EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 71, 1719:1730, April, 2025

Print ISSN 0070-9484 • Online ISSN 2090-2360

EDJ
EGYPTIAN DENTAL JOURNA

Conservative Dentistry and Endodontics

Submit Date : 12-01-2025 • Accept Date : 30-01-2025 • Available online: 25-04-02025 • DOI : 10.21608/edj.2025.352184.3340

EFFECT OF DIFFERENT SURFACE TREATMENTS ON BONDING OF FLOWABLE SHORT FIBER REINFORCED RESIN COMPOSITE TO CONVENTIONAL RESIN COMPOSITE: REVIEW OF LITERATURE

Nermeen Youssef Hamed [*], Youniss Saleh Harp[**] *and* Hamdi Hosni Hamama[***]

ABSTRACT

Dental resin composite materials have been the most frequently used materials for direct restorations nowadays. In small and medium-sized cavities, resin composite restorations have shown satisfactory overall clinical performance. However, in large-sized cavities RC restorations have proven to be more likely to fail due to fractures, resulting in shorter lifespans. A newly-recommended method for restoring large cavities is using short fiber-reinforced composite (SFRC) as dentine-replacing material due to their superior mechanical properties. However, according to the manufacturers' recommendations, SFRC should be covered with a layer (1–2 mm) of PFC to ensure sufficient esthetic appearance. Using two different materials in this situation gives rise to a bi-layered restoration that consists of two different materials with two different properties. The adhesion quality between surface PFC and bulk base SFRC is crucial for restoration success and durability. The aim of this paper was to provide a comprehensive review of the effect of different surface treatments on bonding of flowable short fiber reinforced resin composite to conventional resin composite.

KEYWORDS: Interfacial surface treatment, sandblasting, grinding with abrasive disc, phosphoric acid etching, universal adhesive.

* Post graduate Student in conservative Dentistry Department, Faculty of Dentistry, Mansoura University
** Lecturer, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University
*** Professor, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University

INTRODUCTION

Direct restorative procedure is among the most common treatments in dentistry. Various types of materials are used for dental restorations, including resin composites, glass ionomer cements, ceramics, and amalgam alloys. The selection of material for restoration depends on many factors, such as the size and location of the cavity, the material's physical and biological characteristics, and the patient's age, gender, and socioeconomic status.

Aesthetic considerations have become increasingly important over the last two to three decades. As a result, many tooth-colored restorative materials have been developed. Resin composite, in particular, has become the most frequently used material today. Resin composites are now the preferred choice for anterior restorations, and their use for posterior restorations is also growing, largely due to a decrease in the use of dental amalgam. Thanks to advancements in bonding technology and improvements in their physical properties, resin composites are now suitable for nearly all restorative procedures across the mouth.[1, 2]

Dental composite resin is composed of salinized inorganic fillers, monomeric matrix, polymerization initiators , storage stability inhibitors, and shading pigments.[3] While significant improvements have been made in the mechanical properties of composites over the past 10-20 years, certain factors, such as oral enzymes and fluids, can degrade the composite matrix.[4] The degradation rate is influenced by a number of intraoral factors, including the degree of cross-linking in the polymerized matrix, the presence of dimers and oligomers, and the monomer composition.[5]

In small to medium-sized cavities, resin composite restorations have demonstrated satisfactory clinical performance. However, larger composite restorations are more prone to failure, particularly fractures, which results in a shorter lifespan.[6, 7] The main causes for failure of posterior composite restorations include bulk fractures, secondary caries, marginal deficiencies, and wear. Brunthaler et al.'s review found that early failure was frequently caused by fracture, while long-term failure was more frequently associated with caries.[8, 9] Long-term studies also showed that fractures were a more frequent cause of failure than caries, even with over 10 years of follow-up. This implies that bulk fracture continues to pose a considerable risk to posterior restorations, regardless of their age or duration of use.[10-12]

Several studies have indicated that resin-based composites may not be suitable for high-load-bearing areas. This is due to the mismatch in hardness between the fillers and the matrix, which leads to force concentration on the filler particles and, ultimately, crack initiation in the resin matrix.[13, 14]

A key objective of restorative dentistry is to achieve tightly sealed restorations. However, multiple evidence-based studies have highlighted that the adhesive bond between restorations and tooth structure is often a vulnerable point.[15] To improve the durability of large posterior restorations in areas with high stress and to support the remaining tooth structure, various methods have been suggested. One common approach is the use of an incremental layering technique for composite restorations, which helps minimize polymerization stresses , prevents the formation of gaps , and enhances the mechanical properties.[16, 17] Nevertheless, this method can be time-intensive and technically demanding. To streamline the process and reduce time, bulk-fill materials have been introduced which are designed to have lower polymerization shrinkage compared to traditional incremental techniques, allowing for placement and curing in 4mm thick layers with enhanced mechanical properties, and wear resistance. Although laboratory studies have shown mixed outcomes, some materials have demonstrated superior performance over others.[18-20]

A challenge with using light-cured composites posteriorly is the decreased intensity of curing light as it penetrates deeper. The light intensity and exposure time are critical for the degree of conversion, which directly affects the polymerization of monomers into polymers.[21] This, in turn, impacts the material's mechanical properties, color stability, biocompatibility, and clinical success. Studies on flowable bulk-fill materials have produced varying results. Some research indicates that these materials offer better mechanical performance with less polymerization shrinkage compared to conventional composites.[22, 23] However, other studies report a significant decrease in mechanical performance when the material is used at a thickness of 4 mm or more, as well as higher volumetric shrinkage.[24]

The reinforcing of particulate filler composites (PFCs) has also been extensively studied to improve their performance in high-stress areas. Efforts have focused on altering the size, type, and salinization of the filler particles. One of the most successful strategies has been reinforcing PFCs with short glass fibers. These fibers enhance the mechanical properties by reducing the propagation of cracks and minimizing stress at the crack tip, where the crack would otherwise spread uncontrollably.[25, 26] This leads to improved fracture toughness and fatigue resistance in the composite. Additionally, as the matrix is reinforced with fibers, stress from intense loads is more effectively distributed across the material. Combining both particles and fibers for reinforcement has also been shown to improve physical properties compared to conventional particulate filler-reinforced composites[27, 28]

Fiber reinforced composite is recommended to be used only as a dentin substitute which needs to be covered by a layer of conventional composite. The bond strength between different types of composites with different properties is essential for the success of the final restoration. Therefore, the current paper aims to provide a comprehensive review of the available literature on the short fiber-reinforced composite (SFRC) material; its chemistry, effectiveness, mechanical performance, biocompatibility, and dental applications. Moreover, this article aims to provide the clinicians an overview about the different surface treatment methods that can be used to enhance the interfacial bond strength between the short fiber-reinforced composite substructure layer and the particulate filled composite surface layer.

A web search was performed through PubMed and Google Scholar by crossing the keywords: short fiber-reinforced composite, surface treatments, and interfacial bond strength. During the search process, the relevant studies were further obtained through the reference sections of the retrieved articles to provide more supportive information. Articles that were unpublished, personal communications, or published in another language than English were excluded.

Background

Fiber-reinforced composites (FRCs) have been used for a variety of purposes in both engineering and biomedical fields for many years. Throughout their well-documented history in industry, FRC technology has continuously evolved, driven by innovative solutions.[29] In dental applications, the use of FRCs has been explored since the early 1960s. Nowadays, it has become a widely accepted and effective material in restorative dentistry.[30]

The incorporation of either short or long fibers into dental resins has been discussed for over four decades.[31] Initially, this approach was used to strengthen polymethylmethacrylate, which later found broader dental applications. There are different fiber types including polyaramid, polyethylene, carbon, and glass, that have been studied extensively for use in FRCs. Among these, glass fibers, with their diverse compositions, are most commonly used in restorative and prosthetic dentistry.[32]

Chemistry of fiber reinforced composites

Fiber-reinforced composites are made up of three components: the continuous phase (matrix), the dispersed phase (fibers), and the interphase between the two. FRCs are known for their high stiffness and strength-to-weight ratio when compared to other structural materials while also offering sufficient toughness.[33]

Short fiber reinforced resin composite typically incorporates fibers that are either randomly oriented or aligned in planes. It provides isotropic reinforcement, meaning they enhance the material in multiple directions.[34]

The effectiveness of fiber reinforced composites

Several factors are crucial in ensuring the effectiveness of fiber reinforcement, including their type, distribution, orientation, and the volume fraction.[35] For example, carbon/graphite fibers have been used for fiber posts; however, they cannot be used in aesthetic restorations.[36] In contrast, glass fibers, such as E-glass fibers offer better aesthetic properties and have been widely used to reinforce restorative materials.[37]

The fiber volume fraction directly impacts the mechanical properties of the material. A higher fraction typically enhances the strength and stiffness of the composite.[38] However, too high a fiber content can hinder the composite's flowability during fabrication, which may affect its ability to adapt to the tooth cavity. On other hand, regarding the length of the fibers, longer fibers are more efficient at transferring stress, thus improving mechanical properties. However, shorter fibers can provide better handling characteristics.[39]

Mechanical Performance of FRCs

According to laboratory testing, composites that are reinforced with short E-glass fibers have greater flexural strength, increased fracture toughness, a higher load-bearing capacity, and a noticeably better resistance to crack propagation. Microstructural elements like the kind of resin matrix, fiber length, fiber diameter, fiber loading, and fiber orientation have a significant impact on the characteristics of SFRCs.[40] To obtain the best mechanical qualities, the resin matrix must be properly cured and polymerized. Carefully regulating light curing methods is necessary to guarantee full polymerization of the resin matrix.[41]

Dental Applications of Fiber-Reinforced Composites (FRCs)

In restorative dentistry, several factors are considered, including the alignment of fibers and the design of the restoration, alongside other critical aspects that influence the performance of FRCs.[41]

An ideal dental restoration material must be moldable in place, provide strong adhesion to the underlying tooth, and maintain high strength and toughness after processing. FRCs meet these criteria from a materials science perspective. Clinically, FRCs have been explored for various prosthodontic applications, such as replacing missing teeth with adhesive fixed dental prostheses, reinforcing dentures and pontics, and creating posts and cores directly.[42] FRCs are also used in orthodontics for both active and passive applications, such as anchorage or mass movement units, as well as for post-orthodontic tooth retention. In periodontology, FRCs are employed to splint mobile teeth and potentially delay the need for extractions.[43]

Short fiber-reinforced composites (SFRCs) can efficiently distribute occlusal loads throughout the tooth by adhering well to the cavity walls and the composite layer above. The fibers' random orientation within the composite helps align them perpendicularly to the axial cavity walls during packing, which enhances load distribution. This structure also significantly reduces volumetric shrinkage.[44]

Moreover, SFRCs offer a unique qualities that make them especially suitable for dental use.[45] Because of their high modulus of elasticity, which is very similar to that of tooth structure, the danger of material failure is decreased by enhancing load distribution and minimizing stress concentration. Additionally, SFRCs demonstrate excellent biocompatibility, leading to few negative reactions in the oral cavity. These composites can be aesthetically matched to the teeth natural color, guaranteeing a smooth transition into the surrounding dentition. For applications like reinforcing dentures or splinting broken teeth, the addition of glass fibers to these materials offers additional advantages including superior biocompatibility and radiopacity.[46-48]

According to a study that compared the mechanical characteristics of bulk-fill composites, SFRC exhibited superior fracture toughness, flexural strength, and less shrinkage.[49] A clinical investigation conducted in 2012 found that after a year, SFRC materials performed well in repairing significant coronal defects in both vital and non-vital teeth, with positive one-year results. Furthermore, a case study showed that a combination of flowable SFRC and ceramic restorations could be used to aesthetically restore an endodontically treated tooth.[50, 51]

Biocompatibility of FRC Restorations.

Research has demonstrated that the majority of the fibers used in dental FRCs are highly biocompatible, showing minimal tissue interactions. However, further long-term clinical research is necessary to completely confirm their long-term biocompatibility.[52]

Commercially available (SFRCs)

In 2013, ever X Posterior was introduced, which designed to mimic dentine's ability to absorb stress. It is used particularly as a bulk base for restoring both vital and non-vital teeth. It contains inorganic fillers, and randomly oriented E-glass fibers that range in length from 1,300 to 2,000 μm and have an average diameter of 17 μm. Bisphenol A-Glycidyl Methacrylate (Bis-GMA), Triethylene Glycol Dimethacrylate (TEGDMA), and polymethylmethacrylate are combined to create the resin matrix, which forms a semi-interpenetrating polymer network (semi-IPN) that strengthens bonding and increases the toughness.[53, 54]

In 2019, a flowable version of short fiber-reinforced composite (FSFRC) was introduced, promising easier handling and better adaptability to small, confined spaces. In comparison to the bulk version, the FSFRC has a fiber diameter of 6 μm and an average fiber diameter of 200–300 μm. This material also demonstrated improved mechanical properties that were observed in everX Posterior. However, it is important to note that according to the manufacturer's guidelines, both materials should be only used as dentin substitutes and that they need to be covered with an outer layer of conventional resin-based composite.[54]

Bi-Layered Structure Restoration of SFRC and PFC

Despite numerous laboratory studies showing that everX Flow offers favorable surface and wear characteristics compared to many commercial particulate filler composites (PFCs), and in vitro data suggesting that flowable short fiber-reinforced composites (SFRCs) are safe for use in the oral environment, there are still concerns regarding their application.[55] According to certain researchers, SFRC provides a more reliable option than PFCs; hence they have expanded its application beyond dentin restorations to include interproximal walls reconstruction. However, the manufacturer has recommended that everX flow should be used as a bulk base rather than as a surface layer.[56, 57]

One reason for this is that FRC restorations, being composed of both inorganic and organic compounds, are susceptible to aging due to exposure to the oral environment. Studies have shown that incomplete encapsulation of fibers by the resin matrix leads to the formation of micro voids, which increases water absorption and facilitates hydrolysis and degradation of the polysiloxane network.[58] This results in a gradual deterioration of the mechanical properties of the restoration, leading to issues like composite fracture, discoloration, or even complete debonding.[59, 60]

The manufacturer's instructions suggest covering SFRC with a layer of flowable or packable PFC, typically 1-2 mm thick, to ensure sufficient aesthetic appearance. This creates a bi-layered restoration, where two different materials with distinct properties are combined. The result is a heterogeneous structure that mimics the natural composition of tooth tissue. Laboratory research has shown that using a bi-layered restoration consisting of FRC base and a surface layer of PFC has a significant fracture load increase. The role of the FRC base is to act as a crack propagation barrier, while the surface PFC layer provides a more polished and wear-resistant finish. This combination closely resembles the fibrous structure of the natural dentin-enamel complex, making it a biomimetic restoration system.[61]

However, unlike natural teeth, the fracture behavior of bi-layered restorations can be influenced by the different properties of the materials utilized.[62] Additionally, because an oxygen inhibition layer forms on the freshly cured resin composite, light-curing the two materials in different increments raises questions regarding the adhesion at the composite-composite interface.[63] For optimal adhesion between the layers, it is essential that ideal conditions are maintained. Therefore, the quality of the bond between the surface PFC and the bulk SFRC is critical for the final restoration's success and durability.[64, 65]

Despite a wealth of studies on the bond strength of SFRCs with dentin, there is still limited research on the interlayer bond strength between SFRC and PFC. This area requires further investigation to ensure optimal performance in clinical applications.

Surface Treatment

To enhance adhesion, dentists commonly use phosphoric or hydrofluoric acid etching, along with silane and/or adhesive application for chemical surface treatment. Mechanical methods, like air abrasion and grinding with diamond burs or abrasive discs, are employed to roughen the restoration surface.[66]

Numerous in vitro studies have evaluated how the use of surface treatments can improve the bond strength of composite restorations. However, due to variations in materials and methods, no definitive conclusion can be made on which universal technique is superior.[67]

Mechanical Surface Treatments

Sandblasting

Sandblasting, also known as air abrasion, is a non-rotary, mechanical cutting method where a stream of abrasive particles is propelled at high velocity to remove material from the tooth surface. Originally developed in 1945 to reduce discomfort during caries excavation, it was initially limited in dental practice because it couldn't create precise cavity walls and angles. However, with the advent of adhesive dentistry and a more minimally invasive approach, sandblasting has become a useful tool in dental procedures.[68]

Aluminum oxide, with an average size of particles of 27.5 microns and a hardness of 9 on Moh's scale, is commonly used in sandblasting. It is stable, non-toxic, and cost-effective. Air pressure typically ranges from 60 to 120 psi. Unlike burs, which create wide and shallow cavities, air abrasion produces small, deep access cavities.[69]

Sandblasting is widely used in dentistry, including cavity preparation, stain removal, and surface modification. The impact of aluminum oxide particles creates a rough surface, with the efficiency of the process depending on factors like air pressure, particle size, angle, distance, and time.[70]

Benefits of sandblasting include minimal heat, vibration, and noise, making it more comfortable for patients. However, when waterless air abrasion is used, the accumulation of powder in the operating field can be problematic. Despite many studies on its efficacy, results are conflicting, particularly concerning its potential to interfere with chemical bonding by leaving residual alumina particles or modifying the tooth surface.[71]

Studies have shown that sandblasting can improve interlayer adhesion by increasing surface roughness, cleaning the composite surface, and enhancing wettability. It has been reported to enhance bond strength between composites and other dental materials.[72-75]

Grinding

Grinding involves removing small particles from a surface using abrasive or bladed tools, resulting in a unidirectional scratch pattern. Grinding enhances surface roughness, promoting mechanical interlocking and improving bond strength between composite layers. Various instruments, such as diamond burs, carbide burs, silicon carbide papers, and abrasive discs, can be used for grinding.[76]

Diamond burs, due to their hardness, are particularly effective for cutting, contouring, and adjusting dental restorations. Abrasive discs and strips are made by bonding abrasive particles to a thin plastic or polymer backing, with particle sizes ranging from 100 microns for coarse discs to 7–8 microns for ultra-fine discs.[77,78]

Chemical Surface Treatments

Phosphoric Acid Etching

Phosphoric acid has long been used in dentistry to etch tooth substrates before adhesive application. It removes around 10 microns of non-reactive crystals from the surface, increasing surface energy and improving moisture retention by reducing the adhesive's contact angle. This process creates surface irregularities by breaking down carbon and detaching calcium and phosphorus.[79,80]

Phosphoric acid is also used in surface treatments to improve the bond between composite resin layers. Studies comparing different etchants, including hydrofluoric acid, citric acid, and maleic acid, found that hydrofluoric acid generally provides the best bond strength. However, due to its hazardous nature, hydrofluoric acid must be handled with care. In comparison, while phosphoric acid might not produce the roughest surface, it is effective for cleaning and increasing wettability, making it a useful and safer option for immediate composite repairs.[81,82]

Dental Adhesion

Dental adhesive systems are designed to bond resin composite to dental tissues by creating micromechanical bonds. Adhesive monomers infiltrate the collagen fibrils of dentin, and when polymerized they form a stable bond. Adhesive systems enable the bonding of composite restorations to enamel and dentin, using a copolymerization process where unreacted methacrylate groups on the adhesive react with the composite material.[83,84]

The adhesive process depends on several factors, including substrate type, adhesive composition, humidity, and operator skill. Enamel, being highly mineralized, bonds easily without needing a wet surface, while dentin, with its mix of mineral, collagen, and water, presents more challenges.[85] The ideal moisture condition is critical to ensure proper adhesive penetration into the demineralized dentin without collapsing the collagen matrix.[86,87]

Dental adhesives are typically categorized into three types based on their application strategies: etch-and-rinse, self-etch, and selective etch. These systems differ in how they prepare the surface for bonding, with some techniques involving acidic functional monomers to facilitate bonding.[88]

Universal Adhesives

Universal adhesives, introduced as a flexible option in adhesive dentistry, allow clinicians to choose between different bonding systems, including etch-and-rinse, self-etch, or selective enamel etching. These adhesives are effective for bonding various restorative materials like resin composites, ceramics, zirconia, and metals.[89,90]

The functional monomer 10-Methacryloyloxydecyl Dihydrogen Phosphate (10-MDP) is a key component in many universal adhesives, known for its ability to form strong ionic bonds with hydroxyapatite and its long-term durability. Another monomer, Glycidyl Methacrylate-Phosphate Dimethacrylate (GPDM), is also used in some adhesives but results in less stable bonds due to excessive surface demineralization.[91-94]

Despite their versatility, some studies suggest that universal adhesives may not provide as durable a bond as two-step self-etch adhesives, particularly in dentin.[95,96]

The bond strength of universal adhesives, especially when used with self-etching techniques on dentin, may be compromised by issues such as the instability of the dentin-adhesive interface and the presence of unpolymerized monomers, which can undermine the bond over time.[97]

The use of intermediate adhesives can significantly improve bond strength between composite layers, as shown in various studies.[98,99]

CONCLUSIONS

Based on the reviewed studies in the present review, the following conclusions could be drawn:

1. Short fiber-reinforced composites exhibit a variety in their composition and consequently, a variety of enhanced mechanical and physical properties.
2. Bi-layered restorations, made of a fiber-reinforced composite (FRC) base and a surface particulate filled composite (PFC) layer, can enhance fracture and wear resistance by mimicking natural tooth structure. So, it is recommended to be used as direct restoration of teeth with large cavities in high stress-bearing areas.
3. The success of SFRC and PFC restoration depends on the strength of the bond between the two layers. Application of surface treatments like sandblasting, grinding, and etching can improve adhesion by increasing surface roughness and wettability.
4. The use of sandblasting and grinding techniques yields stronger bond strength than other surface treatment methods by creating micromechanical interlocking between SFRC and PFC.

REFERENCES

1. Heintze SD, Rousson V. Clinical effectiveness of direct class II restorations- a meta-analysis. J Adhes Dent. 2012;14(5):407-31.
2. Baldissera RA, Corrêa MB, Schuch HS, Collares K, Nascimento GG, Jardim PS, et al. Are there universal restorative composites for anterior and posterior teeth? Journal of dentistry. 2013;41(11):1027-35.
3. Gupta S, Parolia A, Jain A, Kundabala M, Mohan M, de Moraes Porto ICC. A comparative effect of various surface chemical treatments on the resin composite-composite repair bond strength. Journal of Indian Society of Pedodontics and Preventive Dentistry. 2015;33(3):245-9.
4. Ferracane JL. Resin composite—state of the art. Dental materials. 2011;27(1):29-38.
5. Heintze SD, Ilie N, Hickel R, Reis A, Loguercio A, Rousson V. Laboratory mechanical parameters of composite resins and their relation to fractures and wear in clinical trials—A systematic review. Dental materials. 2017;33(3):e101-e14.
6. Manhart J, Chen H, Hamm G, Hickel R. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition.OPERATIVE Dentistry-University Of Washington-. 2004;29:481-508.
7. Demarco FF, Corrêa MB, Cenci MS, Moraes RR, Opdam NJ. Longevity of posterior composite restorations: not only a matter of materials. Dental materials. 2012;28(1):87-101.
8. Shouha P, Swain M, Ellakwa A. The effect of fiber aspect ratio and volume loading on the flexural properties of flowable dental composite. Dental materials. 2014;30(11):1234-44.
9. Lassila L, Garoushi S, Vallittu PK, Säilynoja E. Mechanical properties of fiber reinforced restorative composite with two distinguished fiber length distribution. Journal of the Mechanical Behavior of Biomedical Materials. 2016;60:331-8.
10. Rodolpho PADR, Donassollo TA, Cenci MS, Loguércio AD, Moraes RR, Bronkhorst EM, et al. 22-Year clinical evaluation of the performance of two posterior compos-

ites with different filler characteristics. Dental materials. 2011;27(10):955-63.

11. Pallesen U, Qvist V. Composite resin fillings and inlays. An 11-year evaluation. Clinical oral investigations. 2003;7:71-9.

12. Brunthaler A, König F, Lucas T, Sperr W, Schedle A. Longevity of direct resin composite restorations in posterior teeth: a review. Clinical oral investigations. 2003;7:63-70.

13. Garoushi S, Lassila LV, Tezvergil A, Vallittu PK. Load bearing capacity of fibre-reinforced and particulate filler composite resin combination. Journal of dentistry. 2006;34(3):179-84.

14. Garoushi S, Vallittu PK, Lassila LV. Direct restoration of severely damaged incisors using short fiber-reinforced composite resin. Journal of dentistry. 2007;35(9):731-6.

15. Drummond JL. Degradation, fatigue, and failure of resin dental composite materials. Journal of dental research. 2008;87(8):710-9.

16. Maran BM, de Geus JL, Gutiérrez MF, Heintze S, Tardem C, Barceleiro MO, et al. Nanofilled/nanohybrid and hybrid resin-based composite in patients with direct restorations in posterior teeth: A systematic review and meta-analysis. Journal of dentistry. 2020;99:103407.

17. Niu Y, Ma X, Fan M, Zhu S. Effects of layering techniques on the micro-tensile bond strength to dentin in resin composite restorations. Dental materials. 2009;25(1):129-34.

18. Kim RJ-Y, Kim Y-J, Choi N-S, Lee I-B. Polymerization shrinkage, modulus, and shrinkage stress related to tooth-restoration interfacial debonding in bulk-fill composites. Journal of dentistry. 2015;43(4):430-9.

19. Do T, Church B, Veríssimo C, Hackmyer SP, Tantbirojn D, Simon JF, Versluis A. Cuspal flexure, depth-of-cure, and bond integrity of bulk-fill composites. Pediatric dentistry. 2014;36(7):468-73.

20. Musanje L, Darvell B. Curing-light attenuation in filled-resin restorative materials. Dental Materials. 2006; 22(9):804-17.

21. Ferracane J, Greener E. The effect of resin formulation on the degree of conversion and mechanical properties of dental restorative resins. Journal of biomedical materials research. 1986;20(1):121-31.

22. Benetti AR, Havndrup-Pedersen C, Honoré D, Pedersen MK, Pallesen U. Bulk-fill resin composites: polymerization contraction, depth of cure, and gap formation. Operative dentistry. 2015;40(2):190-200.

23. Garoushi S, Säilynoja E, Vallittu PK, Lassila L. Physical properties and depth of cure of a new short fiber reinforced composite. Dental Materials. 2013;29(8):835-41.

24. Garoushi S, Vallittu P, Shinya A, Lassila L. Influence of increment thickness on light transmission, degree of conversion and micro hardness of bulk fill composites. Odontology. 2016;104:291-7.

25. Tiu J, Belli R, Lohbauer U. Rising R-curves in particulate/fiber-reinforced resin composite layered systems. Journal of the Mechanical Behavior of Biomedical Materials. 2020;103:103537.

26. Attik N, Colon P, Gauthier R, Chevalier C, Grosgogeat B, Abouelleil H. Comparison of physical and biological properties of a flowable fiber reinforced and bulk filling composites. Dental Materials. 2022;38(2):e19-e30.

27. Lassila L, Keulemans F, Säilynoja E, Vallittu PK, Garoushi S. Mechanical properties and fracture behavior of flowable fiber reinforced composite restorations. Dental Materials. 2018;34(4):598-606.

28. Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA, Miyazaki M. Mechanical properties, volumetric shrinkage and depth of cure of short fiber-reinforced resin composite. Dental materials journal. 2016;35(3):418-24.

29. Garoushi S, Gargoum A, Vallittu PK, Lassila L. Short fiber-reinforced composite restorations: a review of the current literature. Journal of investigative and clinical dentistry. 2018;9(3):e12330.

30. Lassila L, Tuokko J, Suni A, Garoushi S, Vallittu P. Effect of interfacial surface treatment on bond strength of particulate-filled composite to short fiber-reinforced composite. Biomaterial Investigations in Dentistry. 2022;9(1):33-40.

31. Seemann R, Marincola M, Seay D, Perisanidis C, Barger N, Ewers R. Preliminary results of fixed, fiber-reinforced resin bridges on four 4-× 5-mm ultrashort implants in compromised bony sites: A pilot study. Journal of Oral and Maxillofacial Surgery. 2015;73(4):630-40.

32. Tanner J, Tolvanen M, Garoushi S, Säilynoja E. Clinical evaluation of fiber-reinforced composite restorations in posterior teeth-results of 2.5 year follow-up. The open dentistry journal. 2018;12:476.

33. Alshabib A, Jurado CA, Tsujimoto A. Short fiber-reinforced resin-based composites (SFRCs); Current status and future perspectives. Dental materials journal. 2022;41(5):647-54.

34. Garoushi S, Vallittu PK, Watts DC, Lassila LV. Polymerization shrinkage of experimental short glass fiber-reinforced composite with semi-inter penetrating polymer network matrix. Dental Materials. 2008;24(2):211-5.

35. Lassila L, Keulemans F, Vallittu PK, Garoushi S. Characterization of restorative short-fiber reinforced dental composites. Dental Materials Journal. 2020;39(6):992-9.

36. Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. Journal of dentistry. 2009;37(2):115-21.

37. Zhang M, Matinlinna JP. E-glass fiber reinforced composites in dental applications. Silicon. 2012;4:73-8.

38. Lastumäki T, Lassila L, Vallittu P. The semi-interpenetrating polymer network matrix of fiber-reinforced composite and its effect on the surface adhesive properties. Journal of Materials Science: Materials in Medicine. 2003;|14(9):803-9.

39. Brunner K-C, Özcan M. Load bearing capacity and Weibull characteristics of inlay-retained resin-bonded fixed dental prosthesis made of all-ceramic, fiber-reinforced composite and metal-ceramic after cyclic loading. Journal of the mechanical behavior of biomedical materials. 2020;109:103855.

40. Bijelic-Donova J, Garoushi S, Lassila LV, Keulemans F, Vallittu PK. Mechanical and structural characterization of discontinuous fiber-reinforced dental resin composite. Journal of dentistry. 2016;52:70-8.

41. Alla RK, Sanka GSSJL, Saridena DSNG, Av R, Makv R, Mantena SR. Fiber-Reinforced Composites in Dentistry: Enhancing structural integrity and aesthetic appeal. International Journal of Dental Materials. 2023;5(03):78-85.

42. Vallittu PK. An overview of development and status of fiber-reinforced composites as dental and medical biomaterials. Acta biomaterialia odontologica Scandinavica. 2018;4(1):44-55.

43. Vallittu P. Fibre-reinforced composites for dental applications. Dental Biomaterials: Elsevier; 2008. p. 239-60.

44. Omran TA, Garoushi S, Abdulmajeed AA, Lassila LV, Vallittu PK. Influence of increment thickness on dentin bond strength and light transmission of composite base materials. Clinical Oral Investigations. 2017;21:1717-24.

45. Bijelic-Donova J, Garoushi S, Lassila LV, Vallittu PK. Oxygen inhibition layer of composite resins: effects of layer thickness and surface layer treatment on the interlayer bond strength. European journal of oral sciences. 2015;123(1):53-60.

46. Tezvergil A, Lassila L, Vallittu P. The effect of fiber orientation on the polymerization shrinkage strain of fiber-reinforced composites. Dental materials. 2006;22(7):610-6.

47. Zarone F, Sorrentino R, Traini T, Caputi S. Fracture resistance of implant-supported screw-versus cement-retained porcelain fused to metal single crowns: SEM fractographic analysis. Dental Materials. 2007;23(3):296-301.

48. Aldabib J. Reinforcement of poly (methyl methacrylate) denture base material. Dental and Medical Journal-Review. 2020;2(2):46-53.

49. Lammi M, Tanner J, Le Bell A, Lassila L, Vallittu P. Restoration of endodontically treated molars using fiber reinforced composite substructure. J Dent Res. 2011;90:2517.

50. Garoushi S, Tanner J, Vallittu P, Lassila L. Preliminary clinical evaluation of short fiber-reinforced composite resin in posterior teeth: 12-months report. The open dentistry journal. 2012;6:41.

51. Jurado CA, Tinoco JV, Tsujimoto A, Barkmeier W, Fischer N, Markham M. Clear matrix use for composite resin core fabrication. International Journal of Esthetic Dentistry. 2020;15(1).

52. Keulemans F, Garoushi S, Lassila L. Fillings and core build-ups. A clinical guide to fibre reinforced composites (FRCs) in dentistry: Elsevier; 2017. p. 131-63.

53. Vallittu PK. High-aspect ratio fillers: fiber-reinforced composites and their anisotropic properties. Dental materials. 2015;31(1):1-7.

54. Lassila L, Säilynoja E, Prinssi R, Vallittu P, Garoushi S. Characterization of a new fiber-reinforced flowable composite. Odontology. 2019;107:342-52.

55. Uctasli M, Garoushi S, Uctasli M, Vallittu P, Lassila L. A comparative assessment of color stability among various commercial resin composites. BMC Oral Health. 2023;23(1):789.

56. Volom A, Vincze-Bandi E, Sáry T, Alleman D, Forster A, Jakab A, et al. Fatigue performance of endodontically treated molars reinforced with different fiber systems. Clinical oral investigations. 2023;27(6):3211-20.

57. Hosaka K, Tichy A, Hasegawa Y, Motoyama Y, Kanazawa M, Tagami J, Nakajima M. Replacing mandibular central incisors with a direct resin-bonded fixed dental prosthesis by using a bilayering composite resin injection technique with a digital workflow: A dental technique. The Journal of Prosthetic Dentistry. 2021;126(2):150-4.

58. Braga RR, Meira JB, Boaro LC, Xavier TA. Adhesion to tooth structure: a critical review of "macro" test methods. Dental Materials. 2010;26(2):e38-e49.

59. Frese C, Decker C, Rebholz J, Stucke K, Staehle HJ, Wolff D. Original and repair bond strength of fiber-reinforced composites in vitro. Dental materials. 2014;30(4):456-62.

60. Garoushi S, Vallittu PK, Lassila L. Mechanical properties and wear of five commercial fibre-reinforced filling materials. Chin J Dent Res. 2017;20(3):137-43.

61. Lucchese A, Manuelli M, Ciuffreda C, Albertini P, Gherlone E, Perillo L. Comparison between fiber-reinforced polymers and stainless steel orthodontic retainers. The Korean Journal of Orthodontics. 2018;48(2):107-12.

62. Bijelic-Donova J, Flett A, Lassila LV, Vallittu PK. Immediate repair bond strength of fiber-reinforced composite after saliva or water contamination. J Adhes Dent. 2018;20:205-12.

63. Truffier-Boutry D, Place E, Devaux J, Leloup G. Interfacial layer characterization in dental composite. J Oral Rehabil. 2003;30(1):74-7.

64. Chuang S-F, Liu J-K, Chao C-C, Liao F-P, Chen Y-HM. Effects of flowable composite lining and operator experience on microleakage and internal voids in class II composite restorations. The Journal of prosthetic dentistry. 2001;85(2):177-83.

65. AlJehani YA, Baskaradoss JK, Geevarghese A, AlShehry MA, Vallittu PK. Shear bond strength between fiber-reinforced composite and veneering resin composites with various adhesive resin systems. Journal of Prosthodontics. 2016;25(5):392-401.

66. Zimmer R, Mantelli AR, Montagna K, Reston EG, Arossi GA. Does sandblasting improve bond strength in resin composite repair? Dentistry Review. 2023:100077.

67. Fornazari IA, Wille I, Meda E, Brum R, Souza E. Effect of surface treatment, silane, and universal adhesive on microshear bond strength of nanofilled composite repairs. Operative dentistry. 2017;42(4):367-74.

68. Banerjee A, Watson TF. Air abrasion: its uses and abuses. Dental Update. 2002;29(7):340-6.

69. Ahmadizenouz G, Esmaeili B, Taghvaei A, Jamali Z, Jafari T, Daneshvar FA, Khafri S. Effect of different surface treatments on the shear bond strength of nanofilled composite repairs. Journal of dental research, dental clinics, dental prospects. 2016;10(1):9.

70. Bühler J, Amato M, Weiger R, Walter C. A systematic review on the effects of air polishing devices on oral tissues. International journal of dental hygiene. 2016;14(1):15-28.

71. Puleio F, Rizzo G, Nicita F, Lo Giudice F, Tamà C, Marenzi G, et al. Chemical and mechanical roughening treatments of a supra-nano composite resin surface: SEM and topographic analysis. Applied Sciences. 2020;10(13):4457.

72. Chaiyabutr Y, Kois JC. The effects of tooth preparation cleansing protocols on the bond strength of self-adhesive resin luting cement to contaminated dentin. Operative dentistry. 2008;33(5):556-63.

73. Melo MAVd, Moysés MR, Santos SGd, Alcântara CEP, Ribeiro JCR. Effects of different surface treatments and accelerated artificial aging on the bond strength of composite resin repairs. Brazilian oral research. 2011;25:485-91.

74. Ouchi H, Takamizawa T, Tsubota K, Tsujimoto A, Imai A, Barkmeier WW, et al. The effects of aluminablasting on bond durability between universal adhesives and tooth substrate. Operative dentistry. 2020;45(2):196-208.

75. Nishigawa G, Maruo Y, Irie M, Maeda N, Yoshihara K, Nagaoka N, et al. Various effects of sandblasting of dental restorative materials. PloS one. 2016;11(1):e0147077.

76. Anusavice K, Antonson S. Materials and processes for cutting, grinding, finishing, and polishing. Phillips' Science of Dental Materials St Louis: Saunders. 2013;236.

77. Su N, Yue L, Liao Y, Liu W, Zhang H, Li X, et al. The effect of various sandblasting conditions on surface changes of dental zirconia and shear bond strength between zirconia core and indirect composite resin. The journal of advanced prosthodontics. 2015;7(3):214-23.

78. Ü çtaşli M, Bala O, Güllü A. Surface roughness of flowable and packable composite resin materials after finishing with abrasive discs. Journal of Oral Rehabilitation. 2004;31(12):1197-202.

79. Lopes GC, Thys DG, Klaus P, Oliveira G, Widmer N. Enamel acid etching: a review. Compendium of continuing education in dentistry (Jamesburg, NJ: 1995). 2007;28(1):18-24; quiz 5, 42.

80. Bernales Sender FR, Castaneda Via JA, Tay LY. Influence of different phosphoric acids before application of universal adhesive on the dental enamel. Journal of Esthetic and Restorative Dentistry. 2020;32(8):797-805.

81. Özcan M, Allahbeickaraghi A, Dündar M. Possible hazardous effects of hydrofluoric acid and recommendations for treatment approach: a review. Clinical oral investigations. 2012;16:15-23.

82. Sriamporn T, Thamronganansku N, Busabok C, Poolthong S, Uo M, Tagami J. Dental zirconia can be etched by hydrofluoric acid. Dental materials journal. 2014;33(1):79-85.

83. Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, et al. Adhesion to enamel and dentin: current status and future challenges. Operative Dentistry-University of Washington-. 2003;28(3):215-35.

84. Pashley DH, Tay FR, Breschi L, Tjäderhane L, Carvalho RM, Carrilho M, Tezvergil-Mutluay A. State of the art etch-and-rinse adhesives. Dental materials. 2011;27(1):1-16.

85. Alex G. Is total-etch dead? Evidence suggests otherwise. Compendium of Continuing Education in Dentistry (15488578). 2012;33(1).

86. Van Meerbeek B, Yoshihara K, Yoshida Y, Mine A, De Munck J, Van Landuyt K. State of the art of self-etch adhesives. Dental materials. 2011;27(1):17-28.

87. Münchow EA, Valente LL, Bossardi M, Priebe TC, Zanchi CH, Piva E. Influence of surface moisture condition on the bond strength to dentin of etch-and-rinse adhesive systems. Brazilian Journal of Oral Sciences. 2014;13:182-6.

88. Cengiz T, Ünal M. Comparison of microtensile bond strength and resin–dentin interfaces of two self-adhesive flowable composite resins by using different universal adhesives: Scanning electron microscope study. Microscopy Research and Technique. 2019;82(7): 1032-40.

89. De Munck J, Van Meerbeek B, Satoshi I, Vargas M, Yoshida Y, Armstrong S, et al. Microtensile bond strengths of one- and two-step self-etch adhesives to bur-cut enamel and dentin. Am J Dent. 2003;16(6):414-20.

90. Van Meerbeek B, Frankenberger R. Editorial: What's next after "universal" adhesives, "bioactive" adhesives? J Adhes Dent. 2017;19(6):459-60.

91. Feitosa VP, Ogliari FA, Van Meerbeek B, Watson TF, Yoshihara K, Ogliari AO, et al. Can the hydrophilicity of functional monomers affect chemical interaction? J Dent Res. 2014;93(2):201-6.

92. Perdigão J, Swift JR. EJ. Universal Adhesives. 2015; 27(6):331-4.

93. Yoshihara K, Nagaoka N, Hayakawa S, Okihara T, Yoshida Y, Van Meerbeek B. Chemical interaction of glycero-phosphate dimethacrylate (GPDM) with hydroxyapatite and dentin. Dent Mater. 2018;34(7):1072-81.

94. Han F, Dai S, Yang J, Shen J, Liao M, Xie H, Chen C. Glycerol Phosphate Dimethacrylate: An Alternative Functional Phosphate Ester Monomer to 10-Methacryloyloxydecyl Dihydrogen Phosphate for Enamel Bonding. ACS Omega. 2020;5(38):24826-37.

95. Suda S, Tsujimoto A, Barkmeier WW, Nojiri K, Nagura Y, Takamizawa T, et al. Comparison of enamel bond fatigue durability between universal adhesives and two-step self-etch adhesives: Effect of phosphoric acid pre-etching. Dent Mater J. 2018;37(2):244-55.

96. Tsujimoto A, Barkmeier WW, Takamizawa T, Watanabe H, Johnson WW, Latta MA, Miyazaki M. Comparison between universal adhesives and two-step self-etch adhesives in terms of dentin bond fatigue durability in self-etch mode. Eur J Oral Sci. 2017;125(3):215-22.

97. Cuevas-Suárez CE, da Rosa WLO, Lund RG, da Silva AF, Piva E. Bonding Performance of Universal Adhesives: An Updated Systematic Review and Meta-Analysis. J Adhes Dent. 2019;21(1):7-26.

98. Nagarkar S, Theis-Mahon N, Perdigão J. Universal dental adhesives: Current status, laboratory testing, and clinical performance. J Biomed Mater Res B Appl Biomater. 2019;107(6):2121-31.

99. Irmak O, Celiksoz O, Yilmaz B, Yaman BC. Adhesive system affects repair bond strength of resin composite. J Istanbul Uni Fac Dentist. 2017;51(3):25-31.