Journal of Dental Sciences and Education

Review

DOI: 10.51271/JDSE-0010

Use of fiber-containing materials in restorative dentistry

İbrahim Halil Avcılar, Şeyhmus Bakır

Department of Restorative Dentistry, Faculty of Dentistry, Dicle University, Diyarbakır, Turkey

Cite this article: Avcılar İH, Bakır Ş. Use of fiber-containing materials in restorative dentistry. *J Dent Sci Educ*. 2023;1(2):49-54.

Corresponding Author: İbrahim Halil Avcılar, dtibrahimavclr@gmail.com

Received: 31/05/2023 ◆ **Accepted**: 25/06/2023 ◆ **Published**: 28/06/2023

ABSTRACT

It is aimed at providing chewing function in restorative treatment in dentistry, to protect the tooth structure based on the minimally invasive approach and to meet the aesthetic expectations of the patient. Studies including application techniques are carried out to improve the mechanical and physical properties of composite resins and to reduce polymerization shrinkage. The success of composite restorations has increased with the use of fibers and fiber-reinforced composite resin materials, and the indications of composite resins as direct restoration material have expanded thanks to the production of newly developed fiber-reinforced composite resin materials and their use with the biomimetic restoration technique. In this review, information about the properties and types of fiber structures, advantages, disadvantages, and application areas is explained.

Keywords: Fiber reinforced composite, direct restorations, polyethylene fiber

INTRODUCTION

Although a decrease in the prevalence of dental caries has been observed worldwide in recent years, untreated caries still affect approximately 35% of the world's population. Direct and indirect restorations are at the forefront of our dental caries treatment procedures. Direct posterior restorations are preferred more than indirect restorations due to the possibility of finishing the treatment in a single session, being more economical, and requiring less preparation on the tooth.[1]

The primary goal of dental treatments is to restore the lost function and appearance of teeth or dental hard tissues with appropriate materials, while preserving the integrity of the tooth and its surrounding tissue.[2] When choosing a restorative material; It should be considered that it is the material that causes the least material loss in the tooth, is the most suitable for the structure of the tooth in terms of morphological and mechanical properties, and is biocompatible with the oral tissues.[3,4]

With the introduction of resin-based composites into dentistry, significant advances have been made in restorative dentistry. Due to the advantages of composite resins such as being aesthetic and biocompatible, not containing mercury, having low thermal conductivity, allowing minimally invasive restorations and supporting the dental tissues left after caries removal, they are preferred more and more by physicians.[5] Operative Dentistry Academy European Department (AODES), while accepting composite resins as the restorative material that should be preferred together with the appropriate adhesive in minimally invasive procedures applied to posterior teeth, they report that the structural properties of these materials still do not reach a sufficient level.[6] Restoration size is inversely proportional to the lifetime of composite resin restorations. It is more common for restorations to fail due to fracture, especially in teeth with excessive crown destruction.[7]

In recent years, the use of fiber-reinforced composite resin restorations in dentistry has become popular in order to increase the application of composite resins in these treatments, whose use with the direct method in large restorations in the posterior region is limited due to their mechanical properties.[8] Studies on fiber reinforcement of materials in dentistry date back to 60 years. Glass fibers were first used to strengthen acrylic resins in the 1960s. In the following years, different types of fibers have been developed in order to increase the physical and mechanical properties of composite resins.

Fibers have advantages, such as low modulus of elasticity, good resistance to compression forces, translucency, and resin-adhesive bonding. In addition, fibers increase the resistance of restorative materials to mechanical forces as stress breaker and stress dispersant and reduce polymerization shrinkage. The success of composite restorations has increased with the use of fiber-reinforced composite materials, and the indications of composite resins as direct posterior restoration material have expanded, thanks to the production of new fiber-reinforced composite materials with innovations in their structures and their use with the biomimetic restoration technique.[9]

The combination of polymer matrix and fiber structure constitutes the basic structure of fiber-reinforced composite resins. The stresses that occur in the matrix structure as a result of the forces coming to the restoration are transmitted to the fibers and thus, the fractures that may occur in the restoration or the tooth can be prevented.[10]

In vitro studies on fiber reinforced composite resin applications in dentistry continue and adequate clinical studies are needed. Fibers are widely used in the strengthening and repair of denture bases, fixed bridges applied to anterior and posterior teeth, implant-based prostheses, fixed placeholder construction, as endodontic posts, periodontal splint applications, indirect applications such as inlay-onlay, high-level restorations in vital and non-vital teeth. Its use is increasing in stressed areas.[11]

FIBER REINFORCED COMPOSITE RESINS (FRCS)

Fiber is a cylindrical, thin and flexible fibrous structure that is 100 times longer than its diameter. Fiber reinforced composites;[12] FRC, like conventional composite resins, consists of organic matrix and inorganic filler phase. Organic matrix; polymethyl methacrylate (PMMA), UDMA, TEGDMA, epoxy or Bis-GMA structure. Fibers placed in various lengths, diameters, structures, and directions added to the organic matrix structure form the inorganic filler phase.[13] The fatigue resistance of fiber-reinforced composites is very high because the resin matrix surrounding the fibers stabilizes the geometric structure of the fiber material and holds the fiber in a predetermined position to provide optimal strength. Fibers play an important role in transmitting force from the composite to the fibers by binding to the polymer matrix. Thus, the fibers ensure a balanced distribution of stresses throughout the restoration.[14]

The first studies on fiber reinforcement in clinical dentistry date back to 60 years ago. Glass fibers were first used to reinforce polymethyl methacrylate in the 1960s. In 1973, a report was published on affixing the crowns of avulsed or extracted anterior teeth to the lateral teeth in a single session using acid etching technique and fiber.[15]

The properties of composite fillers continue to be improved by reducing the size of the filler particles and using these fibers. Fiber-reinforced composites are used as dentin replacement, and the double-layered resin composite structure is accepted as a biomimetic restoration system by mimicking the dentin-enamel complex.[16]

Advantages of Fiber Reinforced Composite Resins

- Restorations made with fiber reinforced composites both at the bedside
  It can be produced in the laboratory as well.
- Compared to metals, they have non-corrosive, translucent, high bonding properties and ease of repair, and show superior aesthetic properties.
- They are ideal materials for the restoration of teeth that have lost excessive substance after endodontic treatment.
- The depth of polymerization can be up to 4-5 mm.
- Offers a minimally invasive, low-cost alternative to traditional restorative treatments.
- It prevents crack propagation in a restored tooth.
- It offers interesting applications in adhesive bridges, as splint material, in the provision of aesthetic custom-made posts and cores.
- They have very favorable mechanical properties and their strength-to-weight ratio is superior to most alloys.

Disadvantages of Fiber Reinforced Composite Resins

- The most common problems encountered in fiber-reinforced composite restorations are wear of the composite veneer, chipping of the composite veneer, fractures due to delamination and secondary caries, and occlusal wear. However, most problems can be repaired easily, quickly and economically.
- Mechanical properties of fiber reinforced composites decrease after hydrolytic aging.
- Exposed fiber in the mouth may cause local tissue reaction.
- Since the radiopacity of the fiber material is insufficient, it becomes difficult to diagnose secondary caries radiographically.
- Due to the application of the composite in layers, it may cause separations between the fiber material and the composite in areas that cannot fully polymerize.

Fiber-reinforced composites have the potential to be used in many applications in dentistry and are expected to gain increasing application and popularity in dentistry.[17]

Fiber Types Used in Dentistry

Classification of fibers used in dentistry;

1. **By type of fiber:** Carbon fibers, aramid fibers, polyethylene fibers, glass fibers, nylon fibers
2. **By the orientation of fiber:** unidirectional continuous fibers, bidirectional continuous fibers, short-particle discontinuous fibers
3. **By on whether the fiber is pre-infiltrated with the monomer or not:** pre-infiltrated fibers, non-pre-infiltrated fibers[18]

By Type of Fiber

Carbon fiber: Although the color of carbon fiber, which has good physical and chemical properties, is black, it has been used in dentistry for many years, although it is not aesthetically acceptable. Since such fibers show good bending and bending strength when placed perpendicular to the direction of the applied stress, the placement of the fibers is formed crosswise and perpendicular to each other during the production of the fibers. Unidirectional and knitted ones are frequently used in implant-supported prostheses.[19]

Carbon fibers have been replaced by other fiber systems due to the disadvantages of carbon fibers such as poor aesthetics, potential toxicity of carbon, difficulty in processing the fiber and inability to fully adapt the fiber into the resin, and studies showing that other fiber types are more successful than carbon fibers.[20]

Aramid fiber: Aramid fiber is known as phenylene terephthalamidesynthetic aramid polymer fiber.[19] The trade name of this fiber, which is an organic compound and low density, is "Kevlar". Due to its microfibril structure, it has lower resistance to pressure and bending forces than other fibers, while it has a high resistance to tensile.[20] Kevlar fibers do not require a binding agent because their wettability is very good. Although aramid fibers are more aesthetic than carbon fibers, they are not preferred in areas where aesthetics are at the forefront due to the yellow color of the material and their use is limited.[12]

Polyethylene fiber: In recent years, ultra-high molecular weight polyethylene (UHMWPE) fiber reinforcement systems, one of the fiber systems used to increase the durability and impact resistance of resin-based composites, are gaining popularity.[21] Polyethylene fibers have advantages such as easily shaped, translucency, low density and biocompatibility. They can be produced as monofilament or as knitted fiber. They cannot be used with high-temperature polymerized composites due to their structural deterioration after 140°C.[22]

One of the most important disadvantages of polyethylene fibers is the problem of adhesion with polymer composite. The reason for this is that polyethylene fibers have low surface energies and low wettability due to their hydrophobicity. In recent years, it has been tried to increase the adhesion of the polymer structure to the polyethylene fibers by applying plasma to the surfaces of polyethylene fibers.[23]

Among the most commonly used brands are ribbond and connect. Since both brands are not pre-saturated with resin, they are polyethylene fibers that must be saturated with resin in order to be used.[24] Ribbond; It is widely used as a post-core material, as a substructure material in temporary and permanent bridges, and in the repair of acrylic bases. The braided structure of the ribbons provides versatile support to the composite resin, while being colorless and translucent allows color control of the resin in which it is embedded.[25]

Glass fiber: Glass fibers are the most widely used fiber type. The lattice consists of dispersed or linear fiber bundles and reinforcing dental polymers in different forms. Unidirectional glass fibers are composed of 1000-200,000 single glass fibers and the glass content is kept at 20% of the composition. Glass fibers have a higher density than other (carbon, aramid, polyethylene) fibers.[26]

It has been stated that glass fibers are the most suitable fiber for use due to their resistance to heat, humidity and oil, high mechanical properties, cheapness, easy availability, good polishability, aesthetics because of their white color, translucent feature and dentin bonding capacity. Glass fiber is biomechanically similar to teeth and alveolar bone. The coefficient of thermal expansion is close to that of composite resins.

Widely used glass fiber brands in the market Vectris (Ivoclar, Liechtenstein), Splint-It (Jeneric/Pentron, Germany), GlasSpan (Exton, USA), Fiber Kor (Jeneric/Pentron, Germany) Stick (Stick Tech, Finland), StickNet (Stick Tech, Finland) and EverStick (Stick Tech, Finland).[27]

GlasSpan is a woven glass fiber system that can be used in post-core, periodontal splint and temporary bridge applications. It is not saturated with resin and does not require special equipment.[28] Stick fibers can be used directly in the mouth. Stick fibers are a system with a diameter of 10-12 μm and contain an average of 100,000-180,000 glass fibers and 45% fiber. Surface treatment is carried out by saturating silanized porous polymers. Polymethyl methacrylate (PMMA) chains surrounding the BIS GMA matrix increase the matrix's ability to bond to the product and its placement. In addition to the similarly produced StickNet material, EverStick, the latest material produced by the same company, is densely compacted in a polymer monomer matrix, pre-silanized glass fiber, 55% SiO_2 22% CaO, 15% Al_2O_3, 6% B_2O_3, and the whole structure is surrounded by a PMMA capsule. It is a composite material containing very small amounts of metal oxides.[29]

Nylon fiber: Nylon fibers are polyamide fibers. Polyamides are high molecular weight thermoplastic polymers. Polyamides have high strength, elasticity, hardness, and wear. They maintain their good mechanical properties even at high temperatures. They have high fracture strength and bending strength at low temperatures and are resistant to solvents. Polyamide-based denture base material can be used in patients allergic to PMMA resin or where flexibility is desired. The most important advantage of the polyamide-based denture base material is its shock absorption resistance and resilience for repetitive stresses.[30]

By the Orientation of Fiber

Long fiber reinforced composites are called continuous fiber composites, while short fiber reinforced composites are called short particle/discontinuous fiber composites. Composites in which two or more fiber types are in a single matrix structure are called hybrid fiber composites. Fibers can be placed in the matrix structure of continuous fiber composites in either one direction (rovings and threads) or two directions (weave/weave).[31]

The orientation of the fibers can change the properties of a fiber-reinforced polymer from isotropic to anisotropic or even orthotropic. Continuous unidirectional fiber-reinforced polymers impart anisotropic properties to the composite, while continuous duplex fibers impart orthotropic properties, while randomly oriented fibers impart isotropic properties. Unidirectional longitudinal fibers exhibit superior mechanical properties along their long axis and are often preferred when the direction of greatest stress is known. Discontinuous fibers can be found as aligned or randomly oriented short particle fibers. If the direction of the force is unknown or there is a force vector in more than one direction, omnidirectional woven or randomly oriented fibers may be preferred.[32,33]

By on Whether the Fiber is Pre-Infiltrated with the Monomer or Not

It can also be defined as the saturation of the fiber with the polymer matrix or the monomer infiltration into the fiber structure. The saturation process is the homogeneous coating of each surface of the fiber in the resin matrix with monomer. Adequate saturation of the fiber fibers with the appropriately selected resin ensures better mechanical and physical properties of the fiber-reinforced restoration. In order for the reinforcement to be successful, the forces from the resin matrix must be transmitted to the fiber infrastructure. If insufficient saturation occurs in the fiber reinforced composite, water absorption increases in these regions and the mechanical properties of the composite weaken due to the harmful hydrolytic effect of water. Another problem is the invasion of the oral microflora into the formed microcavities and the resulting color change. It is therefore preferred that the process be carried out by the manufacturer of the fiber product.[34]

This can be done by the manufacturer beforehand or later by the physician/laboratory technician. EverStick C&B and Quartz Splint UD are examples of pre-saturated fibers, while Ribbond is examples of non-pre-saturated fibers.[35]

Usage Areas of Fiber Reinforced Composite Resins

Usage areas of fiber reinforced composite resins;[36]

- Direct adhesive restorations
- Indirect adhesive restorations
- Fixed bridge
- Anterior and posterior single full crowns
- Lamina crowns
- Partial crowns

- Telescopic crowns
- Anterior and posterior extracoronal-intercoronal bridges
- Implant supported fixed and movable bridges
- Periodontal splint
- Implant-supported dental prosthesis
- Endodontic post core construction
- Fixed placeholder in pedodontics
- Strengthening or repairing removable prostheses
- Fixed partial prosthesis applications
- Immediate temporary and long-term temporary bridge

Fiber Reinforced Products and Compounds Used in Dentistry

Table 1. Fiber-reinforced products and compounds used in dentistry[37]

Product	Manufacturer	Fiber Type	Fiber Orientation
Pre-infiltrated Fibers Prepared in the Laboratory			
Fiber Kor	Jeneric/Pentron	S-glass	Linear
Vectris	Ivoclar	E-glass	Linear
Pre-infiltrated Fibers Prepared in the Clinic			
EverStickC&B	Stick Teck/Turku	E-glass	Linear
Quartz Splint UD	RTD	Quartz	Linear
Splint-it	Jeneric/Pentron	Glass	Linear/Mesh
Clinically Prepared Non-Pre-infiltered Fibers			
Connect	Kerr	Polyethylene	Mesh
Ribbond	Ribbond	Polyethylene	Mesh
Glasspan	Exton	S-glass	Linear
Stick	Stick Teck/Turku	E-glass	Linear
Stick Net	Stick Teck/Turku	E-glass	Linear

Factors Affecting Mechanical Properties of Fiber Reinforced Composite Resins

1. Distribution direction of fibers
2. Quantity and volume of fibers, surface widths and position
3. Saturation of fibers with resin
4. Adhesion of fibers to the matrix
5. Surface Treatments Applied to Fibers

Distribution Direction of Fibers

Unidirectional rod-shaped fibers consist of fiber bundles running parallel to each other in one direction. Unidirectional fibers provide anisotropic properties by improving the mechanical properties of composites in one direction. Unidirectional fibers show the highest resistance to forces from the parallel direction, while their resistance to forces from the perpendicular direction is low.

Fibers in the form of a web/weave (weave) are fibers that are formed by arranging them in different directions longitudinally and transversely. It is orthotropic because it is a knitted fiber and provides support to the composite resin from all directions. It allows the restoration to be strengthened in all directions. Therefore, it is appropriate to use in situations where the direction of the incoming force cannot be predicted before.[38]

If random/chopped fibers are randomly oriented as in short fibers, they exhibit equal mechanical properties in all directions when three-dimensional isotropic. If the direction of the force is unknown or there is a force vector in more than one direction, omnidirectional woven or randomly oriented fibers may be preferred.[39]

Quantity and Volume of Fibers

The amount of fiber in the polymer matrix can be expressed as a percent by weight or volume. It has been shown in studies that the increase in the amount of fiber increases the impact strength of the polymer matrix. It has been determined that the fiber reinforced restorations have lower compressive and tensile strengths than expected if the volume is low, even if the fiber content is high.[40] It has been shown that the fiber length, as well as the volumetric ratio of the fiber in the polymer matrix, affect the abrasion resistance of composite resins.

Saturation of Fibers with Resin

It can also be defined as the saturation of the fiber with the polymer matrix or the monomer infiltration into the fiber structure. The saturation process is the homogeneous wetting of each surface of the fiber in the resin matrix with the monomer. Adequate saturation of the fiber fibers with the appropriately selected resin ensures better mechanical and physical properties of the fiber-reinforced restoration.[41] It is very important to saturate the fibers with the monomer matrix surrounding them so that the load on the restoration can be transferred from the resin matrix to the fibers.[42] If the fiber bundles are not sufficiently saturated with the resin matrix, the fiber There are gaps between the bundles and it has been reported that the durability of the restoration against forces from the transverse direction decreases due to these gaps. In addition, the mechanical properties of composites reinforced with insufficiently saturated fiber, such as flexural strength and modulus of elasticity, are adversely affected, which can lead to fluid absorption from the voids, microorganism penetration and color change.[12,41]

Fiber fibers can be saturated in two ways: pre-saturated and saturated. Pre-unsaturated fibers are fiber in which the dentist or technician manually wets the fiber fibers with a low-viscosity resin prior to the procedure. However, manual resin impregnation is a demanding and time-consuming application. Due to application errors, voids and pores may occur that may cause water absorption. Pre-saturation process was applied to the pre-saturated fibers with different techniques as fabrication at the production stage. It does not require the dentist or technician to pre-saturate the resin before the application, thus reducing the technical sensitivity.[43]

Adhesion of Fibers to the Matrix

The connection of the fibers to the polymer matrix has an important place in the durability of FRCs. The chemical bond between the polymer matrix and the fiber is the covalent bond. With the adhesion, the resulting stresses are transmitted from the matrix to the fibers. Good connectivity between the fiber and the matrix is effective in dissipating the incoming forces.[34]

Surface Treatments Applied to Fibers

The adhesion of the fiber to the matrix is one of the most important variables affecting the mechanical properties of FRC. Various surface treatments are suggested during production or prior to used to improve adhesion between fiber and polymer matrix. These transactions are; dental adhesive use, plasma spraying, flame burning and radiation applications. Polymer surfaces often cause bonding and finishing problems due to their high hydrophobicity and low surface energy. With the application of plasma, the surfaces of polymers can be improved in terms of hydrophilicity by forming oxygen-containing functional groups such as carbonyl group (C=O) and hydroxyl group (-OH).

Silane coating agents are used to provide adhesion between the glass fibers and the polymer matrix. Silane coating agents are condensed onto the glass surface at a temperature higher than room temperature.[12]

Studies on Fiber-Reinforced Composite Resins

Bijelic-Donova et al.[44] In their study, they showed that the fracture resistance values of short fiber reinforced composite resins are higher compared to conventional composite resins.

Türkeş et al.[45] In his study, it was reported that if the woven polyethylene fiber is placed in the composite resin, the resistance of the restoration against the incoming pressure forces increases.

Hiremath et al.[46] in their in vitro study, it was concluded that restorations with polyethylene ribbond fiber can be evaluated as an alternative to crown restorations, since the fracture resistance values are very close to natural teeth.

Garlapati et al.[47] showed in their study that EverX-Posterior has superior fracture resistance. EverX-Posterior is a short E-glass fiber reinforced composite that can control polymerization shrinkage and marginal leakage due to the orientation of the fibers.

In the study of Tekçe et al.[48] polyethylene ribbond fiber reinforced composite and short fiber reinforced composite EverX-Posterior were compared and as a result, the fracture resistance values of the two materials were found to be similar. In addition, in this study, the fracture values of EverX-Posterior materials were found to be higher than the average maximum bite force of 700-900 N in the molar regions and the forces that can reach up to 965 N during trauma and hard foreign body bite.

In their in vitro study by Eapen et al.[49] it has been shown that the use of short fiber reinforced composites in the restorations of endodontically treated teeth can preserve the remaining tooth tissue with higher fracture resistance. They reported that the use of a short fiber reinforced composite substructure under the composite resins in areas exposed to high stresses with endodontically treated teeth in order to mimic enamel and dentin in natural teeth will make the restoration more durable and resistant to fracture.

Tanner et al.[50] reported that no secondary caries formation was observed in posterior teeth restored with fiber-reinforced composite in a two-and-a-half-year follow-up study. It has been reported that the decrease in the amount of polymerization shrinkage with the presence of fibers and the associated risk of micro-leakage reduce the risk of secondary caries, especially in FRCs.

CONCLUSION

The use of fiber-reinforced composite materials in dentistry is gradually increasing, and their use with traditional composite materials expands the limits of indications in restorative procedures. The contribution of these materials to the field of biomimetic dentistry will continue with the increasing success rate in composite restorations and the production of new fiber-reinforced composite materials by improving their structures.

ETHICAL DECLARATIONS

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

REFERENCES

1. Sonkaya E, Yazıcı Akbıyık S, Bakır EP, Bakır Ş. Posterior direkt restorasyonlarda nerede başarısızlık yaşıyoruz?. *DÜ Sağlık Bil Enst Derg.* 2021; 11(2): 242-249. doi:10.33631/duzcesbed.885725
2. Erken M, Demirekin ZE, Türkaslan S. Fiberle güçlendirilmiş kompozit köprü uygulamalarının hasta memnuniyetinin değerlendirilmesi. *Süleyman Demirel Üniv Sağ Bil Derg.* 2020; 11(3): 284 - 289. 10.22312/sdusbed.620109
3. Yavuz A. Fiberle güçlendirilmiş dental kompozitler. Sağlık Bilimlerinde. 2022.
4. Sonkaya, E. And Bakır, Ş. Elution of residual monomers from dental composite resins. *Biomed Res.* 2020;31(5):148-154.
5. Altun C. Kompozit dolgu materyallerinde son gelişmeler. *Gülhane Tıp Derg.* 2005:47(1);77-82.
6. Lynch CD, Opdam NJ, Hickel R, et al. Guidance on posterior resin composites: Academy of Operative Dentistry - European Section. *J Dent.* 2014;42(4):377-383. doi:10.1016/j.jdent.2014.01.009
7. Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. A retrospective clinical study on longevity of posterior composite and amalgam restorations. *Dent Mater.* 2007;23(1):2-8. doi:10.1016/j.dental.2005.11.036
8. Candan Ü. Pediatrik diş hekimliğinde fiberle güçlendirilmiş kompozitlerin aşırı kron harabiyeti gösteren dişlerdeki başarısının incelenmesi. Ege Üniversitesi, Sağlık Bilimleri Enstitüsü, Pedodonti Ana Bilim Dalı, Doktora Tezi, 2007, İzmir.
9. Freilich MA, Karmaker AC, Burstone CJ, Goldberg AJ. Development and clinical applications of a light-polymerized fiber-reinforced composite. *J Prosthet Dent.* 1998;80(3):311-318. doi:10.1016/s0022-3913(98)70131-3
10. van Heumen CC, Kreulen CM, Bronkhorst EM, Lesaffre E, Creugers NH. Fiber-reinforced dental composites in beam testing. *Dent Mater.* 2008;24(11):1435-1443. doi:10.1016/j.dental.2008.06.006
11. Freilich MA, Meiers JC, Duncan JP, Eckrote KA, Goldberg AJ. Clinical evaluation of fiber-reinforced fixed bridges. *J Am Dent Assoc.* 2002;133(11):1524-1541. doi:10.14219/jada.archive.2002.0084
12. Candan Ü, Eronat N. Fiberle güçlendirilmiş rezin kompozitler. *Ege Üniversitesi Dişhekimliği Fakültesi Derg.* 2008:29(1);1-12.
13. Martin AF, Meiers JC, Duncan JP, Goldberg AJ (Authors/Editors). Fiber reinforced compositesin clinical dentistry. ISBN-13. 978-0867153736; Edition. 1st; Publisher. Quintessence Pub Co; Publication date. January 15, 2000:9-22.
14. Mortazavian S, Fatemi A, Khosrovaneh A. Fatigue behavior and modeling of short fiber reinforced polymer composites: a literature review. *Int J Fatigue.* 2015;70:297-321.
15. Levent H, Karaağaçlıoğlu L. Protez kaide rezinlerinin güçlendirilmesi. *Gazi Üniversitesi Diş Hek Fak Derg.* 2004;21(2):135-142.
16. Tiu J, Belli R, Lohbauer U. Thickness influence of veneering composites on fiber-reinforced systems. *Dent Mater.* 2021;37(3):477-485. doi:10.1016/j.dental.2020.12.002
17. Baysal N, Ayyıldız S. Sabit bölümlü protezlerde fiberle güçlendirilmiş kompozit rezin kullanımı. *Ata Diş Hek Fak Derg.* 2014; 24(2): 315-325.
18. Ergün G, Yenisey M. Restoratif kompozitlerin farklı ışık kaynakları kullanılarak cam fiberle güçlendirilmiş kompozit materyaline bağlantı dirençlerinin incelenmesi. *Ondokuz Mayıs Üniv Diş Hek Derg.* 2006;7(1):29-36.
19. Kurt EÇ, Özdoğan MS. Seromerler ve fiberle güçlendirilmiş kompozitler. *Ata Diş Hek Fak Derg.* 2006;(2):52-60.
20. Karaalioğlu O, Duymuş ZY. Fiberle güçlendirilmiş kompozitlerin sabit bölümlü protez yapımında kullanımları. *Ata Diş Hek Fak Derg.* 2008;(2):70-7.
21. Eskitaşcioğlu G, Belli S. Use of a bondable reinforcement fiber for post-and-core buildup in an endodontically treated tooth: a case report. *Quintessence Int.* 2002;33(7):549-551.
22. Frese C, Decker C, Rebholz J, et al. Original and repair bond strength of fiber reinforced composites in vitro. *Dent Mater.* 2014;30(4):456-462.
23. Runyan DA, Christensen LC. The effect of plasma treated polyethylene fiber on the fracture strength of polymethyl methacrylate. *J Prosthet Dent.* 1996;76(1):94-96.
24. Lassila LV, Tezvergil A, Lahdenpera M. et al. Evaluation of some properties of two fiber reinforced composite materials. *Acta Odontol Scand.* 2005;63(4):196-204.
25. Ganesh M, Tandon S. Versatility of ribbond in contemporary dental practice. *Trends Biomater Artif Organs,* 2006;20(1):53-58.

26. Vallittu PK, Lassila VP, Lappalainen R. Acrylic resin fiber composit part I: The effect of fiber concentration on fracture resistance. *J Prosthet Dent.* 1994;71(6):607-12.
27. Prashanth S, Subbaya KM, Nithin K, Sachhidananda S. Fiber reinforced composites. *J Mater Sci Eng.* 2017;6(3):2-6.
28. Lassila L, Vallittu PK. The effect of fiber position and polymerization condition on the flexural properties of fiber reinforced composite. *J Contemp Dent Pract.* 2004;5(2):14-26.
29. Tezvergil A, Lassila L, Vallittu P. The shear bond strength of bidirectional and random oriented fibre reinforced composite to tooth structure. *J Dent.* 2005;33(6):509-16.
30. Dogan OM, Bolayir G, Keskin S, Dogan A, Bek B, Boztug A. The effect of esthetic fibers on impact resistance of a conventional heat cured denture base resin. *Dent Mater J.* 2007;26(2):232-239.
31. Panthapulakkal S, Raghunanan L, Sain M, KC B, Tjong J. Natural fiber and hybrid fiber thermoplastic composites: advancements in lightweighting applications. *Woodhead Publ.* 2017;39-72.
32. Kumar A, Tekriwal S, Rajkumar B, Gupta V, Rastogi R. A review on fibre reinforced composite resin. *Ann Prosthodont Restor Dent.* 2017;46(1):257-269.
33. Rajak DK, Pagar DD, Menezes PL, Linul E. Fiber reinforced polymer composites: Manufacturing, properties, and applications. *Polymers.* 2019;11(10):1667.
34. Vallittu P. Oxygen inhibition of autopolymerization of polymethylmethacrylate glass fibre composite. *J Mater Sci.* 1997;8(8):489-492.
35. Juloski J, Beloica M, Goracci C, et al. Shear bond strength to enamel and flexural strength of different fiber reinforced composites. *J Adhes Dent.* 2013;15(2):123-30.
36. Sucu Ö, Köroğlu A. Protetik dişhekimliğinde fiberler. *J Med Dent.* 2021;3(2):1-27.
37. Vallittu P, Özcan M. Clinical guide to principles of fiber reinforced composites in dentistry. Woodhead Publ. 2017.
38. Butterworth C, Ellakwa AE, Shortall A. Fibre reinforced composites in restorative dentistry. *Dent Update.* 2003;30(6):300-306.
39. Brozek R, Koczorowski R, Dorocka-Bobkowska B. Laboratory and clinical evaluation of polymer materials reinforced by fibers used in dentistry. *Eur Rev Med Pharmacol Sci.* 2019;23(5):1855-1863.
40. Yu SH, Lee Y, Oh S, Cho HW, Oda Y, Bae JM. Reinforcing effects of different fibers on denture base resin based on the fiber type, concentration and combination. *Dent Mater J.* 2012;31(6):1039-1046.
41. Bahramian N, Atai M, Naimi JMR. Ultra high molecular weight polyethylene fiber reinforced dental composites: effect of fiber surface treatment on mechanical properties of the composites. *Dent Mater J.* 2015;31(9):1022-109.
42. Ellakwa AE, Shortall AC, Shehata MK, Marquis PM. The influence of fibre placement and position on the efficiency of reinforcement of fibre reinforced composite bridgework. *J Oral Rehabil.* 2001;28(8):785-791.
43. Vallittu PK. Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers. *J Prosthet Dent.* 1999:81(3);318-326.
44. Bijelic DJ, Garoushi S, VallittuPK, Lassila LV. Mechanical properties, fracture resistance, and fatigue limits of short fiber reinforced dental composite resin. *J Prosthet Dent.* 2016;115(1):95-102.
45. Türkeş E, Gürtekin B, Gökçe YB. Fiber ağların farklı pozisyonlarda kompozit materyaline uygulanmasının restorasyonun kırılma direncine etkisi. *Turkiye Klinikleri J Health Sci.* 2018;24(1):1-8.
46. Hiremath H, Kulkarni S, Hiremath V, Kotipalli M. Evaluation of different fibers and biodentine as alternates to crown coverage for endodontically treated molars: An in vitro study. *J Conserv Dent.* 2017;20(2):72.
47. Garlapati TG, Krithikadatta J, Natanasabapathy V. Fracture resistance of endodontically treated teeth restored with short fiber composite used as a core material An in vitro study. *J Prosthodont Res.* 2017;61(4):464-470.
48. Tekçe N, Pala K, Tuncer S, Demirci M, Serim ME. Influence of polymerisation method and type of fibre on fracture strength of endodontically treated teeth. *Aust Endod J.* 2017;43(3):115-122.
49. Eapen AM, Amirtharaj LV, Sanjeev K, Mahalaxmi S. Fracture resistance of endodontically treated teeth restored with two different fiber reinforced composite and two conventional composite resin core buildup materials:an in vitro study. *J Endod.* 2017;43(9):1499-1504.
50. Tanner J, Tolvanen M, Garoushi S, Sailynoja E. Clinical evaluation of fiber reinforced composite restorations in posterior teeth results of 2.5 year follow-up. *Open Dent J.* 2018;12(1):476.