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ORIGINAL RESEARCH

Effect of high-irradiance light-curing on microleakage of resin fissure sealant

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Abstract

Background: Pit and fissure sealing is an effective method to prevent cavities in young permanent teeth. A study was conducted to evaluate the effect of high-irradiance light-curing with a shorter time on the microleakage of resin fissure sealant (Clinpro^{TM}, 3M ESPE, USA). **Methods**: 100 extracted human molars and randomly divided them into five groups (n = 20) based on the light-curing unit used. Group A1 used acid etching for 30 seconds and then 1000 mW/cm^2 light-curing for 20 seconds. Group A2 used acid etching for 30 seconds and then 3200 mW/cm^2 light-curing for 6 seconds. Group B1 used adhesive 1000 mW/cm^2 light-curing for 20 seconds and then fissure sealant 1000 mW/cm^2 light-curing for 20 seconds. Group B2 used adhesive 1000 mW/cm^2 light-curing for 20 seconds and then fissure sealant 3200 mW/cm^2 light-curing for 6 seconds. Group B3 used adhesive 3200 mW/cm^2 light-curing for 3 seconds and fissure sealant 1000 mW/cm^2 light-curing for 20 seconds. After 250 thermocycles, the specimens were sectioned and examined under a stereomicroscope and scored for marginal microleakage. **Results**: All groups showed microleakage. However, after pre-treatment with a self-etching adhesive at 3200 mW/cm^2 light-curing for 3 seconds (B3 group), there was a significant increase in microleakage, which was significantly higher than the other groups ($p < 0.05$). There was no significant difference in microleakage in the remaining groups ($p > 0.05$). **Conclusions**: High-irradiance shorter time light-curing patterns did not significantly affect the microleakage of Clinpro fissure sealant. However, further clinical studies, including randomized clinical trials, are needed to evaluate its clinical use. The self-etching adhesive did not increase the microleakage of the pit and fissure sealant under normal light intensity and exposure time. But, if a high-intensity short-time irradiation mode was used in adhesive curing, it resulted in severe microleakage, so it should be avoided in clinical practice.

Keywords

Adhesive; Light-curing intensity; Microleakage; Resin fissure sealant

1. Introduction

According to the World Health Organization (WHO) 2022 "Global Oral Health Report", around 2 billion people worldwide suffer from permanent tooth decay, out of which 514 million are children affected by primary tooth decay [1]. Studies suggest that the period immediately following the eruption of teeth is the most vulnerable period for the development of permanent tooth decay [2]. Therefore, most efforts to prevent tooth decay are focused on children and adolescents. The most effective method for preventing cavities in young permanent teeth is currently considered to be pit and fissure sealing [3, 4]. However, challenges such as difficult access to teeth, the possibility of saliva contamination, and sometimes lack of cooperation by young patients make it harder to apply pit and fissure sealants [5].

Resin-based pit and fissure sealants are the most commonly used in dental practices for preventing tooth decay [6]. They create a barrier between the occlusal pits and fissures of teeth and the mouth environment. The effectiveness of these sealants in preventing tooth decay depends on their ability to adhere well to the tooth surface and prevent bacterial microleakage [7, 8]. However, like other resin materials, microleakage is a common problem with this type of sealant [9]. The shrinkage of the material during the curing process is one of the main causes of microleakage [10]. Since microleakage can lead to tooth decay under the sealant, preventing it is crucial for the success of pit and fissure sealing procedures.

Manufacturers have introduced high radiant intensity LED (light-emitting diode) light-curing units (LCU) based on the Exposure Reciprocity Law (ERL). This law states that the cured resin's characteristics depend on the cumulative radiant exposure (J/cm^2), *i.e.*, radiant intensity (incident light intensity, mW/cm^2), and exposure time [11]. These LCUs significantly reduce the light exposure time while maintaining a constant radiant exposure, thereby minimizing the risk of saliva contamination. While the effectiveness of ERL has been proven in various dental material studies, including double bond conversion rate (DC), flexural strength, elastic modulus, hardness and others [11], some researchers have found that radiant intensity and exposure time can have individual impacts on polymer chain length, degree of cross-linking, and mechanical properties [12]. As a result, ERL may not be universally applicable under all conditions.

Clinical practitioners always look for ways to save time, especially when dealing with pediatric patients. By reducing the time spent chair-side and minimizing technical sensitivity, behavior management in young patients can be improved and the quality of pit and fissure sealing treatment can be enhanced. This study aims to investigate whether a high-power short-time light-curing mode increases the risk of microleakage in resin-based pit and fissure sealants, as compared to traditional light-curing modes, *in vitro*.

2. Materials and methods

2.1 Specimen preparation

100 third molars were selected that had been extracted due to orthodontic treatment or periodontal disease during clinical practice. We included only those teeth that had intact crowns, deep pits and fissures, no caries, no developmental defects, no restorations and no cracks. Before the experiment, all calculus deposits and connective tissues were removed using manual instruments and ultrasonic scaling. The teeth were preserved in 0.9% saline solution at 4 degrees Celsius for a maximum of three months until the start of the experiment.

We randomly divided all teeth into five groups (n = 20) and applied different methods for pit and fissure sealing. A flow chart (Fig. 1) illustrates the sample allocation and experimental procedure.

This experiment used a resin-based pit and fissure sealant called Clinpro^{TM} without fillers. The teeth in group A1 were treated with 37% phosphoric acid for 30 seconds to etch the pits and fissures. The acid was then removed using an air/water jet. After that, the pits and fissures were sealed with sealant and light-cured at 1000 mW/cm^2 for 20 seconds. In group A2, the same acid-etch procedure was performed, but the sealant was cured at 3200 mW/cm^2 for 6 seconds. In group B1, adhesive was applied to the fissures according to the manufacturer's instructions and then light cured at 1000 mW/cm^2 for 20 seconds. After that, the pits and fissures were sealed with sealant and light-cured again at 1000 mW/cm^2 for 20 seconds. In group B2, the bonding procedures were performed as in group B1, but the sealant was cured at 3200 mW/cm^2 for 6 seconds. In group B3, adhesive was applied to the fissures and light-cured at 3200 mW/cm^2 for 3 seconds. The pits and fissures were sealed with sealant and light-cured at 1000 mW/cm^2 for 20 seconds. The study used a self-etch adhesive called Single Bond Universal by 3M, and Table 1 (Ref. [13, 14]) lists the material composition and manufacturers. A third generation LED curing light called VALO^{TM} Grand Cordless LED Curing Light (Ultradent, USA), was used in this study. Table 2 lists the light-curing units, curing duration and radiant exposure used in the study.

2.2 Microleakage assessment

All specimens were subjected to 250 thermal cycles, with each cycle consisting of immersion in water at 5 °C and 55 °C for 30 seconds alternately, with a 10 second interval, resulting in a total cycle time of 70 seconds. This was done to simulate artificial aging [15]. Microleakage was assessed using methylene blue penetration test. Before staining, the apices of the specimens were sealed with wax. Then, two coats of nail varnish were evenly applied to the root surface and the smooth surface of the tooth crown (1 mm beyond the edge of the pit and fissure sealant) to prevent retrograde dye penetration [10]. Staining was done with a 2% methylene blue solution at 37 °C for 24 hours [16]. The specimens were rinsed under running water to remove excess dye before making longitudinal cuts along the buccolingual direction with a diamond disk. Finally, one researcher examined the specimens with a stereomicroscope to determine the extent of dye penetration (microscopic evaluation was at 20× magnification with Alltion AM-2000, Wuzhou, Guangxi, China). The sealing quality was assessed based on the following criteria [15] (refer to Fig. 2):

0: No staining.

1: Staining confined to less than half the edge of the pit and fissure sealant.

2: Staining extending beyond half the edge of the pit and fissure sealant.

3: Staining penetrating to the bottom of the pit and fissure.

2.3 Data analysis

The microleakage scores for each group were recorded in a table. Statistical analysis was conducted using SPSS 26.0 (IBM Statistics, Armonk, NY, USA). The Kruskal-Wallis non-parametric test was employed to demonstrate any statistically significant differences in the microleakage scores between the sealant groups. The level of significance was set at $p < 0.05$.

3. Results

Resin-based pit and fissure sealants are prone to microleakage regardless of the light-curing mode used. Fig. 3 illustrates the percentage of microleakage scores in each group. The Kruskal-Wallis H test revealed that, there was no significant difference in microleakage produced by Clinpro pit and fissure sealant under the two light-curing modes, whether using acid-etching for 30 seconds or self-etch adhesive light-curing at 1000 mW/cm^2 for 20 seconds as pretreatments. However, microleakage significantly increased only when self-etch adhesive with light-curing at 3200 mW/cm^2 for 3 seconds pretreatment (B3 group) was used. The microleakage score was significantly higher in this group compared to the other groups (refer to Table 3 for more details).

4. Discussion

Microleakage refers to tiny gaps that allow bacteria and fluids to pass between the tooth structure and the restorative

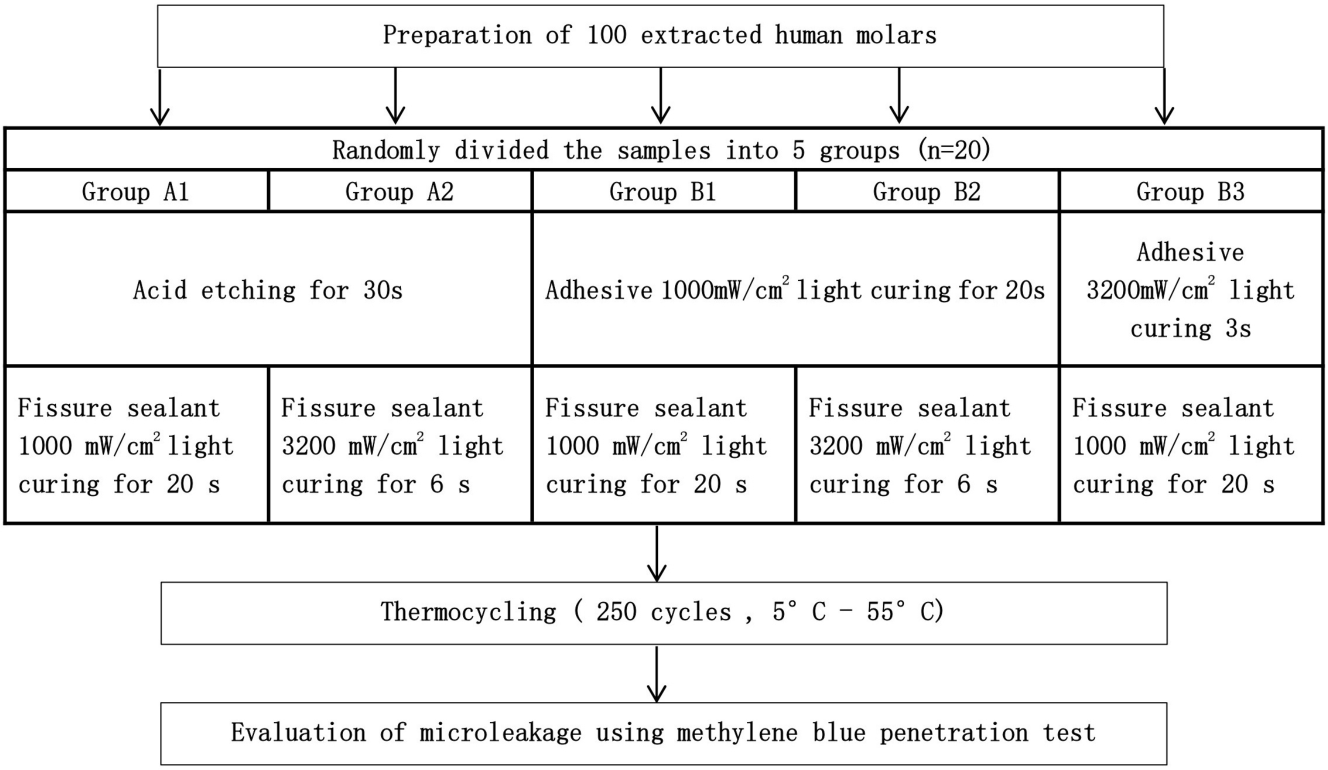


FIGURE 1. Sample allocation and experimental procedure.

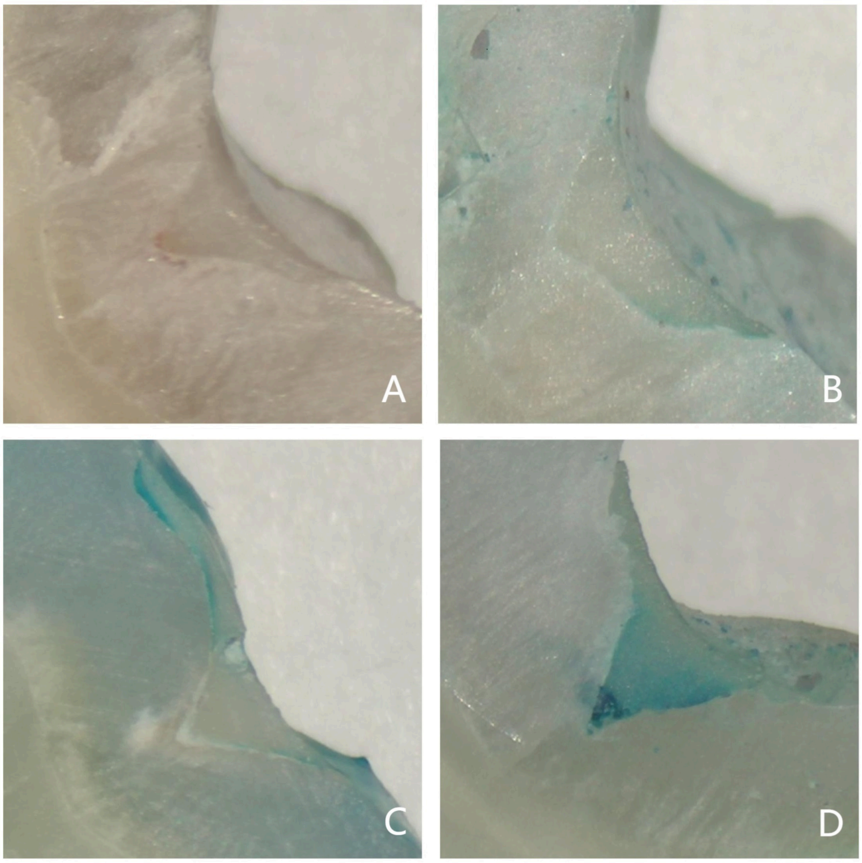
TABLE 1. Manufacturers' information about the materials used in this study.

Materials & Manufacturers	Chemical composition
Clinpro Sealant 3M ESPE, USA Opaque, unfilled	Monomers: triethylene glycol dimethacrylate (TEGDMA) (40–50%), bisphenol A diglycidyl ether dimethacrylate (BISGMA) (40–50%) Filler and fluoride: silane-treated silica (5–10%), tetrabutylammonium tetrafluoroborate (<5%) Photoinitiators: diphenyliodonium hexafluorophosphate (<1%), ethyl 4-dimethyl aminobenzoate (EDMAB) (<0.5%), DL-camphorquinone/hydroquinone (<0.05%) Others: titanium dioxide (<0.5%, providing white color), rose bengal sodium (adding color before curing), butylated hydroxytoluene (stabilizer, radical scavenger) [13]
Single bond universal 3M ESPE, USA	10-MDP, phosphate monomer, Vitrebond, copolymer, HEMA, BISGMA, dimethacrylate resins, filler, silane, initiators, ethanol, water [14]

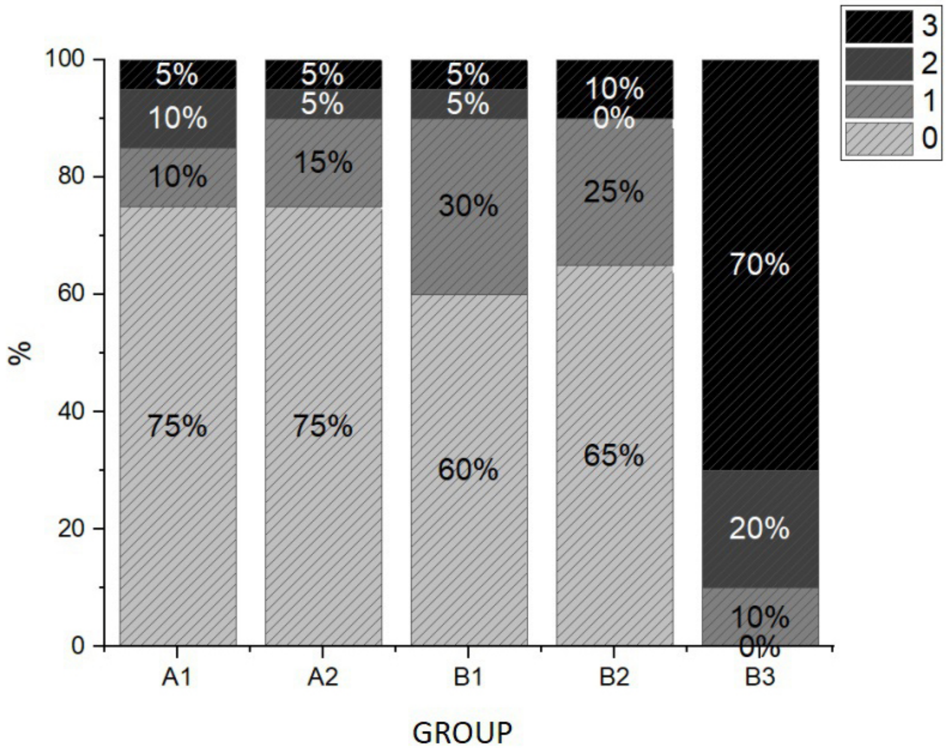
10-MDP:10-methacryloyloxy decyl phosphate; HEMA: Hydroxyethyl-methacrylate.

TABLE 2. Light curing used in the study.

	Manufacturers	Mode	Incident light intensity (mW/cm^2)	Exposure time (s)	The exposure dose (J/cm^2)
VALO	Ultradent, South Jordan, UT, USA	Standard	1000	10	10,000
		Standard	1000	20	20,000
		Xtra Power	3200	6	19,200
		Xtra Power	3200	3	9600



F I G U R E 2. Dye penetration method for microleakage. (A) Level 0, no staining. (B) Level 1, staining limited to less than 1/2 of the fissure sealant margin. (C) Level 2, staining extending beyond 1/2 of the fissure sealant margin. (D) Level 3, staining penetrating to the bottom of the fissure.



F I G U R E 3. Percentage of microleakage scores in each group.

TABLE 3. Comparison results of pairs and pairs between the two groups.

Group	A1	A2	B1	B2	B3
A1	-	-	-	-	-
A2	0.938	-	-	-	-
B1	0.562	0.510	-	-	-
B2	0.658	0.603	0.890	-	-
B3	<0.001*	<0.001*	<0.001*	<0.001*	-

*: $p < 0.05$.

material [17]. This can lead to bacterial infiltration, causing secondary caries under the sealant. Polymerization shrinkage is a common feature of resin-based materials [18]. The stress and elasticity induced by polymerization shrinkage are crucial factors that affect the edge integrity of resin materials [15]. The Clinpro^{TM} Sealant is a low-viscosity, unfilled particle-colored (initially pink, turning gray-white after light exposure) light-cured resin material that may experience microleakage. Regardless of the pretreatment method and light-curing mode used, the experimental results showed varying degrees of microleakage, which emphasizes the importance of evaluating and minimizing microleakage when using resin-based pit and fissure sealants. Manufacturers can reduce polymerization shrinkage stress by improving the composition and changing the content of resin materials. When enamel is contaminated with saliva, its adhesion to pit and fissure sealants decreases, leading to microleakage [19]. As a result, using rubber dams correctly and reducing saliva contamination are also effective methods to reduce microleakage. It is also recommended to use remineralizing fluoride-free toothpastes for children as a supplementary measure to prevent cavities [20, 21].

Various studies have explored the effectiveness of pit and fissure sealants using self-etch bonding mode versus traditional acid. Some studies indicate that both techniques exhibit no significant difference in microleakage [5, 22]. However, others have found that traditional acid etching techniques may be superior to self-etch techniques [23, 24]. In this study, there was no significant difference in microleakage between Groups A1 and B1. The variation in results may be due to the use of different brands and models of adhesive agents and fissure sealants in each study. Phosphoric acid etching enhances bonding strength through mechanical interlocking and increases the roughness of the bonding interface on enamel surfaces. Although the etching pattern produced by self-etch bonding is not as pronounced, the acidic monomers in it can interact with calcium ions in hydroxyapatite, resulting additional chemical bonding. The eighth-generation adhesive Single Bond Universal, used in this experiment contains the hydrophilic acidic functional monomer 10-MDP that can interact with the hydroxyapatite's hydroxyl groups to form a nano-layered hydroxyapatite. These ordered nanostructures are resistant to degradation, which may reduce microleakage and extend the life of the restoration [25]. Penetration depth is crucial in increasing the longevity of sealants and influencing their retention and adaptation of the sealant [26]. The lower the filler content in resin materials, the lower the viscosity and the better the fluidity, which indicates better permeability. Hüseyin Hatirli *et al.* [26] discovered that among pit and fissure sealants with varying filler contents, the unfilled resin-based sealant Clinpro sealant has the highest penetration depth.

The process of light-curing involves the use of a photosensitizer to initiate free radicals, which then triggers a chain polymerization reaction under the influence of light. This leads to the formation of a highly cross-linked polymer network at a rapid pace [27]. During the pre-gel stage, the polymer chains formed are highly flexible and can move freely, which helps to compensate for some of the shrinkage stress. However, as the curing progresses, this fluidity decreases, and ultimately, it cannot compensate for the remaining shrinkage stress [28]. High-intensity irradiation can accelerate the generation of free radicals, speeding up the polymerization reaction, and leading to an inability to compensate for shrinkage strain through fluidity. This ultimately leads to increased shrinkage stress [29]. However, in this experiment with the same pretreatment method, there was no significant difference in microleakage between the pit and fissure sealant under the two light-curing modes. This finding was similar to what Bani *et al.* [30] reported. This may be related to the use of Clinpro pit and fissure sealant, which is a low-viscosity, unfilled material. Polymerization shrinkage stress increases with the filler content of resin materials [31]. Sealants without fillers remove the restrictions of filler material on the flow ability of the resin matrix, avoiding the light attenuation caused by its scattering [32]. Additionally, high-power light-curing modes generate more heat, allowing the unfilled matrix material unrestricted by fillers to gain additional fluidity. This helps to delay the glassy phase of resin polymerization, achieving more stress relief [33]. Regardless of the light-curing mode, the fissure sealant surface might have reached complete polymerization, ensuring the material's edge integrity. Branchal *et al.*'s [13] experiments validated this.

The "Exposure Reciprocity Law (ERL)" suggests that an irradiation intensity of 3200 mW/cm^2 for 3 seconds can generate similar bonding performance for adhesives. However, an experiment showed that using high-irradiance shorter time light-curing patterns significantly increased microleakage of the fissure sealant, suggesting that the "Exposure Reciprocity Law (ERL)" may not apply to adhesives. The termination of resin polymerization is commonly a bimolecular process. A greater number of free radicals leads to a faster loss of free radicals [34]. Under high-intensity irradiation, more free radicals are activated instantly, which could result in bi-molecular termination in the early stage of the reaction. This leads to the loss of a significant number of free radicals [35]. With shorter light exposure time (3 s), the generation of more free radicals to supplement is not possible, leading to a reduced conversion rate. Researchers have detected the conversion rates of bonding agents and composite resins at different light-curing intensities. They found that low-viscosity composite materials (bonding agents) exhibit poorer curing performance under high-power short-time light-curing irradiation compared to high-viscosity composite resin materials [34]. The mechanical properties of light-curing materials are mainly dependent on their curing efficiency. So poor curing performance indicates a higher likelihood of microleakage. The adhesive contains the monomer hydroxyethyl-methacrylate (HEMA), which can slow down the conversion of the polymerization reaction from bimolecular termination to monomolecular termination. This also consumes more free radicals and affects the light-curing polymerization reaction [34]. Higher concentrations of HEMA can lead to a decrease in the conversion rate of adhesives and lower mechanical properties [36]. Different strategies of using adhesive in fissure sealants could also affect the shear bond strength and microleakage of fissure sealants. Placing and curing the adhesive before the fissure sealant would not have any impact. However, curing the adhesive and fissure sealant together would significantly reduce the shear bond strength and increase microleakage. Co-curing may affect the flow-ability of Clinpro [37], which indicates that partially cured adhesive will increase microleakage of pit and fissure sealants. Further experimental investigation is required to determine whether increasing the curing time of the adhesive in high-power irradiation mode to 6 s or 9 s can improve the performance of the adhesive to meet clinical needs.

Dye penetration testing is a dependable method for evaluating microleakage [38]. we used the methylene blue dye penetration method, which allows for easy and precise visualization in digital images for accurate scoring and clear reference points. This method provides excellent contrast with the surrounding environment. However, it has a limitation in that it only provides observation in two dimensions, and due to the limited number and thickness of slices, complete three-dimensional integrity cannot be achieved. To better analyze microleakage, scanning electron microscope-energy dispersive spectroscopy (SEM/EDS) evaluations could be performed. Furthermore, fissure sealants are not only affected by temperature changes in the patient's mouth but also by repeated external forces such as shear and compression forces. In this experiment, we did not simulate the force environment, and the 250 thermal cycles used could only simulate short-term aging. This is also a limitation of the experiment. In future experiments, a more comprehensive scheme for simulating aging needs to be specified.

Various factors affect the polymerization process, apart from the light intensity and curing time. These factors include the distance of the light source, the opacity of the material, and filler content, among others. However, this experiment has some limitations since only one type of pit and fissure sealant was used, and only its microleakage was tested, without investigating the material's strength and wear resistance. According to research, pit and fissure sealants with a higher filler content have lower porosity, better wear resistance, and good shear bond strength, which is closely related to pit and fissure sealant retention rate [30]. As a result, in future experiments, pit and fissure sealants with varying filler contents and capacities must be selected for more comprehensive comparative studies.

5. Conclusions

There were two findings from this study. Firstly, the high-power short-duration light-curing irradiation mode did not have a significant impact on the microleakage of the Clinpro pit and fissure sealant. However, further clinical studies, including randomized clinical trials, are needed to evaluate its clinical use. Secondly, the self-etching adhesive, when compared to traditional acid etching treatment, did not increase the microleakage of the pit and fissure sealant when used under normal light intensity and exposure time. However, if the 3200 mW/cm^2 for 3 seconds irradiation mode was used in adhesive curing, it resulted in severe microleakage. Therefore, it is recommended that this mode be avoided in clinical practice.

ABBREVIATIONS

WHO, World Health Organization; LED, light-emitting diode; LCU, light-curing units; ERL, the Exposure Reciprocity Law; DC, double bond conversion rate; TEGDMA, triethylene glycol dimethacrylate; BISGMA, bisphenol A diglycidyl ether dimethacrylate; EDMAB, ethyl 4-dimethyl aminobenzoate; 10-MDP, 10-methacryloyloxy decyl phosphate; HEMA, Hydroxyethyl-methacrylate; SEM/EDS, scanning electron microscope-energy dispersive spectroscopy.

AVAILABILITY OF DATA AND MATERIALS

The experimental data used to support the findings of this study are available from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

YJL—designed the research study. YJL and QC—performed the research. DYZ—analyzed the data. YJL and DYZ—wrote the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval was obtained from the Human Ethics Review Committee of the Second Affiliated Hospital of Jiaxing University (JXEY-2020JX013). The informed consent process was completed for each participant.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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