Sealant- An In Vitro Study. Int J Drug Deliv Technol. 2026;16(11s): 306-315; DOI: 10.25258/ijddt.16.11s.29

Comparative evaluation of microleakage, penetration depth of hydrophilic and a contemporary hydrophobic pit and fissure sealant- An in vitro study

INTRODUCTION:

Dental caries remains one of the most prevalent chronic diseases affecting children worldwide, with occlusal surfaces of posterior teeth being particularly susceptible to decay. The complex morphology of pits and fissures creates sheltered niches that favor plaque accumulation and bacterial colonization. These anatomical irregularities make effective cleaning difficult through routine oral hygiene practices, thereby increasing the risk of caries development. Studies have shown that occlusal fissures experience dental caries approximately five times more frequently than smooth surfaces. Epidemiological evidence further indicates that nearly 60–75% of carious lesions in children aged 6–16 years originate from occlusal pits and fissures, emphasizing the importance of targeted preventive strategies for these surfaces.[1]

Pit and fissure sealants have been widely accepted as an effective preventive measure for managing occlusal caries. Sealants function by penetrating into pits and fissures and forming a physical barrier that prevents the accumulation of plaque and microorganisms, thereby inhibiting the initiation and progression of dental caries. Several clinical studies and systematic reviews have demonstrated that the application of fissure sealants significantly reduces caries incidence on occlusal surfaces of both primary and permanent teeth.[2] The concept of sealing pits and fissures has evolved considerably over time. Early attempts at caries prevention included mechanical fissure eradication, prophylactic odontotomy, and chemical treatments such as silver nitrate application. These techniques were eventually replaced by the use of restorative materials such as zinc phosphate cement and later by resin-based sealants, which provided better adhesion and preventive outcomes.[3]

An ideal pit and fissure sealant should exhibit excellent penetration into deep fissures, effective sealing ability, adequate retention, resistance to abrasion and wear, and long-term durability. Among these properties, penetration depth and marginal sealing ability are critical factors that determine the clinical success of sealant therapy. Insufficient penetration or inadequate sealing can result in marginal gaps at the tooth–sealant interface. These gaps may permit bacterial infiltration and lead to microleakage, which allows nutrients and microorganisms to access the underlying enamel. As a result, caries progression may occur beneath the sealant, ultimately leading to treatment failure.[4],[5]

Conventional resin-based sealants are hydrophobic in nature and require strict moisture control during application to achieve optimal bonding with the etched enamel surface. However, achieving complete moisture isolation in pediatric patients is often challenging due to excessive salivation, partially erupted teeth, and limited cooperation from young children. Moisture contamination during sealant placement can significantly compromise sealant retention and increase microleakage.[6],[7] To overcome these clinical limitations, moisture-tolerant or hydrophilic sealant materials have recently been introduced, which are designed to perform effectively even in the presence of slight moisture contamination. These materials incorporate hydrophilic monomers that improve wettability and allow better penetration into fissures under moist conditions.[8]

Despite the increasing use of hydrophilic sealants in pediatric dentistry, the existing literature presents limited and sometimes inconsistent evidence regarding their sealing ability and penetration characteristics compared with conventional hydrophobic sealants. While some studies suggest that hydrophilic sealants perform better under moist conditions, others report comparable results between the two materials. Moreover, comparative investigations evaluating both microleakage and penetration depth in primary teeth under different moisture conditions remain relatively limited.

Therefore, evaluating the sealing ability and penetration capacity of different sealant materials is essential to improve preventive strategies in pediatric dentistry. The present in vitro study aims to comparatively evaluate the microleakage and penetration depth of hydrophilic and contemporary hydrophobic pit and fissure sealants in primary second molars under dry and moist surface conditions, thereby providing scientific evidence to guide the selection of sealant materials in clinical practice.

MATERIALS AND METHODS

Materials and Methods

Study Design and Materials

The present in vitro experimental study was conducted to evaluate and compare the microleakage and penetration depth of hydrophilic and hydrophobic pit and fissure sealants applied under dry and moist surface conditions. Two commercially available pit and fissure sealants were used as test materials: a hydrophilic sealant (UltraSeal

XT Hydro S3529) and a hydrophobic sealant (Clinpro™ Pit and Fissure Sealant). The armamentarium used during the study included a dental explorer, small round bur, applicator tips, stereomicroscope, and an LED curing system. This study was approved by the Scientific Review Board (SRB) of Saveetha Dental College and Hospitals, under the approval number SRB/SDC/PM/2023-24/161.

Figure 1. Hydrophilic and hydrophobic pit and fissure sealant materials used in the study.

Sample size estimation:
The sample size was estimated using G*Power software (version 3.1) for comparison among four groups using one-way ANOVA, with a significance level of $\alpha = 0.05$ and statistical power of 80%. Assuming a large effect size ($f = 0.40$) based on previous in vitro studies on pit and fissure sealants, the analysis indicated that approximately 15 samples per group would be required, giving a total sample size of 60 teeth.

Sample Selection and Storage

A total of sixty freshly extracted, non-carious human primary mandibular second molars were used for the study. Teeth with caries, restorations, fractures, or developmental enamel defects were excluded. Immediately after extraction, the teeth were cleaned of soft tissue remnants and stored in 2% thymol solution for 24 hours to prevent microbial growth while maintaining the structural integrity of enamel surfaces.[9]

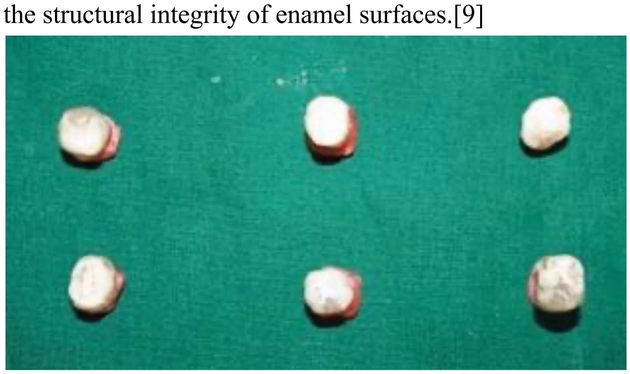

Figure 2. Extracted primary mandibular second molars used as study samples.

Tooth Preparation

Enameloplasty of the occlusal fissures was carried out using a cone-shaped diamond bur, as described by Duangthip et al., to remove organic debris and improve sealant penetration within deep fissures.[10] The occlusal surfaces were then cleaned with a brush mounted on a low-speed micromotor handpiece and rinsed thoroughly with water. A dental explorer was used to remove any remaining debris from pits and fissures. The occlusal surfaces were subsequently etched using 37% phosphoric acid for 30 seconds, rinsed with water, and dried with oil-free compressed air until a chalky white enamel surface was observed. Acid etching increases surface roughness of enamel and enhances micromechanical bonding of resin sealants to tooth structure.[11]

Group Allocation

The prepared teeth were randomly divided into four experimental groups, each consisting of two samples, based on the type of sealant used and the surface condition during sealant application.

Group A1: Hydrophilic sealant applied under dry surface conditions

Group A2: Hydrophilic sealant applied under moist surface conditions

Group B1: Hydrophobic sealant applied under dry surface conditions

Group B2: Hydrophobic sealant applied under moist surface conditions

Sealant Application under Dry Conditions

For Groups A1 and B1, the etched occlusal surfaces were maintained under dry conditions. The hydrophilic sealant (UltraSeal XT Hydro) and hydrophobic sealant (Clinpro) were applied according to the manufacturers' instructions using applicator tips. The sealant material was allowed to flow into the pits and fissures, and polymerization was carried out using an LED curing unit for 20 seconds to ensure adequate curing and retention.[12]

Sealant Application under Moist Conditions

For Groups A2 and B2, the etched occlusal surfaces were intentionally contaminated with 0.1 mL of freshly collected human saliva for 20 seconds to simulate clinical moisture contamination frequently encountered in pediatric dental practice. The surface was then gently dried with a cotton pellet for 5 seconds, leaving it slightly moist. Following this, the respective sealants were applied to the fissures and allowed to remain undisturbed for 10 seconds to facilitate adequate penetration. The sealants were then light-cured using the LED curing system for 20 seconds.

Dye Penetration and Sectioning

To evaluate microleakage, the specimens were immersed in 2% methylene blue dye solution for 24 hours. After dye immersion, the samples were rinsed with distilled water and dried. Each tooth was then sectioned mesiodistally through the center of the sealant using a water-cooled diamond disc to obtain sections suitable for microscopic evaluation.

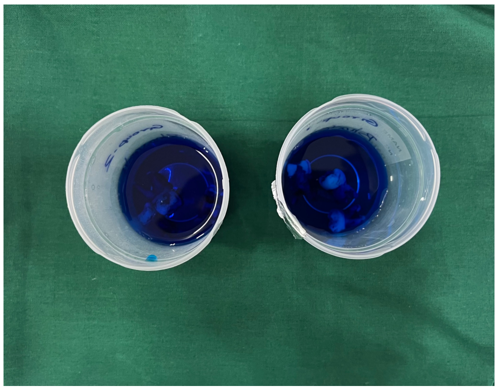

Figure 3. Samples immersed in 2% methylene blue dye for evaluation of microleakage.

Storage and Thermocycling

After sealant placement, all samples were stored in distilled water at 37°C for 24 hours to allow complete polymerization and stabilization of the materials. The specimens were then subjected to thermocycling for 1000 cycles between 5°C and 55°C with a dwell time of one minute at each temperature. Thermocycling simulates thermal stresses that restorative materials experience in the oral cavity during ingestion of hot and cold foods and beverages.[13]

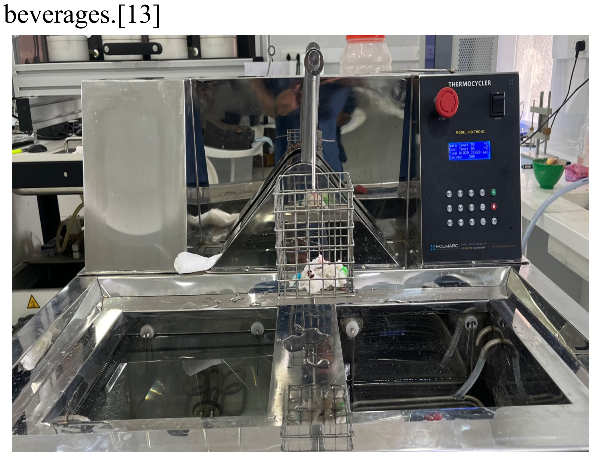

Figure 4. Thermocycling apparatus used for subjecting samples to temperature cycles.

Figure 5. Control panel of the thermocycler showing temperature range and cycling parameters.

Microscopic Evaluation

The sectioned specimens were examined under a stereomicroscope at 10× magnification. Images were captured and transferred to a computer data analyst for further analysis. Microleakage and penetration depth were assessed using image analysis software (SigmaScan; Jandel Scientific, San Rafael, CA, USA), and the data were subsequently analyzed using the Statistical Package for the Social Sciences (SPSS) version 26.

Microleakage Scoring Criteria

Microleakage was evaluated using a standardized scoring system: Score 0: No dye penetration, Score 1: Dye penetration limited to the outer half of the sealant, Score 2: Dye penetration extending to the inner half of the sealant & Score 3: Dye penetration reaching the underlying fissure. Two independent examiners who were blinded to group allocation evaluated the specimens to minimize observer bias.

Statistical Analysis

Since the microleakage scores represented ordinal data, non-parametric statistical tests were used. The Mann Whitney U test and Kruskal Wallis test were applied to compare differences among the groups. Statistical analysis was performed using SPSS software, and a p value < 0.05 was considered statistically significant.

RESULTS

The present study evaluated the microleakage and penetration depth of hydrophilic and hydrophobic pit and fissure sealants under dry and moist surface conditions. The results showed that the hydrophilic sealant demonstrated a lower mean microleakage score (1.50 ± 0.51) compared with the hydrophobic sealant (3.50 ± 0.51), indicating better marginal sealing ability. This difference between the two sealant types was statistically significant ($p < 0.001$). In addition, surface condition influenced sealant performance, as higher microleakage scores were observed under moist conditions compared with dry surfaces.

Parameter	Hydrophilic Sealant (Mean ± SD)	Hydrophobic Sealant (Mean ± SD)	p value
Microleakage Score	1.50 ± 0.51	3.50 ± 0.51	< 0.001

Table 1: Comparison of Microleakage Scores Between Sealant Types

Table 1 presents the comparison of microleakage scores between hydrophilic and hydrophobic sealants. The hydrophilic sealant group showed a significantly lower mean microleakage score (1.50 ± 0.51) compared with the hydrophobic sealant group (3.50 ± 0.51). Lower microleakage scores indicate better marginal sealing and reduced dye penetration at the tooth–sealant interface. The statistically significant p value (<0.001) indicates a strong difference between the two sealant types. These findings suggest that hydrophilic sealants demonstrate better sealing ability and reduced marginal leakage compared with conventional hydrophobic sealants under the conditions tested.

Surface Condition	Mean ± SD	p value
Dry surface	2.00 ± 1.02	<0.01
Moist surface	3.00 ± 1.02	<0.01

Table 2: Microleakage Scores Based on Surface Condition

Table 2 shows the comparison of microleakage scores based on surface conditions. The mean microleakage score under dry surface conditions was 2.00 ± 1.02, whereas under moist surface conditions it increased to 3.00 ± 1.02. This indicates that moisture contamination during sealant placement results in greater dye penetration and marginal leakage. The difference was statistically significant ($p < 0.01$), suggesting that moisture control plays an important role in the effectiveness of fissure sealants. These results emphasize the importance of maintaining adequate isolation during sealant application to achieve optimal sealing and prevent microleakage.

Dye Penetration	Mean ± SD	p value
No dye penetration	1.68 ± 0.48	< 0.001
Outer half penetration	1.93 ± 1.03	
Inner half penetration	3.47 ± 0.52	

Table 3: Microleakage Scores According to Dye Penetration

Table 3 presents the distribution of microleakage scores according to the extent of dye penetration. The results indicate that samples with no dye penetration showed the lowest mean microleakage score (1.68 ± 0.48), reflecting minimal marginal leakage and better sealing ability of the sealant material. Samples exhibiting outer half penetration demonstrated a slightly higher mean score (1.93 ± 1.03), indicating moderate leakage along the sealant–enamel interface. The inner half penetration category showed the highest mean score (3.47 ± 0.52), suggesting deeper dye infiltration and greater marginal leakage. The statistical analysis revealed a significant difference among the dye penetration categories ($p < 0.001$), indicating that increased dye penetration corresponds with higher microleakage scores and poorer marginal sealing.

Group	Sealant Type	Surface Condition	N	Mean Rank	Sum of Ranks	Mann–Whitney U	Z value	p value
A1	Hydrophilic	Dry	15	19.5	292.5	52.5	-3.247	0.001
A2	Hydrophilic	Moist	15	11.5	172.5	52.5	-3.247	0.001

B1	Hydrophobic	Dry	15	9.87	148	28	-3.814	<0.001
B2	Hydrophobic	Moist	15	21.13	317	28	-3.814	<0.001

Table 4: Comparison of Microleakage Scores Among Study Groups

Table 4 summarizes the comparison of microleakage scores among the four experimental groups based on sealant type and surface condition. Group A1 (hydrophilic sealant under dry conditions) showed a mean rank of 19.5, whereas Group A2 (hydrophilic sealant under moist conditions) had a lower mean rank of 11.5. The Mann–Whitney U test demonstrated a statistically significant difference between these groups ($U = 52.5$, $p = 0.001$). Similarly, comparison of the hydrophobic sealant groups revealed that Group B2 (hydrophobic sealant under moist conditions) exhibited a higher mean rank (21.13) compared with Group B1 (hydrophobic sealant under dry conditions) with a mean rank of 9.87. This difference was also statistically significant ($U = 28.0$, $p < 0.001$). These findings indicate that moisture contamination significantly influences the microleakage performance of both sealant types, with higher leakage scores observed under moist conditions.

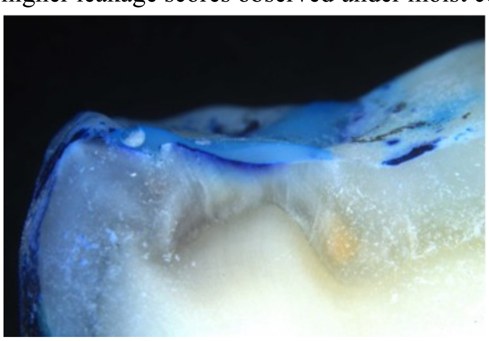

Fig 7: Score 0

Figure 1: Stereomicroscopic image showing Score 0 microleakage, indicating complete marginal sealing of the fissure sealant with no dye penetration at the sealant–enamel interface.

Figure 1 shows an ideal sealant interface where the dye solution did not penetrate along the tooth–sealant interface. This indicates excellent marginal adaptation and effective sealing of pits and fissures, preventing microleakage.

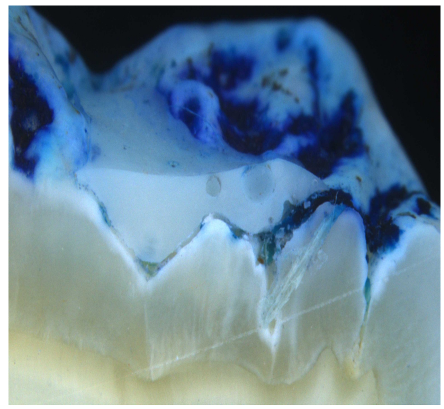

Figure 2: Stereomicroscopic image representing Score 1 microleakage, where dye penetration is observed limited to the outer half of the sealant–enamel interface.

Figure 2 shows mild marginal leakage where the dye has penetrated only into the superficial portion of the sealant interface. Although partial leakage is present, the dye does not extend into the deeper fissure region.

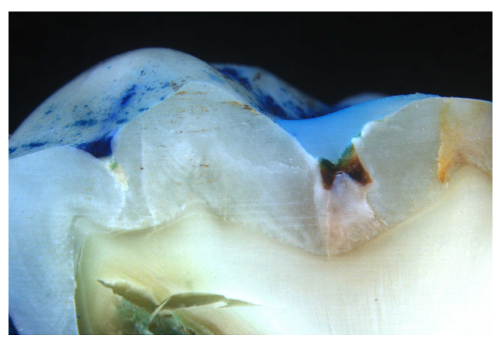

Figure 3: Stereomicroscopic image showing Score 2 microleakage, where dye penetration extends beyond the outer half into the inner portion of the sealant–enamel interface.

Figure 3 illustrates deeper dye penetration along the sealant–tooth interface, indicating compromised marginal sealing and increased microleakage. Such penetration may allow bacterial infiltration and potential caries progression beneath the sealant.

Representative stereomicroscopic images illustrating different microleakage scores are presented in Figures 1–3. The images demonstrate the extent of dye penetration ranging from no leakage (Score 0) to partial penetration (Scores 1 and 2) along the sealant–enamel interface.

Further analysis using the Mann–Whitney U test revealed a significant difference in microleakage scores between hydrophilic sealants applied under dry and moist conditions ($U = 52.5$, $p = 0.001$). A similar significant difference was observed between hydrophobic sealants under dry and moist conditions ($U = 28.0$, $p < 0.001$), with greater leakage occurring in the presence of moisture contamination. Stereomicroscopic images also demonstrated varying degrees of dye penetration corresponding to different microleakage scores, illustrating the extent of marginal leakage along the sealant–enamel interface. These findings indicate that moisture control plays an important role in the sealing effectiveness of fissure sealants.

DISCUSSION

The present study evaluated the microleakage and penetration depth of hydrophilic and hydrophobic pit-and-fissure sealants applied under dry and moist surface conditions in primary mandibular second molars. The results demonstrated that hydrophilic sealants showed lower microleakage under moist conditions compared to hydrophobic sealants, whereas hydrophobic sealants exhibited greater penetration depth under both dry and moist conditions. These findings highlight the influence of material properties and moisture conditions on the sealing performance of fissure sealants.

In the present study, the hydrophilic sealant applied under moist surface conditions (Group A2) demonstrated significantly lower microleakage compared with the hydrophobic sealant under similar conditions. This finding can be attributed to the moisture-tolerant nature of hydrophilic sealants, which contain hydrophilic monomers that enhance wetting ability and adhesion to enamel even in the presence of slight moisture contamination. These results are consistent with the findings of Khogli et al.[14] who reported that hydrophilic sealants exhibited better marginal adaptation and reduced microleakage compared with conventional resin-based sealants when applied under moist conditions. The authors suggested that the improved wettability of hydrophilic materials allows better penetration into fissures and improved adaptation to enamel surfaces.

Similarly, a clinical trial conducted by Prabakar et al.[15],[16] comparing UltraSeal XT Hydro with conventional resin sealants demonstrated that hydrophilic sealants showed favorable retention and marginal integrity, particularly in situations where ideal moisture control was difficult.[17] The authors emphasized that moisture contamination is a major challenge in pediatric dentistry due to excessive salivation, limited patient cooperation, and partially erupted molars. The present findings support this concept, as hydrophilic sealants demonstrated superior performance under moist conditions compared with hydrophobic sealants.

In contrast, the hydrophobic sealant groups in the present study exhibited higher microleakage, particularly when applied under moist surface conditions (Group B2). Hydrophobic sealants require strict moisture control to achieve optimal bonding with etched enamel surfaces. When moisture contamination occurs, the resin material cannot adequately penetrate the microporosities created by acid etching, resulting in marginal gaps and increased microleakage. These observations are in agreement with the study by Gawali et al.[18], who reported significantly greater microleakage in conventional hydrophobic sealants under moist conditions compared with moisture-tolerant sealants.

The present results also demonstrated that hydrophobic sealants exhibited greater penetration depth than hydrophilic sealants under both dry and moist conditions. Penetration depth is an important factor in the success of fissure sealants because deeper penetration into pits and fissures can enhance mechanical retention and long-term durability. The greater penetration observed in hydrophobic sealants may be related to their lower viscosity and superior flow characteristics. These findings are consistent with the study by Mehrabkhani et al.[19], who reported that conventional resin-based sealants with lower viscosity showed deeper fissure penetration and improved resin tag formation compared with moisture-tolerant materials.

The results of the present study also showed a statistically significant difference in penetration depth among the four groups, and the highest mean rank for penetration depth was observed in the hydrophobic sealant applied under moist conditions (Group B2), followed by the hydrophobic sealant under dry conditions (Group B1). In contrast, the hydrophilic sealant under moist conditions (Group A2) showed the lowest penetration depth. These findings suggest that although hydrophilic sealants perform better in terms of marginal sealing under moist conditions, hydrophobic sealants may still provide superior penetration into fissures due to their material composition and flow properties.

These observations are supported by the work of Güçlü et al. [20], who evaluated the microleakage and physical properties of UltraSeal XT Hydro and found that although hydrophilic sealants demonstrated improved adaptation under moist conditions, their penetration depth was sometimes lower than that of conventional resin sealants. The authors suggested that the higher viscosity and filler content of some hydrophilic sealants may limit their ability to penetrate extremely narrow fissures.

A randomized clinical trial by Mohapatra et al.[21] further reported that hydrophilic sealants demonstrated comparable retention rates to hydrophobic sealants in clinical settings, particularly in partially erupted molars where moisture control is challenging. This finding reinforces the clinical relevance of moisture-tolerant sealants in pediatric dentistry.

Another study by Gyati et al. [22] also reported that hydrophilic sealants exhibited improved marginal integrity and reduced microleakage compared with conventional hydrophobic sealants, particularly under simulated salivary contamination conditions. The authors highlighted the importance of moisture tolerance in achieving reliable preventive outcomes in pediatric patients.

Furthermore, Anika et al. [23] evaluated the microshear bond strength, penetration depth, and microleakage of UltraSeal XT Hydro and Clinpro sealants and reported that hydrophilic sealants exhibited lower microleakage values compared with conventional sealants, although penetration depth was sometimes greater in hydrophobic materials. These findings closely align with the observations of the present study.

Overall, the results of the present investigation suggest that hydrophilic sealants may provide better sealing ability under moist conditions, thereby reducing microleakage and the risk of caries progression beneath the sealant. However, hydrophobic sealants may offer superior penetration into fissures, which can enhance retention. Therefore, the choice of sealant material should consider both the clinical environment and the need for effective fissure penetration.

The present study evaluated the microleakage and penetration depth of hydrophilic and hydrophobic sealants under dry and moist conditions, which closely reflects the clinical challenges encountered in pediatric dentistry. Standardized procedures such as enamel preparation, thermocycling, and dye penetration improved the reliability of the results, and stereomicroscopic analysis allowed accurate assessment of sealant performance. However, the study was conducted under in vitro conditions and involved a relatively small sample size, which may limit the generalization of the findings. Future studies with larger samples, long-term clinical trials, and advanced imaging techniques such as SEM or micro-CT are recommended to further validate these results.

CONCLUSION

Within the limitations of this in vitro study, the hydrophilic pit and fissure sealant demonstrated lower microleakage under moist conditions compared with the conventional hydrophobic sealant, indicating better tolerance to saliva contamination. However, the hydrophilic sealant exhibited comparatively lower penetration depth into fissures than the conventional sealant. These findings suggest that while hydrophilic sealants may provide improved marginal sealing in situations where moisture control is difficult, their penetration ability may be limited. Further well-designed in vitro and in vivo studies with larger sample sizes are required to comprehensively evaluate the clinical effectiveness of hydrophilic fissure sealants in pediatric dentistry.

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