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VISEU

Damage of the Enamel After Sealing Occlusal Fissure and Pits:
A Systematic Review

Dissertação apresentada à Universidade Católica Portuguesa para obtenção do grau de Mestre em Medicina Dentária

Por:

Diana Dinis Abrantes

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RESUMO

Introdução: A selagem de sulcos e fissuras é uma medida preventiva eficaz contra a cárie dentária, especialmente em pacientes de alto risco, ao criar uma barreira protetora. O procedimento inclui limpeza, condicionamento, aplicação do selante e fotopolimerização. A escolha do material influencia o sucesso do tratamento: selantes de resina composta oferecem maior retenção, enquanto os de ionómero de vidro libertam flúor e são menos sensíveis à técnica. Apesar de desafios como microfissuras e desgaste, uma seleção criteriosa do material e a aplicação adequada garantem a sua eficácia na prevenção da cárie dentária.

Objetivos: Realização de uma revisão sistemática sobre a relação entre a adesão dos selantes e os danos no esmalte após a selagem de fóssulas e fissuras oclusais com diferentes materiais modernos, tendo em conta o impacto no esmalte.

Materiais e métodos: Foi efetuada uma pesquisa nas bases de dados eletrónicas PubMed e Scopus. Na estratégia de investigação foram utilizados como palavras-chave, os termos em inglês: "damage" OR " degradation" OR "wear" OR "erosion" OR "corrosion" OR "demineralization" OR "roughness" AND "enamel" AND “fissure” OR “pit” AND “sealant”. Foram incluídos estudos em inglês de 2004 até outubro de 2024, abrangendo ensaios in vitro, ensaios clínicos randomizados e estudos de coorte prospetivos. Excluíram-se artigos sem resumo, relatos de caso com follow-up breve e estudos piloto. Os estudos foram selecionados com base em critérios de inclusão e exclusão
previamente definidos.

Resultados: Neste estudo, foram considerados dezassete dos setenta e dois estudos inicialmente identificados, uma vez que estes cumpriram os critérios estabelecidos para a pesquisa. A análise qualitativa dos estudos selecionados revelou a presença de algumas limitações metodológicas, resultando em dados heterogéneos que impedem uma comparação direta entre os diferentes estudos.

Conclusão: A selagem de sulcos e fissuras é eficaz na prevenção da cárie, mas pode causar danos ao esmalte, como desmineralização, microfissuras e desgaste mecânico. A escolha do material e da técnica de aplicação influência

estes efeitos, sendo essencial uma abordagem cuidadosa para minimizar impactos adversos e otimizar a prática clínica.

Palavras-chave: Rugosidade; Esmalte; Fissura; Fossa; Selante

ABSTRACT

Introduction: Pit and fissure sealing is an effective preventive measure against dental caries, especially in high-risk patients, by creating a protective barrier. The procedure involves cleaning, conditioning, sealant application, and light curing. The choice of material influences the success of the treatment: composite resin sealants offer greater retention, while glass ionomer sealants release fluoride and are less technique sensitive. Despite challenges such as microcracks and wear, careful material selection and proper application ensure its effectiveness in caries prevention.

Aim: Perform a systematic review between sealant adhesion and enamel damage after sealing occlusal pits and fissures with different modern materials and considering their impact on enamel.

Materials and methods: A search was conducted in the electronic databases PubMed and Scopus. The research strategy used English keywords such as "damage" OR "degradation" OR "wear" OR "erosion" OR "corrosion" OR "demineralization" OR "roughness" AND "enamel" AND “fissure” OR “pit” AND “sealant.” Studies in English from 2004 to October 2024 were included, covering in vitro trials, randomized clinical trials, and prospective cohort studies. Articles without abstracts, case reports with short follow-ups, and pilot studies were excluded. Studies were selected based on predefined inclusion and exclusion criteria.

Results: Seventeen of the seventy-two initially identified studies were considered in this review since it respected the established research criteria. The qualitative analysis of the selected studies revealed some methodological limitations, resulting in heterogeneous data that prevent direct comparisons between studies.

Conclusion: Pit and fissure sealing is effective in caries prevention but may cause enamel damage such as demineralization, microcracks, and mechanical wear. The choice of material and application technique influences these effects. Which means it is essential to adopt a careful approach to minimize adverse impacts and optimize clinical practice.

Key-words: Roughness; Enamel; Fissure; Pit; Sealant.

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1. INTRODUCTION

Sealing pits and fissures on the occlusal surfaces of molars and premolars has long been recognized as an effective and essential preventive measure against dental caries, especially in high-risk patients. The occlusal surfaces are actually the most susceptible to caries because of its intricate grooves and fissures which is still difficult to clean through routine brushing. By sealing these fissures, the sealant becomes a physical barrier that prevents bacteria and food particles from being trapped and effectively reducing the risk of decay. (1)(2)(3)

The application of pits and fissures sealant is a cornerstone in dental health, as a primary preventive strategy. Such treatment is preferably given to newly erupted molars and premolars. This application is a meticulous process that starts with the proper cleaning of the tooth surface by removing debris and plaque. Subsequently etching to make microscale porous sites that enhance adhesion and finally coating the tooth surface with sealant material. The polymerization or hardening of the sealant material is finally assured with a curing light to enable durability and optimal retention. (4)(5) When performed properly, this process minimizes the risk of dental caries and also reduces the need of more invasive restorative treatments later on.(5)(3)

The selection of the sealant material is critical for success. Currently, resin-based sealants and glass ionomer cements (GIC) are available. These options are different in terms of fluidity, adhesion, and wear resistance. It is preferable in certain situations, but resin-based sealants have a superior bounding retention. However, it requires exact application in a dry field to prevent microleakage. (4)(6)

Although the GIC mechanical properties are inferior to the resin-based sealants, it has a less technique-sensitive process and releases fluoride, providing additional caries protection. (7)(5)

Most literature in dentistry emphasizes the need to choose the right material for the patient's age, caries risk and tooth eruption status. And also, following the clinically accepted protocols is crucial. Proper isolation of the tooth during application, correct curing, and careful post-application checks are necessary to keep the sealant fit for longer and enhance performance. Collectively, these factors determine whether fissure sealants can maintain its status as a reliable primary prevention tool with a lasting positive impact on oral health. (1)(2)(4)(7)

Even though fissure sealants present a lot of advantages, it also has shortcomings. One of the main concerns is microleakage, which occurs when the sealant fails to fully bond to the tooth surface and allows oral bacteria and nutrients to infiltrate in the sealed grooves. This can lead to secondary caries, effectively undermining the preventive purpose of the sealant. (6)(7)

Additionally, differences in thermal expansion between the sealant material and the enamel can increase the risk of detachment, especially in resin-based sealants, which are more prone to this issue due to its rigid nature. (5)(7)

Potential damage to enamel during tooth preparation and application represents another downside. Over-etching and inappropriate material use may weaken the enamel structure and increase the risk of wear or fracture. Frequent replacements due to wear or detachment can further extend this problem, raising concerns about the cost-effectiveness of fissure sealants over time. (8)

However, while fissure sealants are at the heart of caries prevention, success lies in very much balancing the choice of material, technique, and patient-specific factors. As time goes by continual improvements pared with best practices have led fissure sealants to remain one of the best tools in preventive dentistry contributing to better oral health worldwide. (1)(2)(4)

1.1. Objective and Hypothesis

The main goal to perform a systematic review between sealant adhesion and enamel damage after sealing occlusal pits and fissures with different modern materials and considering their impact on enamel. It is possible to investigate which procedures and materials provide adequate sealant adhesion with minimal enamel damage. This study is based on the hypothesis that prior acid etching of the enamel already promotes the removal of a superficial layer of enamel that does not regenerate. Furthermore, continuous procedures contribute to enamel loss and alterations in it roughness, leading to the accumulation of debris and biofilms.

2. STATE OF ART

2.1. Types of Occlusal Fissure and Pits Sealants

Sealants are primarily classified into two categories in the prevention of dental caries on the occlusal surfaces of the teeth: composite resin sealants (RS) and glass ionomer sealants (GI). The major difference between these two types of materials is retention and fluoride release: composite resin sealants retain better, but glass ionomer sealants have the advantage of continuous fluoride release, providing further benefits for enamel remineralization and thus tooth protection and caries prevention. (1)

A third type of sealant is polyacid-modified resin-matrix sealants (PMRS). (1)

Table 1. Chemical composition of the main dental fissure and occlusal pit sealants.

Material Type	Chemical composition
Composite resin sealants (RS)	Organic matrix: BIS-GMA, TEGDMA, UDMA Inorganic fillers: glass, silica, barium
Glass ionomer (GI)	Powder: Polycarboxylic acid, Fluoroaluminosilicate Liquid: water, tartaric acid
Polyacid-modified resin composite (PMRS)	Inorganic filler (ion- leachable glass) Dehydrated polyalkenoic acid

Composite resin sealants (RS) are widely used due to its high durability and adhesion to enamel. Sealant applications are especially recommended for permanent molars in children because it provides an adequate and durable barrier preventing bacterial invasion and the accumulation of food residues within the fissures of the teeth. Several studies show that composite resin sealants can significantly reduce the incidence of caries on the treated surfaces in comparison with untreated surfaces. (1)

To enhance properties of sealants antibacterial agents, such as zincs and fluorides, have been incorporated into resin sealants. These agents inhibit bacterial growth and subsequently lead to a healthier oral environment, particularly valuable for high-caries-risk patients. Nevertheless, it is important to emphasize that more in-depth clinical trials are needed to confirm the prolonged efficacy of these antibacterial components. (1)(9)

One of the most important innovations in composite resin sealants (RS) to date, has been the incorporation of sodium monofluorophosphate into its polymer matrix, which acts as a "reservoir" of fluoride, promoting a prolonged action in preventing dental demineralization. This interaction between fluoride and enamel hydroxyapatite leads to the formation of fluorapatite, a compound that confers greater resistance to enamel demineralization and, consequently, reduces the risk of caries development. (10)

The composition of composite resin sealants (RS) is an organic matrix that contains such monomers as Bis-GMA, often in combination with TEGMA, which facilitates handling by reducing viscosity. These sealants can be developed for both fissure sealing and alternative restorations, with more fluid resin sealants which allows it to reach the deepest regions of dental fissures. The main advantages include ease of application, aesthetics, low thermal conductivity, and dimensional stability. However, sensitivity to moisture during application can compromise adhesion, and the material is subject to polymerization shrinkage. (11)

Resin sealants are more indicated in situations where good isolation and a dry field can be ensured. Because of its sensitivity to moisture, it can compromise the adhesion to the dental enamel. Therefore, these sealants are recommended for patients at high risk of caries, especially children and adolescents. However, application on partially erupted teeth can be challenging; in this case, glass ionomer sealants are preferable due to its greater resistance to moisture and ease of application. (8)

Glass ionomer cements (GIC) were first introduced by McLean and Wilson in 1974. It contain a mixture of calcium, aluminum, silica, and fluoride compounds. (11)
The introduction of glass ionomer sealants (GI) into preventive dentistry, especially its application in caries prevention among children and adolescents, has started to assume an important role in preventive dentistry. The new material provides a unique alternative to traditional resin sealants, endowing it with certain characteristics that render the latter particularly interesting in certain clinical conditions. (12)

Glass ionomer sealants (GI) are essentially a combination of fluoroaluminosilicate glass particles, liquid comprising polyacrylic acids and water. Mixing these components results in an acid-base reaction, which provides a material that has adhesive and fluoride-releasing properties.(13) The continuous release of fluoride is one of the main reasons why ionomeric sealants play a big part in enamel remineralization and the reduction in caries development. (14) (13)

During the following decades, several modifications to the original formula led to the introduction of resin-modified glass ionomers (RMGI). This material contains some resinous monomers, imparting it with enhanced properties such as increased wear resistance and improved aesthetics. (14) (12)

Another advantage of glass ionomer sealant is the minimum sensitivity to moisture during application. With this property, it is especially advantageous using it in challenging clinical situations such as partially erupted teeth and patients with poor cooperation. (12)

Additionally, the application technique for ionomeric sealants is generally simpler and faster, as it does not require acid etching of the enamel or the use of adhesive systems. (13)

Several clinical studies have evaluated the effectiveness of glass ionomer sealants (GI) in caries prevention. Although the results in terms of retention are often inferior to resin sealants, it is important to note that the preventive effect of ionomers can persist even after apparent loss of the material. (15) Due to the presence of small amounts of material in the fissures and the continuous release of fluoride, maintains a cariostatic effect.

The indication of glass ionomer sealants (GI) is particularly relevant in public health programs and in contexts where rigorous moisture control is difficult. It is also a valid option for patients with high risk of caries, due to its ability to release fluoride. (12) Nevertheless, oral health professionals should be aware of the limitations of these materials: it wears off more easily than resin sealants (RS) and it needs to be applied more often.

In recent years, new formulas of high-viscosity glass ionomers were introduced in an attempt to improve retention and durability of these materials. According to some studies, the application of these ionomers via the digital pressure technique may achieve better adaptation and retention of the sealant.(12)

Based on these observations, is concluded that glass ionomer sealants application is a very valuable procedure in preventive dentistry. The long-term retention may have some limitations, but the unique qualities of glass ionomer sealants, such as fluoride release and moisture tolerance, often makes it preferable in many clinical scenarios. (14)

The polyacid-modified resin composite (PMRS), commonly known as a compomer, is also used as a fissure sealant. This substance combines the advantages of a visible light-cure resin sealant with the fluoride-releasing ability that characterizes a glass ionomer cement (GI) sealant. The polyacid-modified resin sealant (PRS) exhibits strong adhesion to enamel and dentin while being less technique-sensitive than traditional resin sealants. (14)

2.2. Clinical Techniques

Sealant application techniques may be classified as either non-invasive or minimally invasive. Each one has its own characteristics and indications.
The most widely used, non-invasive method, also known as the conventional technique, requires a few conservative procedures, which involve minimal wear of dental enamel. First, the tooth surface is thoroughly cleaned and the operating field is isolated to prevent contamination. After the acid conditioning of enamel

using a gel with a 37% phosphoric acid concentration for about 30 seconds, the whole area is rinsed and dried very carefully. Then, the sealant is applied directly to pits and fissures and cured with a light for about 20 seconds. (16) It is popular because of its conservative nature, rapid execution, painless approach, and relatively affordable. (16)

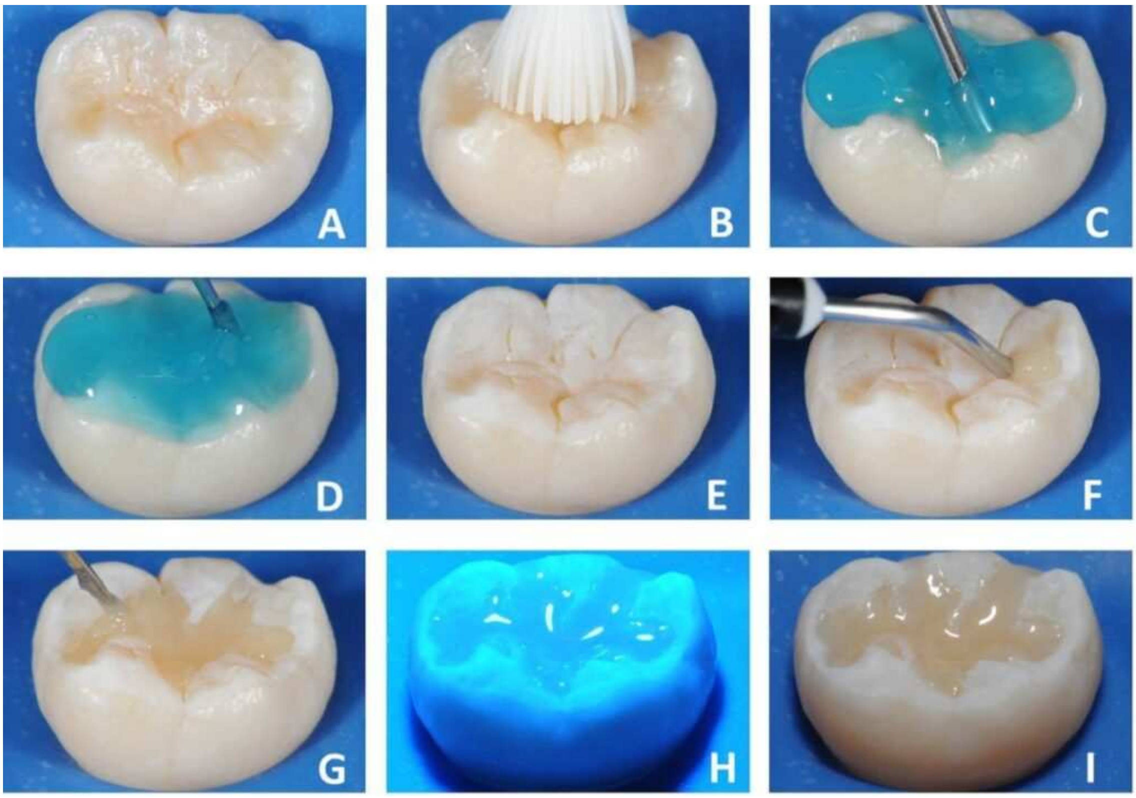

Image 1. Laboratory sequence of the minimally invasive technique for applying a resin sealant to pits and fissures. A – Grooves, pits and fissures of an extracted molar; B – Prophylaxis with pumice stone and water; C – Etching with 37% phosphoric acid (Condac 37, FGM); D – Total etching for 30 seconds; E – Opaque whitish appearance of the enamel after etching; F – Application of sealant (Prevent, FGM); G – Applying over the

entire area of pits and fissures; H – Light curing for 20 seconds; I – After sealing the fissures. Adapted from (17).

A variation of the non-invasive technique includes applying a layer of glass ionomer cement before the resin sealant. This approach can be particularly useful in situations where absolute isolation is challenging, providing a viable alternative to ensure effective sealing. (18)
On the other hand, minimally invasive techniques involve limited mechanical manipulation of the tooth surface. Such a technique should be used a smooth, round carbide bur ¼ on pits and fissures that show colour changes. The aim is to enhance the penetration and the adaptation of the sealant, which is performed before the conventional sealing procedure. This approach seeks to improve the sealant's efficacy in areas with a higher risk of developing caries. (19)

For each technique, the procedure includes the following steps: isolation of the working area (preferably absolute isolation), prophylaxis with pumice and water, application of enamel acid conditioning, rinsing and drying, sealant application, and light-curing. The technique selection should be guided by other factors that should include tooth morphology, caries risk associated with the patient as well as requirements for proper isolation. (20) Also, the moisture control is critical for the success of the sealant, regardless of technique. Contamination with saliva can considerably compromise the adhesion of sealants to the enamel, thus lowering their preventive effectiveness. (21)

Sealant application is highly recommended for children between the ages of 5–8 to protect the first permanent molars and between 11–14 years for premolars and second molars. However, it is important to note that the sealant is no substitute for good oral hygiene, nor does it eliminate the need for regular check-ups. (22)

The prevention of caries by fissure sealants is confirmed in the literature. Sealants can reduce dental caries levels by 60% on average, within a range of 2 to 5 years after application. Furthermore, if properly applied, sealants prevent the early stages of caries progression, and provide a preventive and partial restorative function. (23)

According to Boj (2011), there are two application techniques: the non-invasive and the invasive technique.

The non-invasive technique is a method that does not need direct intervention on the dental enamel before the sealant application on healthy pits and fissures or in a caries lesion in a very early-stage. In this process, the enamel only needs to be properly cleaned before acid conditioning, and it is recommended cleaning with a prophylactic brush and water. This approach allows a gentler preparation of the tooth surface and is indicated for cases where there are no advanced signs of caries. (11)(24)

The invasive technique, known as ameloplasty, involves mechanical widening of the fissures limited to the enamel. This intervention facilitates access and improves the sealant's effectiveness. However, now it is considered unnecessary to apply such method on all suspicious fissures or cavities before applying the fissure and pit sealant. With meticulous cleaning of the enamel, followed by effective conditioning, it is possible to prevent the progression of early-stage caries without invasive intervention. (11)(24)
There are different systems for performing the invasive technique:

1) Fissurotomy burs: These burs have specific shapes and sizes for treating fissure lesions, allowing a controlled preparation of the enamel in the affected areas. (11)

2) Air abrasion: This technique uses a handheld device that projects abrasive aluminum oxide particles, approximately 27 microns in size, which cuts and removes the necessary dental structure as well as any organic debris that may be present in the pits and fissures of cavities. (11)

After preparing the treated areas, restoration is carried out by applying flowable composite resin to the prepared area followed by the application of the fissure and pit sealant (SSF) on adjacent areas that were not prepared. This allows the protection of the tooth from future lesions. (11)(25)

Regardless, the choice of the most appropriate technique should be based on the patient's individual needs, the practitioner's careful evaluation and the specific characteristics of each clinical case. The proper use of fissure sealants, combined with other preventive measures, remains a key strategy in promoting oral health, especially in pediatric populations. (25)

2.3 Adhesion to Enamel

2.3.1 Bond Strength Values

Bond strength of dental materials and enamel is usually expressed in megapascals (MPa). The general consensus is that a minimum of 17-20 Mpa is required for enamel and dentin bonded resin composite materials in the ability to resist contraction forces. (26)However, bond strength values can vary significantly depending on the adhesive system used and the surface preparation.

In a study comparing different adhesive systems, the following bond strength values were observed. (26)

Table 2. Different adhesive systems and bond strength.

Adhesive System	**Bond Strength**
Total-etch systems	On average 26.092 MPa (e.g., Prime and Bond NT)
Self-etching adhesives: -Clearfil Protect Bond	On average 24.526 MPa
-Clearfil S3	On average 22.060 MPa
-Xeno III	On average 24.858 MPa
-G Bond	On average 16.378 MPa

Based on the presented analysis, it is possible to observe that total-etch adhesive systems, such as Prime and Bond NT, consistently demonstrate higher bond strength values. Often exceeding 20 MPa, which makes it highly effective in terms of adhesive performance. (26)
Even though, self-etching adhesives, generally exhibit lower bond strength values, it still achieves clinically acceptable levels for dental applications. (26)

Among the self-etching adhesives, Xeno III and Clearfil Protect Bond stand out, showing bond strength values close to 20 MPa. Followed by Clearfil S3, with slightly lower performance, and G Bond, whose bond strength values were slightly below the ideal range. (26)

Another study comparing etch-and-rinse adhesives with self-etch adhesives reported the following results:

Table 3. Comparison of Etch and Rinse Adhesives with Self-Etch Adhesives.

Adhesive	Substrate	Bond Strength
Single Bond	Uncut enamel	4.94 ± 0.83
Single Bond	Cut enamel	25.44 ± 5.25
iBond	Uncut enamel	3.62 ± 1.56
iBond	Cut enamel	8.51 ± 2.45

These results highlight the significant differences in bond strength between etch-and-rinse and self-etch adhesives, particularly on cut enamel surfaces. (27)

2.3.2 Comparison Among Materials

The type of adhesive makes a difference in the strength of bonds that are formed between the enamel. Etch-and-rinse adhesives are known to bond the dental enamels more strongly by using acid etching; the bond strengths are usually higher than those in the self-etch group. (27) (28) This superiority is attributed to the deeper patterns made by phosphoric acid etching on the enamel surface, enabling better micromechanical interlocking of adhesive. (28)

Even though self-etching adhesives generally produce a lower bond strength, it is considered to have a less technique-sensitive application. (28) Effectiveness can also vary based on its acidity:

1) Strong self-etching adhesives: can demineralize dentin completely but may show lower bond strengths to enamel. (28)

2) Mild self-etching adhesives: can partially demineralize dentin, leaving some hydroxyapatite attached to collagen, which can be beneficial for bonding. (28)
3) Ultra-mild self-etching adhesives: can have limited demineralization capability and may struggle to bond effectively to unprepared enamel. (28)

To compensate the lower enamel bond strengths of self-etching adhesives, some studies recommend selective enamel etching with phosphoric acid prior to applying universal adhesives. (28)

Table 4. Comparison of different dental sealant materials and their properties.

Type of Sealant	Wear Resistance	Bond Strength (MPa)
Composite resin sealants	High	20-25
Glass ionomer	Moderate	5-10
Polyacid-modified resin composite	Moderate/ High	10-15

2.3.3 Roughness of Enamel

Roughness imposes an inverse influence on adhesion, as the interaction of these factors on bond strength is complex. Several studies highlight that enamel roughness does not have any direct correlation with bond strength. (29)

The study on natural bovine enamel roughness and its influence on bond strength indicates:

1) A significant difference between the roughness characteristics in the longitudinal and transverse directions of the enamel. (29)

2) The mean bond strength was 13.3 MPa, somewhat higher than the clinically recommended range of 5.9 to 7.8 MPa. (29)
3) Whatever the case may be, there was no direct correlation drawn between the cited roughness characteristics, and the bond strength. (29)
4) As far as adhesion goes, these results led to the conclusion that while roughness may have an influence in some context, there are far more decisive factors on bond strength like the type of adhesive system, etching process, or surface preparation. (29)

2.3.4 Retention of Occlusal Enamel

To improve longevity of dental restorations and orthodontic appliances, the retention at occlusal enamel is critical. The conducted dental research has proven that the use of bonding agents could enhance retention of pit and fissure sealants (PFS) on occlusal surfaces. (30)

In a 12-month clinical study:
- PFS placed with a bonding agent showed a retention rate of 80%. (30)
- PFS placed without a bonding agent had a retention rate of 72%. (30)

While the difference was not statistically significant, the trend suggests that using a bonding agent can improve retention. However, the study also showed that the additional step of bonding might be excluded in children, as it did not show a statistically significant difference in clinical retention rates. (30)

Factors affecting the retention of materials on occlusal enamel include:

1) Surface preparation: Etching with phosphoric acid generally produces better retention than polyacrylic acid conditioners. (31)
2) Moisture control: Saliva contamination is a common cause of sealant failure, emphasizing the importance of proper isolation techniques. (30)
3) Patient factors: Age, behaviour and the ability to maintain proper moisture control during the procedure can significantly impact retention rates. (30)

Adhesion to enamel is complex and it is altered by many factors. Bond strengths are indicative, but technicians should consider the specific clinical situation, patient factors, and properties of the material when selecting an adhesive system. Phosphoric acid etching is still a reliable way of establishing a strong bond to enamel, especially when using etch-and-rinse systems. (31) Even so, self-etch adhesives have an easier application and could be the more reliable choice in some situations. Particularly so in combination with the selective enamel etching. (26)

2.4. Failures

2.4.1 Detachment and Debonding

Dental sealants have been recognized as a significant preventive measure in dentistry, especially when considering protection against caries of occlusal surfaces of molars. The effectiveness of sealants depends significantly on their retention over time. The roughening of enamel is the greatest asset for retention.

Traditionally, phosphoric acid etching has been the preparation of choice to create a micro retentive surface. However, it removes several microns of enamel, which may harm the retention process. There are reports exploring other conditioning methods, including self-etching agents, which can give comparable or better performance than conventional etching. (32) The use of a binding agent as an intermediate layer between the enamel and the sealant has been suggested to improve sealant retention. However, the evidence is still quite weak. (32)

Different types of sealant materials exhibit various retention rates:

-Resin-based sealants (RBS): considered the most commonly used and presented good retention rates. (4)

-Glass ionomer (GI) sealants: In general, have lower retention rates than RBS, but release fluoride. (4)

Sealant retention is an indicator of the caries-preventive effect. In a Cochrane review, resin-based sealants reduced caries increment by 11 - 51% during the two-year follow-up compared to no sealant. (4) However, that preventive effect may not last long if the sealant comes off prematurely.

It is crucial that during placement, the tooth surface is properly prepared and totally isolated from saliva. Saliva might contaminate the bonding surface and leading to bubbles and very weak adhesion. (4)

2.4.2 Fracture

Fractures and failures may compromise the longevity and effectiveness of sealants.

The susceptibility of sealant material to fracture is highly dependent on its physical characteristics. Glass ionomer cements may fracture more easily due to its lower adhesion and occlusal tension. Although, resin-based sealants generally resist fracture better, most will shrink during polymerization, which can create a microleakage condition and hence, making it weak. (33)

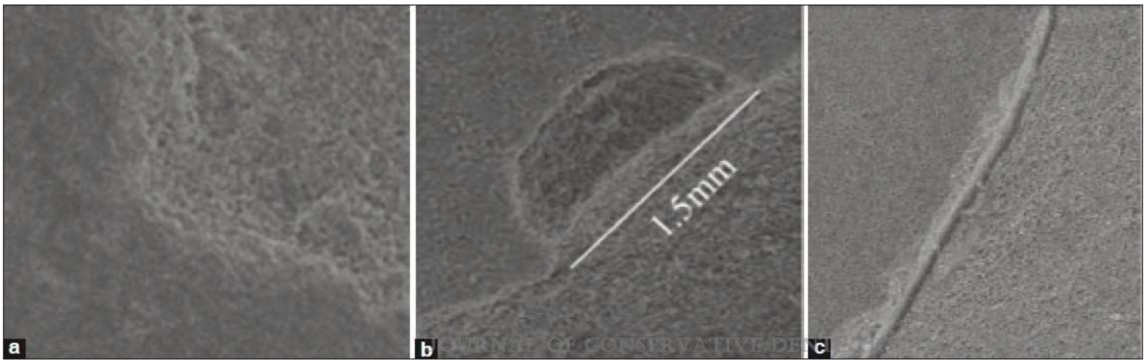

Image 2. (a) Continuous margin (b) Sealant fracture (c) Marginal fissures. Adapted from (34).

The geometry of the fissures on the tooth plays a significant role in the penetration of the sealant and its resistance to fractures. It has been shown that fissures that have a "U" or "V" shape, compared to the "Y"-shaped fissures, allow a better penetration of the sealing materials. This greater penetration most probably favours retention and thus helps reduce the risk of fracture. (33)

When sealants fail due to fractures, the consequences can be significant:

1. Microleakage: On sealant fracture, saliva and bacteria can seep inside the tooth and beneath the sealant. This will surely rupture the seal of the material, thus leading to carious lesions. (33)
2. Reduced Effectiveness: A study by Haricharan *et al*. found that after 24 months, resin sealants had a retention rate of only 39%, while glass

ionomer sealants retained at 32%. (35) This low retention rate directly impacts the sealant's ability to prevent caries.

3. Need for Replacement: Fractured or lost sealants often require replacement, leading to additional dental visits and costs. (35)

Various pretreatment strategies have shown promising in improving sealant adhesion:

1. Laser Irradiation: This technique may enhance the tooth surface for better sealant bonding. (33)
2. Air Abrasion: A roughened tooth surface could increase the surface area available for adhesion. (33)
3. Preheating: Heating the sealant material before application could enhance its flow and adaptation to the tooth surface. (33)

2.4.3 Wear Sealant

These sealants possess a high wear-resistance quality that significantly improves its long-term efficacy alongside with clinical benefits.

Resin-based sealants are very often used due to their good properties. Studies show that filled resin sealants generally have better wear resistance than unfilled ones. (36) The wear resistance of resin sealants is influenced by several factors:

1. Filler content: Higher filler content typically results in improved wear resistance. (37)
2. Filler size: An increase in filler size has been associated with higher wear rates. (38)
3. Filler distribution: A homogeneous distribution of filler particles contributes to better wear resistance. (37)

Generally, glass ionomer sealants offer benefits such as fluoride release, but are generally less resistant to wear compared to resin-based materials. It is susceptible to degradation under acidic conditions because it contributes to the wear. (38)

Several factors influence the wear resistance of sealant materials:

1. Acidic conditions: Exposure to acidic environments can accelerate wear, particularly in glass ionomer materials. (38)
2. Occlusal loading: Higher masticatory forces lead to increased wear. (37)
3. Filler characteristics: Size, hardness, and surface percentage occupied by filler particles all contribute to wear resistance. (37)

The wear resistance of sealant materials has important clinical implications:

1. Retention: Materials with higher wear resistance tend to have better retention rates. This is important for long-term prevention of caries. (35)
2. Material selection: technicians should consider the wear properties of different materials when selecting sealants for specific clinical situations. (35)

Wear resistance is an important characteristic of dental sealants which significantly influence its clinical performance and longevity. The wear properties of sealants should be taken into consideration by technicians when selecting and applying, along with other factors like, dental caries risk and oral environment. Regular follow-ups are also essential in tracking the sealant's integrity and continued protection against caries.(35) (37) (38)

2.4.4 Wear of Enamel

Enamel is the hardest tissue in the human body, subjected to several wear processes in the oral environment. The main mechanisms that cause wear of enamel are:

1. Fatigue: During mastication, cyclic contact forces may result in the initiation and propagation of subsurface cracks in enamel.(39)
2. Abrasion: Abrasive particles derived from the diet or restorative materials may accelerate wear by lowering the forces required to induce contact fatigue cracking. (39)
3. Attrition: Direct contact between opposing curves due to normal function or parafunctional habits causes mechanical wear. (39)
4. Erosion: Chemical processes, often due to acidic foods or beverages, can soften and dissolve enamel, making it more susceptible to mechanical wear. (39)

The wear of enamel in contact with fissure sealants is determined by several factors:

1. The type of sealant material used;
2. Applied masticatory load;
3. Physical properties of the sealant;
4. The characteristics of the enamel surface.

Some studies have shown that wear rates of primary tooth enamel are variable depending on the type of pit and fissure sealant used and when subjected to a variety of loads. Such variability emphasizes the importance of material selection in clinical practice. (37)

The interaction between fissure sealants and enamel involves complex wear mechanisms:
- Mechanical Wear: Occurs due to direct contact between the antagonist tooth and the sealant material during occlusal movements. (37)
- Chemical Wear: Initiated by water absorption that diffuses into the matrix and filler interfaces, affecting the hydrolytic stability of the material. (37)

Research on primary teeth revealed that the values of volume loss for enamel were statistically different and increased with higher loads applied during wear tests. (37) This finding highlights the importance of considering masticatory forces when selecting sealant materials for primary dentition.

The wear of enamel in relation to fissure sealants has several clinical implications:

1. Material Selection: technicians should consider the wear characteristics of different sealant materials when making treatment decisions. (36)(37)
2. Load Considerations: The applied masticatory load affects wear rates, suggesting that patient-specific factors such as bite force should be considered. (37)
3. Retention Rates: The effectiveness of dental sealants in caries prevention is closely linked to its retention. Studies shown various retention rates for different sealant types over time. Ranging from 11% to 89% at 6 months and 21% to 80% at 24 months for resin sealants. (35)

Enamel wear associated with fissure sealants represents a complicated set of processes under the influence of many factors. Knowing the interactions between these factors is important to optimize caries prevention strategies for better oral health outcomes in the long run. Material properties, patient characteristics, and expected loads while eating must be carefully considered by the technician when selecting fissure sealants. (35)(36)(37)

3. MATERIALS AND METHODS

The search results were imported into Rayyan to help visualize and operationalize the selection of articles and to evaluate the methodological quality of the studies. The evaluation tool - Joanna Briggs Institute (JBI) will be used.

3.1. Search Strategy

A bibliographical search was carried out on PubMed (via National Library of Medicine) and Scopus regarding such database includes the main studies in the field of dentistry. The present method was performed in accordance with the search approach used in previous studies on scoping and systematic reviews. The following combination of search terms was used in this study: "damage" OR " degradation" OR "wear" OR "erosion" OR "corrosion" OR "demineralization" OR "roughness" AND "enamel" AND “fissure” OR “pit” AND “sealant”.

The inclusion criteria included studies published in the English language, up to October 2024, reporting the interaction between adhesion and enamel damage after sealing occlusal fissures with different sealants. The eligibility criteria used for the article searches also involved in vitro studies; randomized controlled trials; and prospective cohort studies. Ongoing studies were searched in the following clinical trial registries: Current Controlled Trials, International Clinical trials registry platform, ClinicalTrials.gov, ReBEC, and EU Clinical Trials Register. Also, a manual search was carried out on the reference lists of all main sources and eligible studies of this review for further relevant publications. The exclusion criteria were the following: papers without abstract; case reports with short follow-up period; and pilot study.

3.2. Study Selection and Data Collection

The studies retrieved by the search approach were assessed in three steps. Studies were primarily examined for relevance by title and then the abstracts were evaluated. Three of the authors (JCMS, DA, RP) independently analysed the titles and abstracts of potentially relevant studies. A fourth author (NV) accomplished a final evaluation in case of disagreement. The studies were compiled for each combination of search items, and therefore, the duplicates were removed using Mendeley citation manager (Ed. Elsevier). The second step encompassed the evaluation of the abstracts and non-excluded studies, giving the eligibility criteria in the abstract revision. A preliminary evaluation of the abstracts was carried out to establish whether the articles met the purpose of the study. Selected articles were individually read and evaluated concerning the purpose of this study. At last, the eligible articles received a study identification label, combining first author and year of publication. The following factors were retrieved for this review: authors' names, publication year, journal, purpose, study design, type of sealant, surface analysis, main outcomes.

The PICO (population, intervention, comparison, and outcome) approach was followed as a framework to structure the following research question: "Can fissure and pits sealants damage the occlusal enamel?"

Regarding the PICO question, the following factors were taken into consideration:

Table 5. Research Question (PICO).

Population	***Intervention***	***Comparison***	***Outcome***
Molars, premolars, sealants, animal models, patients, volunteers.	Surface conditioning, clinical procedure, surface analysis; microscopy.	Minimally invasive, invasive, without sealants, type of materials, techniques.	Major findings on the damage of occlusal enamel.

The systematic review was registered in the OSF (Open Science Framework), with the DOI 10.17605/OSF.IO/YEM4H (Annex I).

4. RESULTS

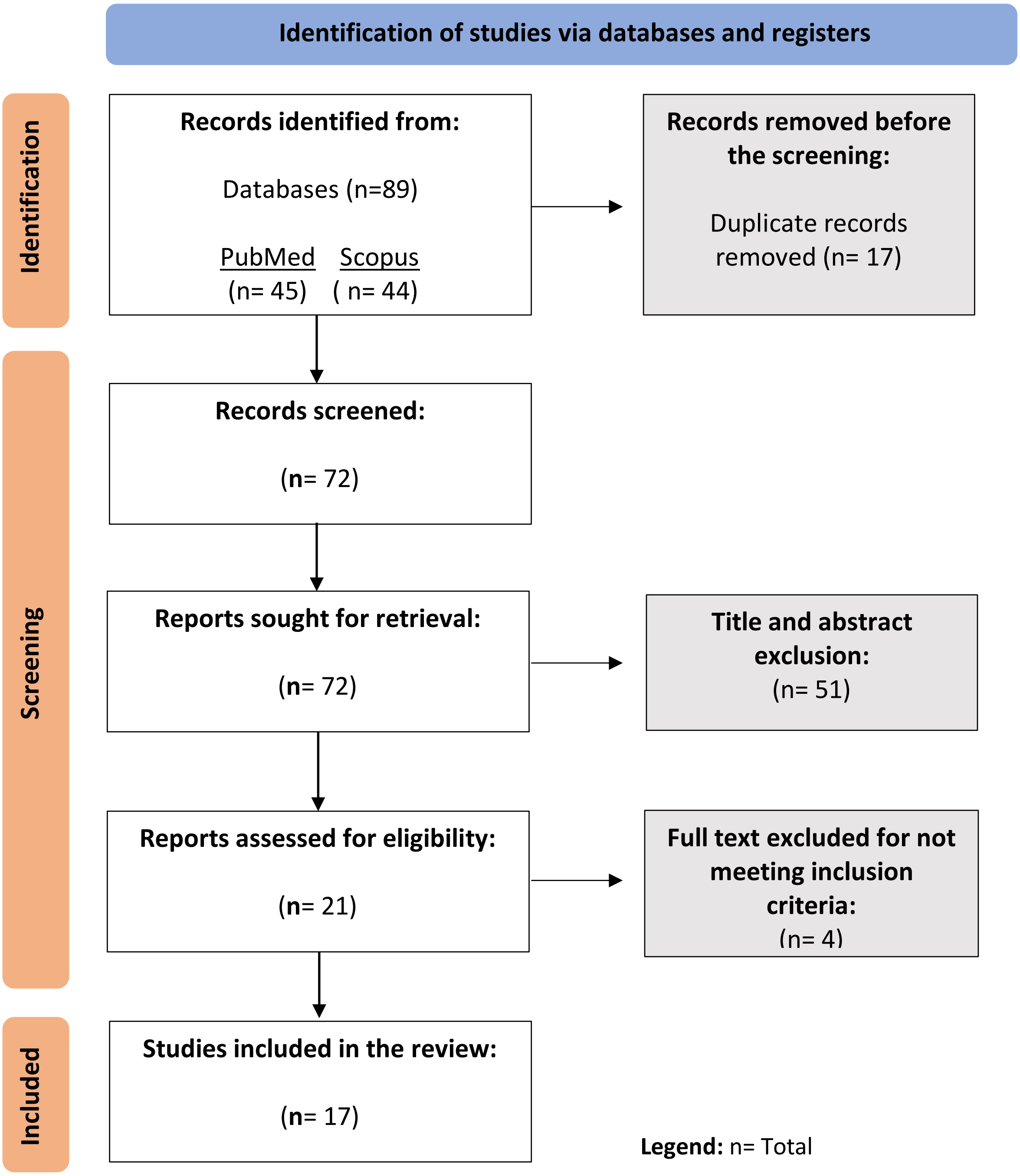

Image 3. Overview of article selection procedure according to PRISMA guidelines.

Table 6. Data retrieved from the selected studies.

Author (YEAR)	Purpose	Study design	Sealant materials	Analyses	Enamel roughness or loss	Main outcomes
Feda I Zawaideh *et al.* (2016) (40)	To evaluate the effect of amorphous calcium phosphate (ACP)-containing pit and fissure sealant on inhibition of enamel demineralization in vitro.	In vitro experimental design	Experimental groups: - Group 1 (n=25): Conventional resin-based sealant (Concise™) - control group - Group 2 (n=25): Amorphous calcium phosphate (ACP) containing sealant (Aegis®) - Group 3 (n=25): Fluoride-containing	-One-way ANOVA was used to compare means between groups -Tukey's post hoc test was used for multiple comparisons	Grupo 1: 269,17 ± 47,49 Grupo 2: 151,39 ± 23,96 Grupo 3: 175,79 ± 32,39	-Similar initial microhardness among groups. -Significant decrease in microhardness across all groups after acid challenge. -Effectiveness in inhibiting demineralization: ACP sealant > fluoride sealant > conventional sealant.

			sealant (Conseal-F™)			
Yoshishige Yamada *et al.* (2007) (41)	Improve fissure sealing through pre-treatment with Carisolv in order to remove organic debris	In vitro experimental study	-Group A: Cleaned with Carisolv -Group B: Cleaned with bristle brush and prophylaxis paste	-Morphological study using stereoscope and SEM -Surface roughness analysis using 3D laser microscopy -Microleakage test after applying sealant -SEM observation of enamel-sealant interface	-Roughness values increased after acid conditioning in both groups. Group A: Before acid conditioning: 0.32 ± 0.04 µm After acid conditioning: 0.51 ± 0.05 µm Group B: Before acid conditioning: 0.25 ± 0.03 µm After acid conditioning: 0.38 ± 0.04 µm	While Carisolv treatment resulted in cleaner surfaces with higher roughness, both methods showed similar microleakage results.

Shinichi Kakuda *et al.* (2015) (42)	Evaluate the buffering capacity of glass-ionomer pit-and-fissure sealant materials and their effect on environmental acidity and tooth substrate.	In vitro experimental study	-BS + tooth fragment -IIILC + tooth fragment -TM + tooth fragment -Lactic acid only + tooth fragment (LA, control) -PFS materials without tooth fragments	-Statistical analysis using SPSS software -Games-Howell test for comparing ion concentrations	-BS + tooth fragment and IIILC + tooth fragment: there were no significant signs of roughness or enamel loss. -Lactic acid only (LA)+ tooth fragment: signs of roughness - TM + tooth fragment: Significant loss of the enamel surface layer	- BS and IIILC maintained a relatively smooth enamel surface. - LA showed a rough surface. - TM exhibited significant loss of the enamel surface layer. - Glass ionomer-based sealants have superior buffering capacity, protecting the enamel in an acidic environment.
Shimazu K *et al.* (2012) (43)	Evaluate how the S-PRG filler-containing sealant impacts enamel demineralization and	In vitro experimental study	4 groups: (3 sealant types) BeautiSealant (BS) Delton FS+ (DE)	-Polarizing microscopy - Microradiography -Image-analyzing software program	DE and TE groups: -Enamel surface defects in subsurface lesions.	Conventional resin-based sealants caused significant enamel surface defects and increased lesion depth, while the S-PRG filler-

	remineralization, bond strength, and the integrity of debonded enamel surfaces compared to conventional sealants		Teethmate F-12.0 (TE) UN group	- Scanning electron microscopy at 5.0 kV	- Significantly increased the lesion depth -Demineralization 19,8 (2,8) e 17,5 (1,6) µm BS group: -Maintained the integrity of the enamel surface. -Inhibited enamel demineralization	containing sealant preserved enamel integrity and inhibited demineralization.
Zeynep A. GÜÇLÜ *et al*. (2016) (44)	Investigated the properties of the hydrophilic sealant UltraSeal XT® hydro™ and its resistance to microleakage in molars treated with different enamel	In vitro experimental study	20 extracted human molars, divided into two groups: - Group I: Conditioning with phosphoric acid only.	- Fourier Transform Infrared Spectroscopy (FTIR) - Scanning Electron Microscopy (SEM)	The use of the laser increased the enamel surface roughness, facilitating the segregation of the filler particles at the enamel-sealant interface.	The pre-treatment with Er:YAG laser significantly improves resistance to microleakage due to the increased enamel roughness and better sealant adaptation.

	conditioning methods.		- Group II: Conditioning with Er:YAG laser followed by phosphoric acid.	- Energy Dispersive X-ray Analysis (EDX) - Vickers Microhardness Test.		
Rehab Samir Salma *et al.* (2022) (45)	Assess the effect of bioactive and fluoride fissure sealants on calcium and phosphate content and surface topography of artificially demineralized enamel in young permanent teeth.	In vitro study	-Group I: Bioactive fissure sealant (BioCoat) -Group II: Fluoride-containing fissure sealant (Fisseal) -Group III: Control group (no sealant applied)	-Scanning electron microscopy imaging (SEM) -Statistical analysis using ANOVA, post-hoc tests, and non-parametric tests	-Group I: smooth and intact enamel surface after remineralization. -Group II: minor defects and irregularities, but still showed signs of remineralization. - Group III: increased roughness and loss of enamel, with multiple cavities and defects and no signs of remineralization.	The bioactive sealant demonstrated superior remineralization effects compared to the fluoride sealant.

S.-Y. Yang *et al.* (2016) (46)	Evaluate the enamel surface adjacent to sealants containing 45S5 bioactive glass (BAG) under simulated microleakage between the material and the tooth in a cariogenic environment.	In vitro experimental study	5 sealant groups with different BAG concentration -0% 45S5BAG + 50.0% glass (BAG0 group), -12.5% 45S5BAG + 37.5% glass (BAG12.5 group), -25.0% 45S5BAG + 25.0% glass (BAG25.0 group), -37.5% 45S5BAG + 12.5% glass (BAG37.5 group),	-Surface roughness measurement -Microhardness testing -Scanning electron microscopy imaging (SEM)	Increasing roughness indicated more enamel demineralization.	The results showed that increasing the bioactive glass content in the sealants led to: Lower surface roughness values Higher microhardness values This indicates the bioactive glass helped inhibit both enamel roughening and demineralization under acidic conditions.

			-50.0% 45S5BAG + 0% glass (BAG50.0 group). 2 control groups: distilled water and lactic acid solution			
GC Oliveira *et al.* (2015) (47)	This study evaluated resin-based materials for protecting eroded enamel from further erosion, analyzing material penetration, thickness, and enamel loss. It also assessed the impact of surface etching, hypothesizing all materials provide protection	In vitro experimental study	9 groups (n=12 per group) based on different resin-based materials and application methods: - Control (no treatment) - 4 materials (pit & fissure sealant, self-etching adhesive, conventional adhesive, infiltrant)	Non-parametric tests (Kruskal-Wallis and Dunn post hoc); Confocal microscopy; Profilometric analysis; Confocal laser scanning microscopy.	-Control group: greater enamel loss. -Groups Hel, Adh and Inf with prior conditioning: effective protection against erosion, with values close to zero; -Group Tet with conditioning; did not provide protection. -Groups without conditioning (Helno, Adhno): enamel loss like the control.	The infiltrant (Icon) showed the best results, being effective both with and without enamel conditioning. Most of the other resin-based materials (pit and fissure sealant and self-etch adhesive) were effective in protecting against erosion only when applied after enamel conditioning. The conventional adhesive with

	regardless of etching.		- Each material applied with and without enamel etching		-Groups Tetno and Infno without conditioning: some protection against erosion.	conditioning resulted in enamel loss after application.
San Ling Zhou *et al.* (2011) (48)	Compare the remineralization effects of five different dental materials on artificially eroded bovine enamel	In vitro experimental study	The specimens were divided into 5 groups treated with different dental materials: -Clinpro XT varnish -F-varnish -Tooth Mousse -Fuji III LC glass ionomer sealant -Base Cement glass ionomer cement	Quantitative light-induced fluorescence Microhardness Surface 3D topography Scanning electron microscopy (SEM).	All materials promoted some degree of remineralization and reduction in enamel roughness/loss, with the glass ionomer cement-based materials (CV, FJ, BC) generally performing better than the fluoride varnish (FV) or Tooth Mousse (TM) in terms of sustained effects over 6 weeks. The CV group showed the best results for	- All materials demonstrated remineralization capability. - Base Cement (BC) was the most effective in the surface microhardness analysis. - Clinpro XT varnish (CV) was the most effective in the 3D surface topography analysis after 6 weeks. - Glass ionomer-based materials (CV, FJ, and BC) generally showed greater remineralization

					reducing surface roughness long-term.	potential compared to NaF-based materials. - Tooth Mousse (TM) exhibited the lowest remineralization values. - Clinpro XT varnish (CV) proved more effective than traditional F-varnish (FV) in promoting remineralization.
J Mueller *et al.* (2006) (49)	Comparison of the effectiveness of a sealant and adhesives in inhibiting the progression of lesions in demineralized bovine enamel.	In vitro experimental study	Fissure sealant: -Helioseal Adhesives: -Heliobond, -Excite, -Resulcin, -Solobond M, -Prompt L-Pop	Confocal laser scanning microscopy (CLSM) Statistical tests included Kolmogorov-Smirnov, ANOVA with Bonferroni, and t-tests for	The mean (SD) depths of the lesions after the first demineralization period: Lesion I - 105 (21) µm Lesion II - 237 (53) µm After the second demineralization, the untreated lesions showed a mean	Untreated lesions progressed by 52% after re-demineralization. Helioseal, Heliobond, Resulcin Monobond, and Excite fully inhibited progression, outperforming solvent-based materials. Solobond M required a second application to

				depth comparisons.	progression of 52 (31) %.	reduce progression. Adhesive penetration effectively inhibited demineralization, with solvent-free materials performing best.
A. Alsaffar *et al.* (2010) (50)	Evaluate the in vitro effect of sealants in protecting adjacent enamel from acid demineralization.	In vitro experimental study	Ten extracted molars received sealants: -- conventional nonfluoride (DO; -resin-based sealant (RBS); -fluoride-containing RBS; -amorphous calcium phosphate-containing RBS; -glass ionomer sealant.	-Cross-sectional microhardness testing - Conversion of microhardness to mineral content - Mineral profile analysis - Mineral profile analysis	This study did not directly measure enamel roughness or loss. The focus was on internal patterns of demineralization rather than surface changes.	- Glass ionomer sealant showed the least mineral loss, offering the best protection. - Fluoride- and ACP-containing resin sealants reduced mineral loss more than conventional sealants. - Conventional resin-based sealant had the highest mineral loss.

				- Student-Newman-Keuls post-hoc test		
Natalie K. Smith *et al.* (2014) (51)	This study aimed to test the hypothesis that the residual cariostatic effect observed in clinical studies is due to remaining glass ionomer (GI) in the deepest fissure areas and/or its ability to inhibit enamel demineralization after an artificial caries challenge.	In vitro experimental study	14 pairs (28) of extracted molars/premolars: - One tooth from each pair was randomly selected as the control. - The other tooth received a glass ionomer (GI) sealant. GI sealant (Fuji IX) was applied to the experimental group teeth.	- Cross-sectional microhardness technique - Knoop hardness testing - T-test	This paper does not discuss or directly measure enamel roughness or loss. Although it does not directly measure roughness or loss, they found that the artificial caries challenge "caused softening of the enamel surface up to 100 µm in depth."	-Enamel Demineralization: No significant difference in demineralization between debonded GI and control groups (p=0.88). -Caries Prevention Mechanism: Residual cariostatic effects likely stem from physical barriers, not fluoride release.

Mozammal Hossain *et al.* (2012) (52)	The study compared laser vs. bristle brush for fissure cleaning, assessing morphology, roughness, debris removal, and sealant microleakage.	In vitro experimental study	Group A: 30 teeth treated with Er:YAG laser Group B: 30 teeth treated with bristle brush and prophylaxis paste	- Stereoscopic; - Scanning electron microscopy (SEM); - Color 3D laser microscopy; - Statistical analysis using Mann-Whitney U test.	Laser-treated cavities had greater roughness (155 ± 6 µm) than those treated with brush + acid etching (82 ± 4 µm).	Er:YAG laser created rougher enamel and improved sealant adhesion by removing debris. Microleakage was similar between laser and brush-treated groups, with better resin tag formation in non-leaking samples.
Z. A. Güçlü *et al.* (2016) (53)	Evaluated UltraSeal XT® hydro™ microleakage, enamel-sealant interface, and filler behavior with different etching methods: acid, Er:YAG laser, and combined laser/acid.	In vitro experimental study	Group I: Acid etching (n=10) Group II: Er:YAG laser ablation (n=10) Group III: Sequential laser ablation and acid etching (n=10)	-Optical microscopy; -Microleakage scoring; -Scanning electron microscopy (SEM); -Energy-dispersive X-ray (EDX) analysis.	Increased enamel surface roughness on a 50-100 µm scale for laser-treated samples. Laser-treated samples exhibited regions of sub-surface cracking at depths of 10-75 µm from the enamel surface.	Laser and acid etching together reduced microleakage ($p<0.001$), but not individually. Laser increased enamel roughness, led to filler particle zoning, and caused sub-surface cracks (10–75 µm).

Sahili Mungekar *et al.* (2023) (54)	The study compared RI and sealants on caries lesions by assessing microhardness and roughness changes.	In vitro study	Each group (12 samples) received different sealants Group I: nonfluoridated pit and fissure sealant; Group II: RI; Group III: fluoridated pit and fissure sealants.	The study used parametric statistical tests including one-way ANOVA and independent sample t-tests to compare outcomes between groups.	The surface roughness values for group I was 0.377 µm; Group II 0.296 µm; Group III 0.434 µm.	Group II showed minimum surface roughness, followed by groups I and III with highest surface roughness, the same being statistically significant.
Alyssa Teixeira Obeid *et al.* (2024) (55)	The study examined NbF5 nanoparticles in pit-and-fissure sealants.	In vitro experimental study	Experimental sealants were reinforced with 0.3, 0.6, and 0.9 wt% NbF5 nanoparticles.	Scanning electron microscopy (SEM)	No significant differences were found in surface roughness across the different groups.	NbF5 nanoparticles (0.3 wt%) enhance sealants, aiding decay prevention through demineralization reduction, ion release, and remineralization.
Neslihan TEKÇE *et al.* (2017) (56)	To evaluate the effect of surface sealant application and thermocycling on the surface roughness and	In vitro experimental study	4 types of composite resins: -micro-hybrid; -nano-hybrid; -nano-fill;	Scanning electron microscopy (SEM) and atomic force microscopy (AFM).	Following Sealant Application -micro-hybrid (0.635 µm ± 0.161)	The surface roughness values of some materials increased significantly after surface sealant application.

	microhardness of different resin composite systems.		-bulk-fill resin composite.		-nano-hybrid (0.476 µm ± 0.198) -nano-fill (0.527 µm ± 0.137), -bulk-fill resin composite (0.524 µm ± 0.135).	

5. DISCUSSION

According to the Cochrane Handbook, a systematic review is a meticulous and structured process that seeks to gather all relevant empirical evidence that meets pre-established eligibility criteria, with the aim of answering a specific research question. This methodology is based on explicit and systematic procedures, carefully chosen to minimize bias. Thereby ensuring that the results obtained are reliable and rigorous. This allows to draw well-founded conclusions, providing a solid foundation for informed decision-making. (57)

This type of review differs from other forms of research synthesis by focusing on a comprehensive and exhaustive search for relevant studies, as well as on the impartial evaluation of results. The process includes a methodical search across various scientific databases, a rigorous assessment of study quality, and the application of specific inclusion criteria. This ensures that the process is transparent and replicable, providing a more complete overview of the current state of knowledge in a specific area, which is crucial for supporting clinical decisions, policies, or guidelines for future scientific research. (57)

The importance of this method lies in its ability to reduce the possibility of bias, such as the inclusion of lower-quality studies or the omission of unpublished results. Thus, a systematic review enables a more robust and reliable assessment of the available evidence, serving as a foundation for informed and evidence-based practice. (57)

In this systematic review, we analyzed studies that investigated damage to the enamel following the sealing of occlusal fissures and pits. Although minimal, the results indicate that enamel damage does occur. However, we observed considerable variation in the methodologies employed to assess both surface roughness and damage, which may influence the interpretation of findings. (57)

Feda I. Zawaideh *et al.* addressed enamel loss indirectly, by analyzing demineralization and the reduction in enamel microhardness after exposure to an acid challenge. The findings demonstrated that all tested groups experienced mineral loss, albeit at varying levels. The control group, restored with Concise™ sealant, exhibited the highest degree of mineral loss, indicating lower protective capacity against demineralization. (40)
In contrast, the Aegis® sealant, which contains amorphous calcium phosphate (ACP), proved to be more effective in inhibiting mineral loss, suggesting that the release of calcium and phosphate contributed to the reduction in enamel demineralization. The Conseal-F™ sealant, which contains fluoride, also offered a protective effect, although its efficacy was inferior to that of ACP. (40)

Although the study did not directly address enamel surface roughness, mineral loss and reduced microhardness may be associated with changes in surface texture, rendering the enamel more susceptible to wear and erosion. (40)

Yoshishige Yamada *et al.* investigated the efficacy of Carisolv in removing organic debris from dental fissures prior to sealant application. The goal was to enhance fissure sealing through pre-treatment with Carisolv and to compare surface morphology and microleakage levels following treatment with Carisolv versus bristle brushing. (41)

Fifty extracted human teeth were randomly divided into two groups of 25. In one group, fissures were cleaned using Carisolv for 30 seconds, followed by excavation with a dental explorer until the gel became clear. In the other group, fissures were cleaned using a brush and prophylactic paste. Surface roughness was analyzed using 3D laser microscopy and scanning electron microscopy (SEM) on five samples from each group. Sealants were applied to the remaining samples, which were then subjected to microleakage testing following thermocycling. (41)

Results showed a significant increase in surface roughness after acid etching in both groups, with a higher roughness observed in the Carisolv-treated group. (41)

The greater surface roughness in the Carisolv group may facilitate better sealant adaptation to the dental enamel, which is beneficial for long-term sealant retention. (41)

Shinichi Kakuda *et al.* examined the surface roughness of dental enamel by analyzing the effects of immersion in lactic acid, with or without the presence of pit and fissure sealants. Scanning electron microscopy (SEM) was used to assess structural changes in the enamel after seven days of exposure to the tested solutions. (42)

Initially, the freshly prepared dental enamel exhibited a relatively smooth surface, covered with residues from the polishing process. In addition, wear marks from silicon carbide (SiC) abrasive papers were clearly visible, with well-defined edges. However, when enamel was exposed to lactic acid without the protection of a sealant, a significant increase in surface roughness was observed. The surface became more irregular and coarser, and the polishing marks lost its definition—indicating an advanced demineralization process. (42)

In the groups where pit and fissure sealants were applied, the effects on surface roughness varied depending on the material used. In subjects treated with BeautiSealant (BS) and Fuji III LC (IIILC), the enamel surface remained relatively smooth, with the presence of residues contributing to a homogeneous appearance.

Furthermore, the wear marks remained visible, suggesting that demineralization was minimized and the increase in surface roughness was significantly reduced. (42)

Conversely, enamel exposed to the TEETHMATE F-12.0 (TM) sealant exhibited the highest surface roughness among all the groups analyzed. Microscopy revealed a highly irregular surface, with the enamel prism structure clearly exposed. This outcome indicates a higher level of demineralization, possibly associated with the release of fluoride and hydrogen ions (F^- and H^+) from the material, which contributed to a more pronounced erosion of the dental surface. (42)

Furthermore, it was observed that the use of glass ionomer materials, such as BeautiSealant (BS) and Fuji III LC (IIILC), demonstrated a protective effect on enamel, helping to preserve surface integrity and reducing the increase in roughness. In contrast, the TM sealant, by promoting greater ion release, resulted in more intense demineralization and, consequently, a significant increase in enamel surface roughness. (42)

Shimazu K. *et al.* addressed enamel roughness and loss in the context of the application and removal of different types of fissure sealants. The results demonstrated that conventional resin-based sealants, applied with acid etching (DE and TE), caused significant surface defects on the enamel, including fractures and increased roughness, particularly in areas that were previously demineralized. Following debonding, the surfaces treated with these sealants exhibited considerable damage, characterized by rough and fractured textures. (43)

In contrast, the sealant containing pre-reacted glass ionomer (S-PRG) particles, applied with a self-etching primer (BS), preserved the integrity of the enamel surface. The surfaces treated with this sealant remained smooth and showed no signs of fractures or roughness after removal. This outcome suggests that the use of a self-etching primer is less aggressive to enamel compared to the acid etching technique employed with conventional sealants. (43)

Furthermore, the study highlighted that acid etching not only increased the depth of enamel lesions but also contributed to the destruction of its superficial structure. In contrast, the self-etching primer used in the sealant containing S-PRG was effective in preserving the enamel surface and preventing the progression of demineralization. Thus, this type of sealant proved to be a safer and more effective alternative for protecting fissures in immature permanent teeth without compromising enamel integrity. (43)

Zeynep A. GÜÇLÜ *et al.* explored enamel roughness and loss in the context of surface preparation for the application of the hydrophilic sealant UltraSeal XT® hydro™. Enamel roughness was significantly increased through the use of an Er:YAG laser prior to phosphoric acid etching, creating surfaces with a coarser texture in the range of 50 to 100 µm. This increase in roughness facilitated the segregation and concentration of filler particles at the enamel–sealant interface, thereby enhancing sealant adaptation. (44)

Additionally, laser application effectively removed organic debris and biofilms and provided superior conditioning of a prismatic enamel typically found in dental fissures. However, the study also cautioned that laser use, when applied at inappropriate or excessive energy levels, can induce vitrification or microcracks in the enamel, which may be considered forms of enamel loss or damage. Despite these potential drawbacks, laser preparation proved effective in improving sealant adhesion and reducing microleakage. (44)

Rehab Samir Salma *et al.* analyzed the effects of two types of pit and fissure sealants—one bioactive and the other fluoride-releasing—on the remineralization of demineralized dental enamel. (45)

Following demineralization, all groups exhibited enamel surfaces with significant defects, such as collapse of enamel prisms, lack of structural orientation, and irregular microscopic voids. These findings indicate increased surface roughness due to mineral loss. However, the bioactive sealant demonstrated greater efficacy in reducing roughness after the remineralization process. Surfaces treated with this sealant showed uniformity and smoothness, as well as white zones at the tooth/sealant interface, indicating mineral deposits. (45)

By contrast, the fluoride-releasing sealant also reduced surface roughness but exhibited more irregularities compared to the bioactive sealant. The control group (with no material application) retained a rough surface with multiple defects. Demineralization led to a significant reduction in mineral content (calcium and phosphate), contributing to enamel fragility and increased porosity. This mineral loss was most evident in the control group.
During the remineralization phase, the bioactive sealant demonstrated a superior capacity to restore mineral content—particularly calcium—when compared to the fluoride-releasing sealant and the control. This sealant promoted a continuous ion release (calcium, phosphate, and fluoride). Thereby reinforcing enamel structure and reducing mineral loss. Nevertheless, none of the materials were able to fully restore the original calcium/phosphate ratio characteristic of healthy enamel. (45)

S.Y. Yang *et al.* examined enamel roughness and loss in teeth subjected to simulated cariogenic conditions, focusing on the efficacy of sealants containing bioactive glass 45S5 (45S5BAG). The investigation was conducted using in vitro methods, simulating microleakage between sealants and bovine enamel discs exposed to acidic solutions. The results demonstrated that increasing the proportion of 45S5BAG in the sealants significantly contributed to enamel preservation by reducing both surface roughness and demineralization. (46)

Regarding enamel surface roughness, it was observed that roughness increased as the proportion of 45S5BAG in the sealants decreased. The group without bioactive glass (BAG0) presented the roughest surfaces compared to those with higher 45S5BAG content. Conversely, the BAG50.0 group — with the highest bioactive glass content — exhibited roughness levels comparable to the control group exposed to distilled water, even after prolonged acid exposure. Furthermore, while the BAG0 and BAG12.5 groups demonstrated increasing roughness with prolonged immersion in acidic solution, the BAG50.0 group showed the opposite trend, with a reduction in surface roughness over time. (46)

Regarding enamel microhardness and mineral loss, the results indicated that groups with lower proportions of 45S5BAG experienced greater hardness loss. BAG0 showed significantly lower microhardness values compared to groups containing higher amounts of bioactive glass. In contrast, the BAG50.0 group maintained microhardness values similar to the control group exposed to distilled water, suggesting that this material is effective in preventing enamel demineralization. (46)

Observations conducted through electron microscopy revealed distinct surface patterns across the groups. Lower 45S5BAG groups presented rougher surfaces and characteristic signs of acid attack. By contrast, the BAG37.5 and BAG50.0 groups exhibited smoother surfaces and were less affected by demineralization.(46)

GC Oliveira *et al.* investigated the effects of resin infiltration on enamel protection against erosion, focusing on enamel loss and surface roughness after the application of various resin-based materials. The study tested a pit and fissure sealant (Helioseal Clear), a self-etch adhesive (AdheSE), a conventional adhesive (Tetric N-Bond), and a resin infiltrant (Icon), applied with and without prior acid etching. The efficacy of these materials was assessed through fluorescence confocal microscopy and profilometry, aiming to quantify the thickness of the formed layer and the extent of enamel loss after an erosive cycle. (47)

The results demonstrated that resin infiltration with Icon exhibited the highest penetration capability into erosive lesions, forming a homogeneous layer and providing significant protection against erosion, particularly when applied after hydrochloric acid etching. The fissure sealant and the self-etch adhesive also reduced erosion progression, but its penetration was more superficial and its protective effect less pronounced than in the infiltrant. Conversely, the conventional adhesive did not provide adequate protective effects and, in some cases, even led to increased enamel loss, especially when applied following acid etching. (47)

Analysis of enamel roughness showed that materials with higher penetration capacity, such as the resin infiltrant, resulted in a more uniform and erosion-resistant surface. In contrast, conventional adhesives, particularly when applied without acid conditioning, demonstrated poor adhesion, leading to increased roughness and subsequent enamel loss following the erosive cycle. In groups where materials were applied without etching, protection was limited, resulting in enamel loss similar to that observed in the control group. Only the resin infiltrant maintained some degree of protection even in the absence of prior acid conditioning, although its effectiveness was reduced. (47)

In conclusion, resin infiltration emerged as the most effective strategy to minimize enamel loss and reduce surface roughness, ensuring enhanced resistance against erosive challenges.(47)

San Ling Zhou *et al.* evaluated the effects of different fluoride-releasing dental materials on the remineralization of bovine enamel subjected to an erosion model. Five distinct materials were analyzed: Clinpro™ XT varnish (CV), F-varnish (FV), Tooth Mousse (TM), Fuji III LC1 (FJ), and Base Cement1 (BC). To assess the effectiveness of these materials in promoting enamel remineralization, the researchers employed four methods: quantitative light-induced fluorescence (QLF), surface microhardness (SMH), 3D surface topography (3D-ST), and scanning electron microscopy (SEM). (48)

Enamel roughness and enamel loss were two key parameters closely examined. The 3D surface topography analysis (3D-ST) demonstrated that enamel roughness varied depending on the material used. The group treated with Clinpro™ XT varnish (CV) exhibited the lowest surface roughness after six weeks of remineralization, showing a significantly smoother surface than the other groups ($p < 0.05$). The surface roughness of the F-varnish (FV) and Tooth Mousse (TM) groups decreased progressively over time, indicating a moderate remineralizing effect. By contrast, the groups treated with Fuji III LC1 (FJ) and Base Cement1 (BC) showed a different pattern: initial roughness reduction after two weeks, followed by an increase at four and six weeks, suggesting irregular mineral accumulation on the enamel surface. (48)

Scanning electron microscopy (SEM) revealed notable structural changes in the enamel following treatment. Prior to remineralization, enamel surfaces appeared porous and structurally disorganized due to erosion. After treatment, mineral deposit patterns varied according to the material applied. The group treated with F-varnish

(FV) showed spherical calcium fluoride (CaF_2) deposits, indicating a unique fluoride release and retention mechanism. In other groups, particularly those treated with Clinpro™ XT varnish (CV), Fuji III LC1 (FJ), and Base Cement1 (BC), needle-like crystal formations were observed, suggesting a distinct remineralization mechanism likely based on the deposition of fluorapatite or modified hydroxyapatite. (48)

Based on these findings, the authors concluded that glass ionomer cement (GIC)-based materials, such as Clinpro™ XT varnish (CV) and Fuji III LC1 (FJ), promoted greater remineralization of artificially eroded enamel lesions than sodium fluoride (NaF)-based materials such as F-varnish (FV). Moreover, resin-modified GICs exhibited a controlled and sustained release of remineralizing agents, contributing to lower surface roughness over time. Among all tested materials, Clinpro™ XT varnish (CV) demonstrated the best performance in reducing enamel roughness after six weeks of treatment, suggesting its potential as an effective option for the remineralization of eroded dental enamel. (48)

J. Mueller *et al.* investigated the progression of early enamel lesions and evaluated the effectiveness of various resin materials in penetrating and sealing these lesions. The key findings regarding enamel roughness and enamel loss highlighted important aspects of the effects of the applied treatments. (49)
Regarding enamel roughness, the initial treatment involved the application of 20% phosphoric acid for five seconds to remove the superficial enamel layer and expose a more porous structure, thereby facilitating the infiltration of adhesive resins. Confocal microscopy analysis revealed that some resins achieved homogeneous penetration into the enamel, whereas others formed irregular layers, leaving residual porous areas. (49)

A significant progression of the lesions was observed over the demineralization period. After 14 days of the initial demineralization phase, the mean lesion depth was 105 µm. Following an additional 14 days of demineralization, there was an average 52% increase in lesion depth in untreated areas. Among the tested resins, Helioseal, Heliobond, Resulcin Monobond, and Excite demonstrated effectiveness in preventing lesion progression. In contrast, Adper Prompt L-Pop and Solobond M showed insufficient protection against demineralization, particularly after a single application. However, a second application of Solobond M significantly improved resistance to demineralization, reducing lesion progression. (49) Enamel roughness can be influenced both by the type of resin used and the application method employed. (49)

A. Alsaffar *et al.* evaluated the protective effect of different types of pit and fissure sealants on adjacent enamel demineralization. The study tested conventional fluoride-free resin sealants, fluoride-containing resin sealants, resin sealants with amorphous calcium phosphate, and glass ionomer sealants. To simulate demineralization, teeth were subjected to an acidic environment for 20 days, and mineral loss was subsequently assessed via transverse microhardness analysis. (50)

The results indicated that mineral loss (ΔZ) was significantly higher in the groups treated with conventional fluoride-free resin sealant and in one of the fluoride-containing sealants. In contrast, the enamel adjacent to the glass ionomer sealant exhibited the lowest mineral loss, demonstrating its superior protective efficacy against demineralization. The sealant with amorphous calcium phosphate and one of the fluoridated sealants showed an intermediate protective effect, reducing mineral loss compared to the conventional resin sealant. (50)
Although enamel roughness was not directly assessed, the observed demineralization suggests that mineral loss may contribute to increased surface irregularity over time. Based on these findings, glass ionomer sealants appear to be the most effective in

protecting adjacent enamel from demineralization, due to its sustained fluoride release. Meanwhile, resin-based sealants containing fluoride or amorphous calcium phosphate offer some additional protection, though to a lesser extent. (50)

Natalie K. Smith *et al.* aimed to investigate the residual retention of glass ionomer (GI) sealants following their detachment and to evaluate their impact on enamel demineralization. The study was conducted in vitro using extracted human molars and premolars, on which GI sealants were applied. After application, the teeth underwent a thermocycling process of 4,000 cycles, alternating between temperatures of 5°C and 55°C, in order to simulate approximately one year of clinical use. Subsequently, the sealants were manually removed with the aid of a dental explorer, and three technicians confirmed the clinical failure of retention. (51)

Microscopic evaluation of the occlusal surfaces revealed that, despite the apparent clinical removal of the sealants, small amounts of GI remained in the deeper regions of the dental fissures. Analysis indicated that 86% of the samples exhibited some degree of sealant retention, suggesting that the material is not completely eliminated even after mechanical removal. (51)

To assess enamel mineral loss, all samples were subjected to an artificial cariogenic challenge, which revealed no statistically significant difference in mineral loss between the teeth with detached GI and the control group. This indicates that the residual presence of GI acts as a physical barrier, but there is no evidence that fluoride release provides a prolonged effect in inhibiting demineralization. (51)

Regarding enamel roughness, the study suggests that the process of sealant removal may cause superficial damage, making the enamel more vulnerable to demineralization. Therefore, the protective effect of GI appears to be more related to its physical retention in the fissures than to its chemical capacity to inhibit caries. (51) Mozammal Hossain *et al.* evaluated the removal of organic debris in dental fissures using Er:YAG laser irradiation and its impact on sealant microleakage. Surfaces treated with the laser were compared to those cleaned with a brush and prophylactic paste, with assessments of enamel morphology and roughness, as well as the sealant's adaptation to the tooth. (52)

The results showed that the Er:YAG laser was effective in removing debris, exposing the enamel structure and creating an irregular surface. Scanning electron microscopy revealed that laser-treated cavities exhibited a rough topography, characterized by conical-shaped enamel rods and thin, irregular edges. Quantitative analysis of surface roughness indicated that laser-treated teeth had greater surface roughness than those cleaned by brushing, both before and after phosphoric acid application. It was also observed that the laser caused slight widening and deepening of the fissures, without inducing cracks or excessive enamel removal. (52)

The rough surface generated by the laser appears to favor sealant adhesion, providing a better interface between the material and the enamel. In some cases, the presence of gaps at the enamel-sealant interface suggested that factors such as residual debris and air bubbles may compromise the sealant's effectiveness. (52)

Z. A. Güçlü *et al.* analyzed the impact of enamel conditioning with Er:YAG laser on the microleakage of a new hydrophilic sealant, UltraSeal XT® hydro™, focusing on enamel roughness and loss. The study compared three enamel preparation techniques: acid etching, laser ablation, and a combination of both. (53)

The use of the Er:YAG laser significantly increased the enamel surface roughness, creating irregularities ranging from 50 to 155 µm. This enhanced roughness favored the mechanical adhesion of the sealant to the enamel, concentrating material particles at the interface. However, the laser also caused subsurface microcracks in the enamel, with depths between 10 and 75 µm, whose influence on the long-term durability of the sealant remains unclear.
Laser ablation proved effective in removing organic residues and conditioning aprismatic enamel, surpassing acid etching in some respects. Nevertheless, the laser can cause uneven vitrification and microcracks in the enamel. The combined technique (laser + acid) yielded the best results in reducing microleakage, suggesting that this approach better preserves enamel integrity while optimizing sealant adhesion. (53)

Although there was no significant difference in microleakage between the groups treated with acid or laser alone, the combination of both techniques demonstrated the lowest infiltration index. The increase in roughness caused by the laser favored the retention of UltraSeal XT® hydro™, especially due to its fluid and hydrophilic nature. (53)

Sahili Mungekar *et al.* evaluated and compared resin infiltration (RI) and pit and fissure sealants (fluoridated and non-fluoridated) in the treatment of demineralized enamel lesions, focusing on surface roughness and enamel microhardness. (54)

Resin infiltration (Group II) showed the best results, with the lowest surface roughness (0.2968 µm) and the highest microhardness (315.50 VHN). These results were statistically superior to those obtained with non-fluoridated sealants (Group I: 0.3770 µm roughness and 275.66 VHN microhardness) and fluoridated sealants (Group III: 0.4345 µm roughness and 213.16 VHN microhardness). (54)

The lower roughness in the RI group was attributed to the resin's ability to smooth the enamel surface, reducing bacterial plaque accumulation. Additionally, the higher microhardness was explained by the deep penetration of the resin into the pores of demineralized enamel, providing added mechanical strength to the dental structure. This also blocks acid access to remaining micropores, preventing lesion progression. (54)

Alyssa Teixeira Obeid *et al.* evaluated the effects of incorporating niobium fluoride (NbF_5) nanoparticles into pit and fissure sealants, focusing on its physic-mechanical properties and mineral deposition. The main results related to enamel roughness and enamel loss are summarized below. (55)

The analysis of surface roughness (Ra) showed no statistically significant differences between the groups treated with different concentrations of NbF_5 (0.3%, 0.6%, and 0.9%) and the control group ($p = 0.458$). This indicates that the addition of nanoparticles did not compromise the surface texture of the sealant, which is essential to prevent biofilm accumulation and reduce the risk of recurrent caries. (55)

Regarding enamel loss, bovine enamel blocks were subjected to demineralization to simulate carious lesions. After treatment with the modified sealants, there was a significant increase in surface hardness (SH), indicating remineralization potential. The group treated with 0.9% NbF_5 showed hardness values similar to the initial enamel, demonstrating greater effectiveness in protecting against demineralization. Moreover, energy-dispersive X-ray spectroscopy (EDX) analysis revealed that the groups treated with 0.3% and 0.6% exhibited higher Ca/P ratios compared to the control, suggesting enhanced mineral deposition. The 0.3% group was notable for the early formation of apatite crystals on the enamel. (55)

These results indicate that the incorporation of NbF_5 into sealants can enhance resistance to enamel loss without altering surface roughness. Although the group with 0.9% NbF_5 demonstrated greater surface hardness after pH cycling, the group with 0.3% presented an optimal balance between mechanical properties and remineralizing capacity. (55)

Neslihan TEKÇE *et al.* analyzed the effects of the application of a surface sealant and accelerated aging (10,000 thermal cycles) on the roughness and microhardness of different composite resin systems used in posterior dental restorations. The study aimed to evaluate the hypothesis that the sealant would decrease the roughness and increase the microhardness of the restorative surfaces, as well as investigate the impact of thermal aging. (56)

The initial surface roughness (Ra) of the tested composite resins was similar among the materials, ranging from 0.312 µm to 0.425 µm. After the application of the Fortify Plus sealant, a significant increase in roughness was observed for two resins: G Aenial Posterior and Filtek Ultimate Universal Restorative. This increase was attributed to the high content of micro filled particles in the sealant, which caused surface irregularities. Images obtained by scanning electron microscopy (SEM) and atomic force microscopy (AFM) confirmed these changes, showing more irregular surfaces after the sealant application. (56)

After accelerated aging (10,000 thermal cycles), surface roughness slightly increased in some materials, such as G Aenial Posterior, but without statistically significant differences compared to the values obtained after the sealant application. This indicates that the thermal cycles did not significantly exacerbate the irregularities created by the sealant. (56)

Contrary to initial expectations, the application of the sealant did not reduce the roughness of the polished surfaces; on the contrary, it increased. Furthermore, thermal aging resulted in partial removal of the sealant in some areas of the samples, exposing the hard surface of the composite resin. This exposure may have contributed to small changes in the surface topography and microhardness of the materials.(56)

Although sealants are commonly used to improve the surface properties of dental restorations, their impact may vary depending on the chemical and physical composition of both the sealant and the composite resin used. (56)

6. CONCLUSION

The systematic review conducted highlights that, although fissure sealants are an effective measure in preventing dental caries, the procedure may lead to structural damage to the enamel. These damages vary depending on the technique used, the type of sealant applied, and the methods of material removal. Were identified changes such as demineralization caused by acid conditioning, microfractures from mechanical removal and alterations in the enamel's surface morphology.

Resin-based sealants offer good adhesion but present a higher risk of microfractures, while glass ionomers show remineralizing potential due to fluoride release. Careful selection of materials and less invasive techniques is essential to minimize negative impacts.

The review emphasizes the need for ongoing research on the long-term effects of sealing and on new formulas and application technologies. The decision to apply sealants should be based on an individual caries risk assessment, balancing preventive benefits with the preservation of enamel integrity, always guided by scientific evidence.

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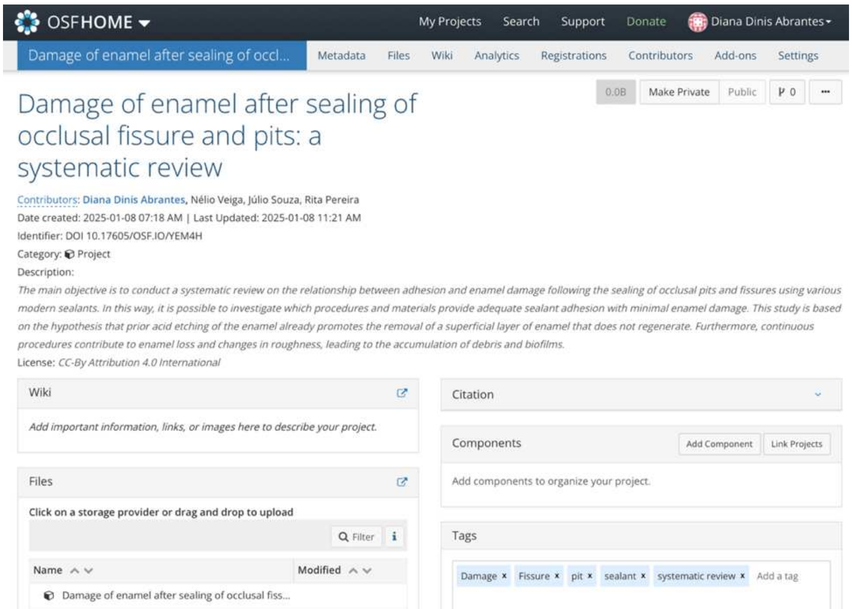
8. ANNEXES

Annex I: Registration in OSF (Open Science Framework)



Annex II: Poster Participation Certificate