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Original Article

Marginal integrity evaluation of resin pit and fissure sealant with different application techniques

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Abstract

Introduction: Marginal integrity can be defined as the ability of a sealant to establish a robust and resilient bond at the interface between the sealant and the tooth surface, preventing microleakage, discoloration, the formation of voids and cracks, and the subsequent development of caries lesions.

Aim: To make a scanning electron microscopy (SEM) evaluation of the marginal integrity of resin sealant applied on the occlusal surfaces of permanent molars, using different techniques.

Materials and methods: The study involved 80 non-carious human third molars that were subjected to three different sealant application methods: conventional, heating, and the use of a vibrating instrument. Epoxy resin replicas were created from each occlusal surface of the teeth. The teeth underwent thermocycling, after which new replicas were made. All replicas were coated with gold powder and observed under scanning electron microscopy. Marginal integrity of the replicas was assessed and compared before and after the thermocycling process. The extent of gaps was measured as a percentage of the restoration edge's total length.

Results: The data show that marginal adaptation ranges from 90% to 94% before thermocycling. Sealants' marginal adaptation was compromised in all study groups and decreased between 81% and 88% after thermocycling. There were statistically significant differences between the control and the other three groups in the study (heating and application of vibrations) before and after thermocycling (p<0.001). The best sealant adaptation was observed when vibrations were applied along the fissure system.

Conclusion: The method of sealant application plays a crucial role in determining its marginal integrity and sealing ability.

Keywords

heating, marginal integrity, resin sealants, scanning electron microscopy, sonic vibrations

Introduction

Sealants are used to avoid the development of occlusal caries lesions, particularly in children and adolescents.[1] Introduced in the 1960s, sealants are resin-based materials applied to the occlusal surfaces of molars and premolars, where the retentive pits and fissures tend to trap food debris and bacteria, ultimately leading to the development of caries lesions.[2] The American Academy of Pediatric Dentistry recommends using pit and fissure sealants as part of a comprehensive approach to treating and preventing caries.[3] Clinical evidence supports their effectiveness, show-

ing a significant reduction in occlusal caries in permanent molars.[3] Sealants have been demonstrated to keep their caries-preventive effect over extended periods. Resin-based sealants reduce caries risk by 78% after one year and 59% after four or more years.[3]

Adverse reactions or complications associated with sealant application in children are minimal.[4,5] The durability of sealants significantly impacts their long-term effectiveness and safety in preventing dental caries.[6-8] According to studies, up to 70% of sealants are still in place after 44 months, demonstrating their strong retention rates.[9] Even if partially lost or worn down, sealed teeth have a lower risk of caries than unsealed teeth.[9] Resin-based sealants generally demonstrate higher retention rates than glass ionomer cement (GIC) used as sealants.[10,11] For instance, resin-based sealants can achieve a retention rate of 56.4% after three years, while GICs tend to have lower retention rates.[12] Factors such as proper tooth preparation, careful application techniques, a dry working field, and the use of appropriate bonding agents enhance the retention and marginal integrity of sealants.[13-15]

Marginal integrity refers to the ability of a sealant to maintain a tight and strong bond at the interface between the sealant and the tooth surface, preventing microleakage, discoloration, voids and cracks formation, and subsequent caries lesion development.[16] It plays a significant role in the effectiveness of the sealant and in preventing the development of caries.[16]

Various studies have evaluated the factors affecting the marginal integrity of dental sealants. For example, Stewart et al. demonstrated that using a C-Shape It instrument for sealant placement significantly improved marginal adaptation and reduced voids compared to traditional applicators.[16] Additionally, research has shown that sealants containing 45S5 bioactive glass (BAG) with a higher BAG content significantly reduced demineralization of the enamel, thus enhancing marginal integrity and preventing development of carious lesions.[17] Fluoride-containing sealants provide better marginal integrity than non-fluoride sealants, suggesting that fluoride release may enhance the protective effect of sealants at the interface between enamel and sealant.[18] Therefore, the marginal integrity of dental sealants is influenced by a number of factors, with application technique, material composition, and the presence of bioactive or fluoride-releasing components playing a significant role.

Scanning electron microscopy (SEM) reveals critical aspects of sealant structure and durability in children, allowing assessment of retention and integrity over time.[19] In addition, the method can reveal the microstructural characteristics of sealants, such as the presence of voids, microcracks, and the quality of marginal adaptation to the enamel surface. These microstructural characteristics are critical for understanding sealant placement's mechanical stability and potential risks.[20] However, no research has studied the marginal adaption of sealants that are applied with vibration or after heating.

Aim

This study aimed to evaluate the marginal integrity of resin sealant applied to the occlusal surfaces of permanent molars using scanning electron microscopy (SEM), employing different techniques.

Materials and methods

The study involved 80 non-carious human third molars extracted for orthodontic reasons. All patients provided informed consent after the purpose of the study was explained. After extraction, the teeth were irreversibly anonymized. The crowns were cleaned with 3% hydrogen peroxide and stored in 1% thymol solution until the study began. The inclusion criteria in the study were intact third permanent molars with an occlusal surface resembling a first permanent molar without signs of demineralization, initial carious lesions, or other defects. A dental operating microscope (Semorr 3000E, Semorr Medical Tech Co., Jiangsu, China) with an 8× magnification was used for the evaluation. Before sealant placement, the fissures were cleaned with pressurized sodium bicarbonate powder (PROPHYflex 3, Kavo, Biberach, Germany) and rinsed with water-air spray to ensure the removal of any debris and/or contamination before the sealant was applied. They were then randomly divided into four groups of 20, as described in **Table 1** based on the sealant application method. The chosen heating temperatures of 41°C and 51°C for the sealant application were consistent with the standard factory-set temperatures of composite heating devices available in the market.

After sealant placement, a two-step impression was taken of the crowns of the teeth with a silicone impression material, Class A (Variotime, Kulzer, Hanau, Germany) **(Figs 1A, 1B)**. From this impression, replicas of the occlusal surface were created with a transparent two-component epoxy resin (Liquid Glass resin, Reschimica). The two components of the resin were mixed in a ratio of 2:1 (200 g of component A to 100 g of component B), making the resin ready for use.

The silicone impressions, which included five teeth in one mold measuring 5×5×1 cm, were placed in a transparent plastic box measuring 5×5×5 cm **(Fig. 1C)**. The mold was filled with the resin until all the crowns of the teeth were filled and at least 1 cm above them. To reduce the risk of void formation in the replicas, the resin was heated with a heat gun. The prepared epoxy resin specimens were removed from the impressions 10 hours after casting to achieve complete curing of the material at room temperature of 18°C to 25°C **(Fig. 1D)**.

Table 1. Groups according to the sealant placement method

Group	Method of sealant application
1 – control, silanization at room temperature (21.5°C)	A conventional resin sealant, Grandio Seal (VOCO, Cuxhaven, Germany) was applied. Fissure sealant was applied directly with the disposable cannula at room temperature (21.5°C) using air conditioner. A sharp explorer was used to remove any air bubbles and ensure uniform flow of the material. This was followed by 10 seconds of waiting, removal of the excess with a dry cotton pellet, and curing for 20 seconds with a light-curing lamp.
2 – heating to 41°C	Applying Grandio Seal resin sealant at the entrance to the pits and fissures after heating it to 41°C using a composite resin heater (AzDent Dental Composite Resin Heater, Henan Baistra Industries Corp., Zhengzhou, China), waiting 10 seconds, removing excess with a dry cotton pellet, and light curing for 20 seconds.
3 – heating to 51°C	Application of Grandio Seal resin sealant, heated to 51°C with a composite heater, waiting for 10 seconds, removing excess with a dry cotton pellet, and light-curing for 20 seconds.
4 – vibration method with sonic vibrations of 140 Hz	Application of Grandio Seal resin sealant using a micro cannula at the pits and fissures entrance at room temperature, followed by 140 Hz vibrations applied along the fissure system using a vibrating instrument with a conical tip (Compothixo, Kavo Kerr, California, USA) for 10 seconds. Excess sealant is removed with a dry cotton pellet, and the sealant is cured for 20 seconds.

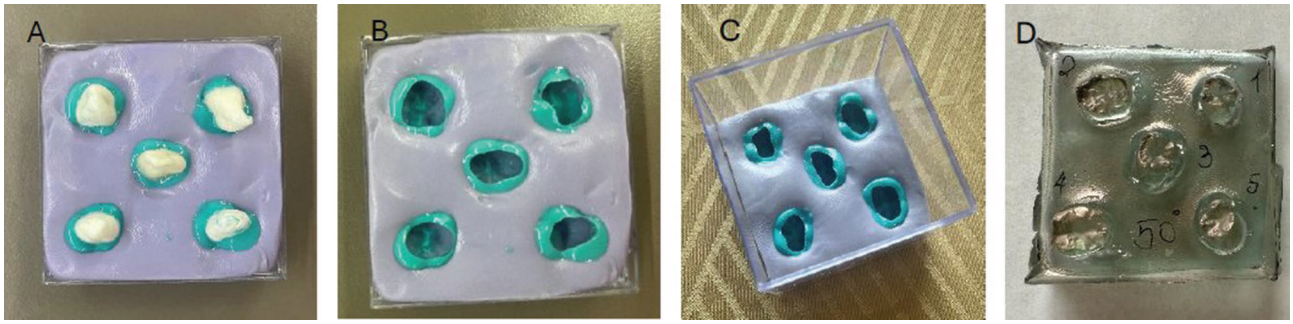

Figure 1. Prepared silicone impressions and epoxy resin replicas.

Impregnation of the samples with gold and observation with SEM

The replicas were fixed on an aluminum platform and placed in a vacuum device, where they were coated with a 25-nm-thick layer of pure gold using an ion sputtering unit (JEOL JFC—1200 fine coater). The impregnation with gold was carried out for 40 seconds. This enabled observation with a JEOL JSM—6390 scanning electron microscope (JEOL USA Inc, Peabody, United States).

Thermocycling method

The silanized teeth were subjected to thermocycling (thermocycler SD Mechatronik) to mimic the sealants' natural aging process and simulate the oral environment. The operating mode was 500 cycles, with samples being soaked in a water bath at 5°C for 30 seconds, resting at room temperature for 20 seconds, then soaking them in a water bath at 55°C for 30 seconds and resting at room temperature for another 20 seconds for each cycle.[21] After the applied cycles, new impressions of the silanized occlusal surfaces were taken, and new replicas were prepared from epoxy resin. They were once again coated with gold dust and examined using a scanning electron microscope for comparison with the original samples before the temperature exposure.

Methodology for assessing the marginal integrity of the sealants (Figs 2, 3)

Four images were taken from different parts of the occlusal surface of each specimen, which were then stacked using the ImageJ image processing software (National Institutes of Health, Bethesda, MD, USA) **(Figs 2, 3)**. The same software package was used to assess the marginal integrity. It was used to record the presence of a gap between the peripheral contour of the sealant and the enamel. The marginal integrity of the replicas was compared before and after the thermocycling process, with gap extent measured as a percentage of the sealed area's total length.

Statistical analysis

Statistical analyses were performed using SPSS 19.0 for Windows (IBM, Armonk, NY, USA). The Shapiro-Wilk test was used to test the normality and homogeneity of the dispersion distribution. The data were subjected to parametric analysis using the independent samples t-test at a significance level of $p<0.05$.

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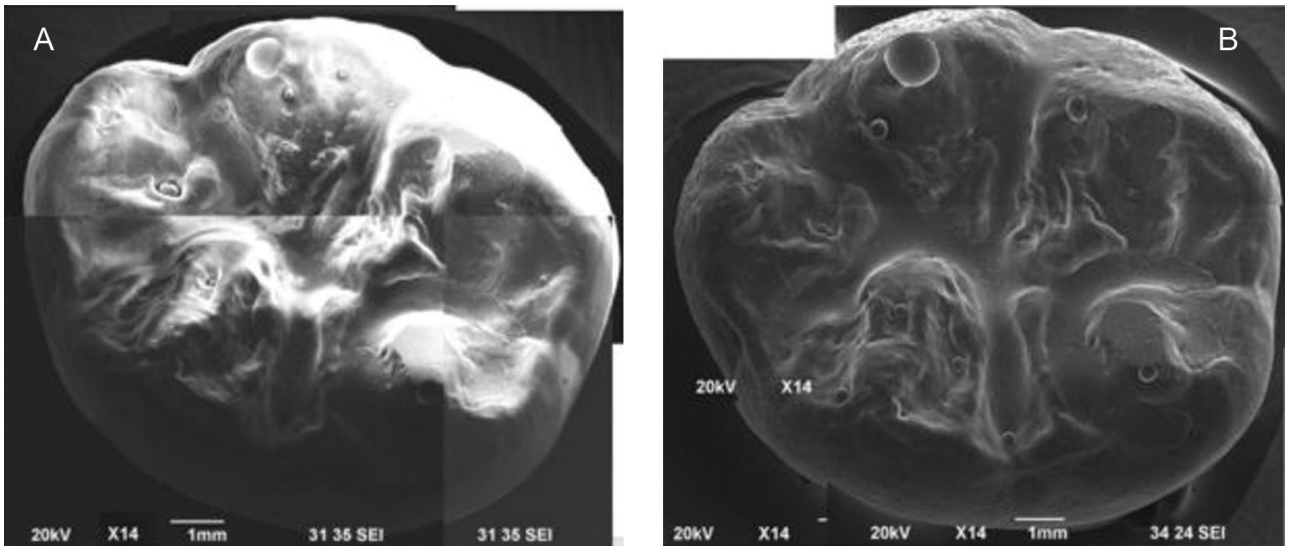

Figure 2. Comparative images of a molar silanized with a conventional technique at room temperature before (**A**) and after (**B**) thermocycling.

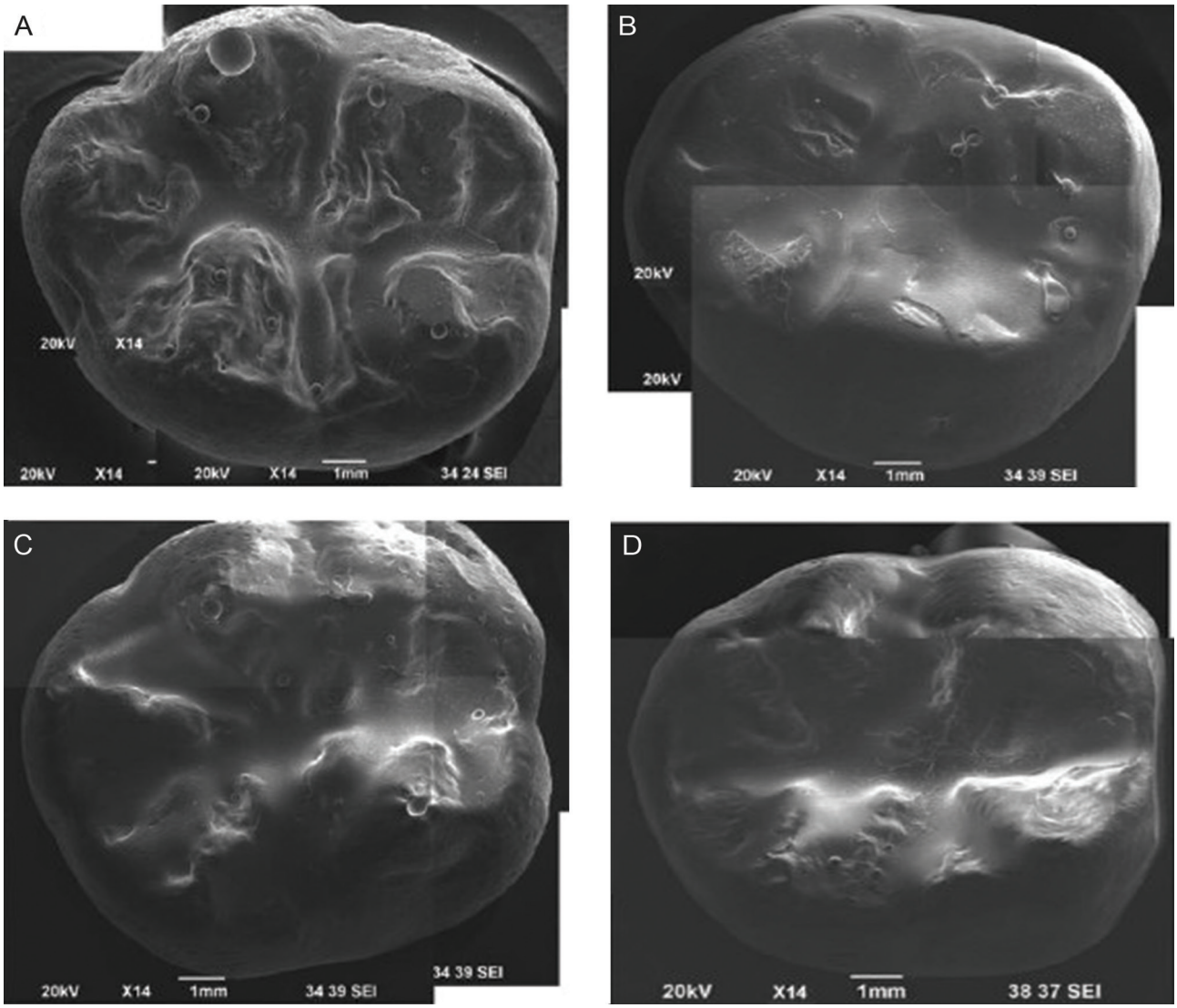

Figure 3. Representative SEM images after thermocycling of silanized molars: **A**) with conventional technique and room temperature sealant; **B**) after heating the sealant to 41°C; **C**) after heating the sealant to 51°C; **D**) after applying 140 Hz sonic vibrations along the course of the fissure system.

Results

Fig. 2 demonstrates comparative images of a silanized molar with the conventional application technique at room temperature before and after thermocycling.

Fig. 3 shows representative combined SEM images of the occlusal surfaces of molars that have been silanized using different techniques after undergoing thermocycling.

Fig. 4 shows the results of the SEM analysis of the sealants before and after thermocycling.

The data showed that marginal integrity ranged from 90% to 94% before thermocycling. There were statistically significant differences between the control (conventional silanization) and the other three groups in the study (heating and application of vibrations, $p<0.001$). Marginal integrity decreased after thermocycling in all groups studied with worst adaptation observed in the control group. The difference was statistically significant ($p<0.001$). In the other three groups, the data ranged from 88% to 86%, with the best adaptation observed after applying vibrations along the fissure system. There was no statistically significant difference between the groups when the material was heated to 51°C or when vibrations were applied ($p>0.05$). However, a significant difference was observed when comparing heating the sealant to 41°C and applying vibrations along the fissure system ($p=0.004$).

Discussion

Modern preventive dental practices have reduced the incidence and progression of caries.[22] Despite this, the worldwide incidence of occlusal carious lesions remains high.[23] Pits and fissures represent only 22%-24% of the entire occlusal surface and 6% of the entire clinical crown of the tooth. Still, occlusal caries remain a global problem, especially in children.[24] Sealants have a proven effect against the development of occlusal lesions in both primary and permanent teeth. They act as a mechanical barrier against the accumulation of bacterial biofilm and impaction of food in the deep areas of the fissure, where toothbrush bristles do not have the potential to reach and clean adequately.

For long-term effectiveness, sealants must achieve maximum adhesion and retention to the tooth enamel surface, as well as maintain good marginal adaptation. This is essential to prevent the development of microcracks and voids that can lead to leakage and bacterial invasion, which may ultimately result in the formation of caries lesions or loss of the sealant itself. Sealants face various types of problems in the oral cavity, including thermal, mechanical, and chemical stress. Over time, these challenges can lead to changes in the sealant's integrity, causing wear and potential partial or complete loss of the sealant.[25]

Therefore, our study aimed to evaluate the marginal adaptation of Grandio Seal resin sealant applied using conventional application techniques and after heating or with sonic vibrations. The results show lower risk of margin integrity and adaptation disruption when the sealant is applied with a vibrating tool or preheated, regardless of temperature **(Fig. 4)**. Statistically significant differences support these findings. The conventional method of using the sealant showed a higher percentage of marginal integrity decrease both before and after thermocycling **(Fig. 4)**.

The technology of the vibrating Compothixo instrument (Kavo Kerr, California, USA) improves the thixotrop-

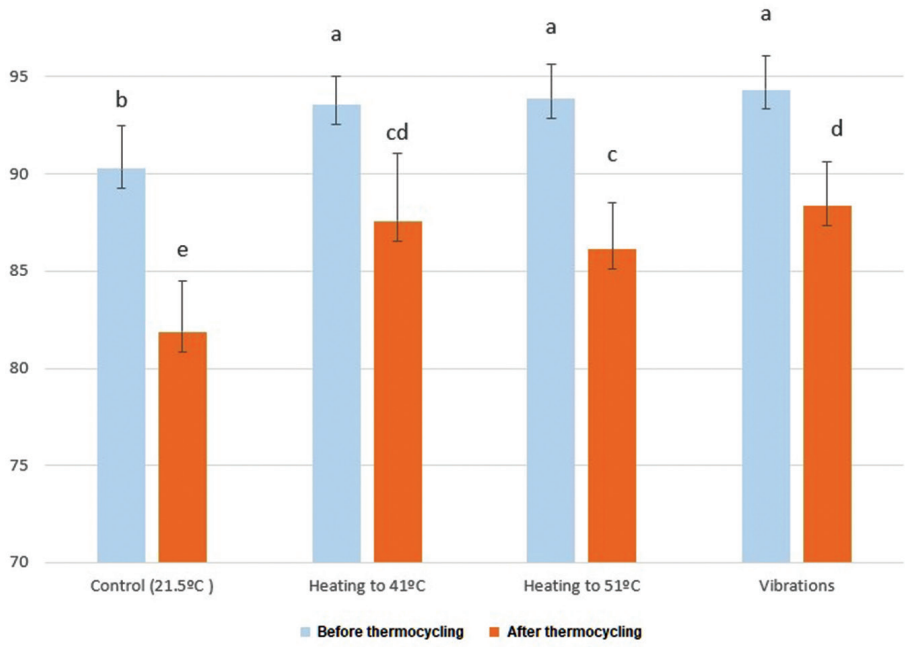

Figure 4. Mean marginal adaptation in percent (%) for sealants, applied using different methods, different lowercase letters a–e indicate significant difference ($p<0.05$; independent samples t-test).

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ic properties of resin composites and sealants by changing only their viscosity without affecting the chemical and mechanical properties of the material. In our study, we found that significantly minor defects in the marginal adaptation of the sealant were detected precisely when this method of sealant placement was used **(Fig. 4)**. This is probably due to the increased viscosity of the material, leading to better penetration into the depth of the fissures, better adhesion to the tooth enamel surface, and better marginal adaptation.

The polymerization of composite sealants causes stress from shrinkage and the material's elastic modulus. High polymerization shrinkage can lead to microleakage and compromised marginal integrity. Heating reduces the viscosity of the sealants significantly.[26] This contributes to its better penetration into the retentive zones of the molars and, therefore, longer sealant retention. The better the flowability of the fissure sealant, the less likely it is to form voids and other defects during its application.[27] The current study showed that even after thermocycling, applying sealants after heating leads to significantly fewer defects along the enamel-sealant interface compared to the conventional protocol **(Fig. 4)**. Other study confirms low-viscosity materials generally showed better marginal adaptation than higher-viscosity sealants.[28]

According to another study, a marginal adaptation of different types of sealants ranges from 93% before simulated aging to 81%–84% afterward.[29] Some studies noted a greater reduction to about 72% after thermocycling.[26] The variations in the recorded data are likely due to the different types of vibrations used for enhanced penetration of the materials – sonic frequencies in the current study and ultrasonic frequencies in the previous study. Not all methods investigated marginal adaptation only after thermocycling as a method of stimulation of aging. Other studies combine thermocycling with thermomechanical stimulation of the masticatory process or other methods. In all cases using vibrations during the application procedure improves the marginal integrity.[25,29]

Conclusion

Using sonic vibrations or preheating the sealant in a composite heater has the potential to improve the marginal integrity of the sealants. Thus, the method of sealant application plays a crucial role in determining its marginal integrity and sealing ability.

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Competing interests

The authors have declared that no competing interests exist.

Author contribution

All listed authors have contributed to the preparation of this manuscript and have permitted their names to be included as co-authors.

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