Fiber Materials Used in Prosthetic Dentistry

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Abstract: The aim of this systematic review is to examine the past daily use of fiber, the articles that evaluate the mechanical properties of fibers and the current approaches of fibers especially those used in prosthetic applications. Fiber materials have high quality properties that strengthened the material, increase the elasticity modulus and fracture strength of the material added into. This systematic review investigated the articles that pointed out all the properties of fibers used in prosthodontics.

Keywords: Fiber, material, prosthetic dentistry, review.

INTRODUCTION

Nowadays, materials need to have certain properties in order to be used in dentistry such as mechanically: high tensile-compression-shear strength, high fatigue resistance, physically: dimensional accuracy to low water absorption and solubility, chemically: the amount of residual monomer should be low. It must also be biologically biocompatible and non-toxic [1].

WHAT IS FIBER?

Fiber reinforced materials used in dentistry are basically similar to resin composites and consist of organic matrix and inorganic filler phases as in resin composites. Organic matrix: polymethyl methacrylate (PMMA), epoxy or bisphenol A diglycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA). The inorganic filler phase of fiber consist of various length, diameter, structure and direction added to the organic matrix structure. The fiber in the composite matrix is bonded to the resin by an adhesive interface. The interface between the matrix and fiber plays an important role in the transfer of composite charge to the fibers. While the fibers, which are reinforcing components, provide durability and rigidity, the resin matrix surrounding the fibers maintains their geometrical structure, protects them from the influence of the moisture and maintains them in the predetermined position, support and applicability in order to provide optimal strength [2,3].

Fiber reinforced materials consist of fiber materials held together with the resin matrix. Fibers which are cylindrical, thin and flexible in structure, 100 times longer than their diameter, are characterized by their lengths being much larger than their diameter. According to the American Standard Test Method (ASTM), the fiber length to diameter ratio should be at least 10/1 and the cross section to be <0.005 mm [2,4].

Fibers used in dentistry can be classified in order to: the type of fiber, the orientation of the fiber, whether the fiber saturating process is preformed, and whether the material is shaped by hand or by a machine [5].

FACTORS AFFECTING MECHANICAL PROPERTIES OF MATERIAL

1. Types of Fiber

a. Carbon Fibers

The production of carbon fibers starting at the end of 1960s contained at least 90% by weight of carbon. Carbon fibers are light, chemically inert. Also tensile and compressive strengths are good. Researchers have reported that carbon fibers added inside to acrylic resin increase transverse stiffness, impact resistance, fatigue resistance, and carbon toxicity and carcinogenicity of the composite structure [6,7]. It has been stated that the use of carbon fibers placed in the acrylic resin is not suitable for use in areas where the aesthetic is important, because of their black color [7,8].

b. Aramid Fibers

Aramid is an organic compound whose polyparaphenyl-terafelamide trade name is "Kevlar". The polyaramid fiber does not need to be treated with a binding agent because its wettability is very good. It does not show toxic properties [9]. Aramid fibers with a tensile strength of 104 MPa, an elastic modulus value of 50-130 GPa and a density of 1.4 gr/cm3 have good mechanical properties. It has been reported that the continuous parallel aramid fiber increases the fatigue

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resistance and tensile strength of the acrylic resin but the aesthetic hazards can be caused because of the yellow color of the aramid fibers [10].

c. Polyethylene Fibers

Polyethylene: is the name given to all of the ethylene polymers in the natural polymer structure. It has a high molecular weight. They are durable, biocompatible, translucent, non-fragile materials. It has a density of 0.99 g / cm3 and light weight [11]. Because of its natural color, low density, biocompatibility and hydrophobic properties, polyethylene can be preferred as a reinforcing material in acrylic resins [12].

It has been reported that the addition of polyethylene fiber to acrylic prosthetis enhances the transverse strength of PMMA, as it has higher impact strength, lower modulus of elasticity, and lower bending strength than polyethylene used in strengthening acrylic prosthesis [12,13]. However, polyethylene fiber reinforced materials have a rougher surface than other fiber types, plaque accumulation is reported to be higher [14].

d. Glass Fibers

The glass contains silica sand (sand containing 50% excess SiO2), limestone (CaCO3), aluminum hydroxide, boric acid, sodium sulphate and anhydrous borax. In the first stage of glass fiber production, it melts together with the mentioned materials by heating to 1500 – 1700^{0}C. The glass fibers are cooled to obtain fibers with diameters ranging from 5 to 24 µm. E, C, R, S, T glass fibers with different properties can be prepared by changing the composition of the ingredients in the content. Glass fibers have good resistance to flame and heat. They are not affected by microorganisms, they have high density (2.5 g / cm3). They are not affected by humidity and their mechanical properties do not change in wet and dry environments, but they are fragile and not flexible [9,15,16].

Generally, E type glass fiber used in dentistry [16]. E type glass fibers have good insulation property, is not cytotoxic, wear resistant in water and alkalis and aesthetic. It has been reported that glass fiber added into acrylic resin improves the transverse strength, flexural modulus, fatigue and impact resistance of acrylic resin [17], better adhesion to polymer matrix when treated with surface silane [16]. Nagakura *et al*. [18] showed that the glass fiber reinforced thermoplastics (GFTRP) showed clinically acceptable color stability and might be satisfactory for clinical use.

A good adhesion between the polymer matrix and the fiber must be ensured so that the resins can be reinforced with the fiber. The fiber, which does not contain a physical or chemical bonding agent, acts as a foreign agent in the resin. Instead of strengthening, it weakens the resin. Glass fibers without silanes can disrupt the homogeneous matrix structure. It has been reported that silane agents, which chemically bind glass fibers to resin matrix, strengthen the acrylic resin by making the mixture more homogeneous [19]. For this reason, when the prosthetic acrylic base resins are reinforced with glass fiber, silane application to the fiber surface is recommended to increase the connection between the fiber and matrix [16]. Solnit [20], has reported that if the acrylic resin is mixed directly with the glass fiber surfaces without the use of a binding agent, the fibers behave like a foreign body to weaken it rather than strengthen it.

e. Nylon Fibers

Nylon fibers are polyamide fibers. Polyamides are high molecular weight thermoplastic polymers. The differences in the crystalline content of polyamides increase resistance and reduce their transparency. Polyamides are resistant to high strength, elasticity, hardness and abrasion. They maintain good mechanical properties at high temperatures. At low temperatures, fracture toughness and bending strength are high. The polyamides are resistant to solvents [21]. The aesthetic and mechanical properties of polyamide fibers which are used frequently in dentistry are good. For this reason, studies have recently been carried out in which nylon 6.6 and nylon 6 fibers are added to the acrylic base to improve the properties of the prosthetic base materials [22,23]. Polyamide based prosthetic materials can be used in patients with PMMA resin allergy or where flexibilisation is desired. The most important advantage of the polyamide based prosthetic materials is the presence of shock absorption resistance and resilience for repetitive stresses [24]. Stafford *et al*. [25], reported that polyamide 12 base resin had the highest bending property in the conventional denture base materials and polyamide 12 based prosthetic base material in the bending strength test, no fracture occurred during loading.

f. Polypropylene Fiber

Polypropylene fibers (pp) are olefinic fiber types. The high durability, low cost and excellent biocompatibility of the fiber also allows surface polishing. Because the fibers used in the strengthening of the PMMA did not spread homogeneously and there were gaps in the resin-fiber linkage, there remained perforated areas on the surface. This problem was solved by increasing surface energies by applying chemical or plasma treatments to polypropylene fibers, resulting in a homogeneous resin-fiber bond. It is stated that the resin reinforced with polypropylene fibers, which is not surface treated, exhibits very high impact strength and surface hardness compared to unreinforced resin. Plasma treated polypropylene fiber reinforced resin showed statistically high surface hardness compared to the control group (fiber unreinforced resin), but due to the plasma treatment, the hydrophobic surface of polypropylene fibers was converted to a hydrophilic surface, thereby water absorption increased [26]. Mowade *et al*. [27], investigated the impact strength values of PMMA reinforced with different fibers and reported that plasma-treated polypropylene fibers had high impact strength. In the study, the impact resistance values were reported respectively as plasma treated polypropylene fibers, plasma treated polyethylene fibers, untreated polypropylene fibers and glass fibers. A recent study found that incorporating silanized polypropylene fiber in heat-cured PMMA resin significantly improved its transverse, tensile, and impact strengths, but its wear resistance was highly decreased [28].

2. Fiber Form and Direction

The fiber form and direction affect the mechanical properties of the obtained material. According to the physical forms of fiber systems: continuous unidirectional / parallel fibers, short / chopped fibers, woven / mesh and finely grounded particles. Typically, the fibers are 7-10 µm in diameter and in the length of the prosthesis or the site of the prosthesis. Particles used in standard dental composites are 1-5 µm in diameter or submicron size and are in millimetric length [29]. The most popular ones are parallel fibers which run parallel to each other in one direction and are followed by mesh and woven fibers [2]. Depending on the configurations and orientations of the fibers, the areas of clinical use are changing. Huang *et al*. [30] showed in their study that the strip fibers showed better mechanical behavior than mesh fibers and were suggested for resin-based composites restorations reinforcement: however, different polymerization methods did not have a significant effect on the strength and failure mode of fiber-reinforced resin-based composites.

3. Saturation of Fiber With Resin (Impregnation)

The greatest difficulty in using fibers in partial prostheses was that the prosthetic base material could not be adequately saturated with the polymer during the application of the fibers.

In dentistry, fibers can be made ready for use by two methods:

a. Unsaturated fibers: such fibers should be wetted with the fourth or fifth generation bonding agent, which is absolutely free of fillers, before use. The bonding agent containing the partial filler should not be used because it is more dense. Although unsaturated fibers do not show a good adhesion between the resin matrix and fiber, it is a fact that they have a longer lifetime clinical use and are more durable than other glass fibers. However, when they meet with moisture, these properties are rapidly decreasing.

b. Saturated fibers: saturated fiber concept provides the fiber's ability to achieve immediate durability and high resistance. The saturating of the fibers is achieved by the manufacturer in a controlled way during the production of the fibers to the resin [31].

As a result of unsatisfactory saturation, the mechanical properties of fiber-reinforced materials may be impaired with increased water absorption. As a result, porosity formation and penetration of oral microorganisms in the areas where unsaturation is insufficient may result in discoloration. This can lead to insufficient polymerisation, increased residual monomer content and reduced durability of fiber-reinforced materials [32]. Tabatabaei *et al*. [33], report that color stabilizations are more acceptable after accelerated aging compared to unsaturated fiber-reinforced materials for composites reinforced with saturated fibers.

4. Fiber Quantity and Volume

The strength of fiber-reinforced materials depends on the volume of fiber in the matrix. It is stated that when the fiber amount is increased in the studies performed, the transverse and impact resistance of the acrylic resin polymer matrix is also increased [11,34,35]. High density glass fiber has high mechanical resistance [36]. Generally, the fiber volume ratio in glass fiber reinforced resin composites is high (up to 60%), but in dentistry the fiber ratio is relatively low. This is because the glass fiber must be coated with a polymer layer without filler or with a particulate filler composite layer. Lassila and Vallitu [37] and Callaghan *et al*. [38], have investigated the wear behavior of glass fiber reinforced resin composites with different fiber volumes in different concentrations. It has been reported that a sample of 7.6% by weight glass fiber results in a low matrix fiber cluster with too much fiber content. High concentrations of glass fibers can lead to premature fiber breaks in addition to significant fiber breakage. The ideal abrasion resistance is between 2.0% and 7.6% by weight for the ideal fiber quantity matrix.

5. The Position of the Fiber In The Restoration

The fibers should be placed in the region where the tension is most intense. In this way, fracture can be prevented in the restoration. When fiber-reinforced restorations are being made, adequate space should be left for the composition for proper aesthetics, and stress-intensified zones should be fiber supported. The placement of the fibers where the tension is greatest ensures that the initial and final fractures of the restoration can be avoided [39]. In the studies conducted with the end-effectors stress analysis, it was seen that the most stressed support tooth in the three unit bridges was at the connection with the body facing the toothless space and the gingival side facing the tissue [40]. In another study done with finite element analysis, it was seen that the most stress accumulation in the inlay bridges was in the cervical margins and connection areas of the prepared inlay cavities [41]. It has been reported that the correct positioning of the polyethylene fiber implant and in the complete denture is important in the finite element analysis study and the fracture strength is increased [42].

6. Matrix Adhesion of Fibers

The polymer matrix with the fibers is held together by covalent bonds. These bonds provide adhesion and transfer of stresses to the matrix fibers. Silane agents are used in the development of adhesion between polymer and glass fibers [43]. The good connection between the fiber and the matrix is effective in dissipating incoming forces. The force is transmitted to the strongest fiber zone so that fiber can be used as a reinforcer [44]. When there is a problem with fiber-matrix adhesion, the first fractures occur in the affected area and the material breaks [45]. For dental applications, acrylic based polymers such as polyurethane, polycarbonate and bisphenol-A glycidyl methacrylate (bis-GMA) and polymethylmethacrylate (PMMA) are reinforced with glass fibers and silanized to increase the chemical adhesion between the fibers and the polymer matrix [46]. It is difficult to increase the fiber concentration correctly for a number of reasons: the acrylic yarn may be squeezed while the fiber is pressed, the fiber may not be sufficiently wetted with acrylic liquid, and the polymerization shrinkage ruptures the acrylic resin layer on the fiber surface, so that the fiber polymer can not bind matrice. One of the main concerns about clinical life is the quality of adhesion between glass fiber reinforced composites and other polymer matrix, mainly due to the deformation behavior resulting in excessive stress accumulation near the interface of the double material and the significant differences between the other composites. The interface forces holding the two components together may be caused by Van der Waals forces, without chemical bonding, by electrostatic interaction or by mechanical locking. Adhesion bond strength is significantly related to bond type, adhesive viscosity, chemical composition and mechanical properties of bonded substrates. Moreover, since the determination of any adhesion strength involves the measurement of fracture stress, the stress state plays an important role throughout the entire adhesion joint [47].

The physical, mechanical, biological and chemical properties of the fibers greatly affect the properties of the materials they are added to. Water absorption and dissolution, thermal expansion linear coefficient, and polymerization shrinkage affect physical properties of the fibers. Flexural strength, fracture toughness, fracture resistance, and transverse resistance are efficient factors to influence mechanical properties of them. As in point of biological properties, cytotoxicity and allergic reactions were caused by the fibers are take into account when considering material type. Chemical properties of the polymer products are highly influenced by monomer-polymer conversion.

FIBER APPLICATIONS IN PROSTHETIC DENTAL TREATMENTS

a. Prosthetic Treatments For Tooth Deficiencies (Single Tooth / Multiple Tooth Defects)

It is a great convenience to apply fiber-reinforced material in the chairside treatment. Among the previous treatment options, crowns of teeth or acrylic resin teeth were stuck with a resin composite using lingual wire or without lingual wire. These applied to the existing dentures with using acid and bond technique and then fixed with the composite. The abutment teeth used were usually made without preparation. A short-term solution was provided with this method.

Fiber-reinforced restorations have become a treatment approach requiring a faster, minimally invasive approach and utilizing all the aesthetic, functional, and long-term availability of fiber-reinforced material. Natural teeth (extracted due to periodontal causes) or acrylic teeth can be used as the body. Selection criteria for this system to replace the missing tooth [29]: the patient needs a quick and minimal treatment approach, immediate restoration request of the patient in the aesthetic area after extraction of tooth, long-term prognosis of the abutment teeth is not good, anterior disarticulation conditions during mandibular protrusion movements, patients without bruxism and patients with price concerns.

Perea *et al*. [48], investigated how the load-bearing capacity of a fixed bridge restoration system is improved by reinforcing with fibers and increasing the thickness of the body. It is known that the fiber-reinforced ceramic fixed restorations have a high load-bearing capacity as the body thickness increases. They have reached a higher load-bearing capacity than ceramic bodies.

In another study, Aktaş *et al*. [49], investigated the effect of different cavities on fracture strength in fixed prosthetic restorations made in the anterior region and found that the cavity difference did not make a statistically significant difference in the fixed restorations made of glass fiber reinforced materials and that the fracture strength of elongated regions in the cantilever prosthesis was lower. In the data obtained from the samples, they stated that the most prominent failure type is the composite separation.

Araujo *et al*. [50], have shown that porcelains obtained by the use of fiber reinforcing and heat pressing techniques in their work increase the mechanical properties and reduce the porosity on the porcelain compared to porcelains with or without sintered metal and show that it is a system that can be used to strengthen inlay, onlay and veneers.

b. Strengthening of Partial Dentures

Polymethyl methacrylate-based acrylic resins have been used in the manufacture of complete dentures for approximately 80 years. The prostheses that the acrylic resins used as the base material have many advantages such as aesthetics, surface smoothness, low water absorption and reasonable price but the mechanical properties are low. Inadequacy of the mechanical properties of the base resins, low fracture, and fatigue may cause frequent complaints of prosthetic fracture in patients' removable prosthesis [51]. Prosthetic fractures usually result in small bending stresses that spread over a long period of time, are repeated continuously and eventually break [52].

Karacaer *et al*. [53] reinforced the prosthesis of patients complaining of midline fracture with very high modular braided polyethylene fibers and stated that no cracks or fractures were observed even after 18 months of clinical observation.

Kostoulas *et al*. [54] have stated that the most effective method of strengthening acrylic resins is to add unidirectional glass fiber and strengthen with autopolymer resin. The fracture strength according to the unstrengthened group was significantly lower than that of the strengthened group at flexure and flexure toughness. Venkat *et al*. [55], in their study of prosthetic repair, reported that high mechanical properties were achieved by the reinforcement of polymethylmethacrylate resin with polyethylene fiber.

Atiyah *et al*. [56] reported that the different sizes of palatal vault shapes and acrylic resin materials reinforced with braided type glass fiber affect the linear dimension variation of each other, whereas Dalkız *et al*. [57] stated tha the use of palate shape and fiber reinforced acrylic resin did not affect the dimensional change.

Ribbond (polyethylene) plasma is produced with a cross link lero-stitch special form in strips 1-2-4-10 mm width. Ribbond 4 and 10 mm forms on very high molecular weight polyethylene fiber structure were produced to strengthen prosthetic bases [13,58,59]. There are also polyethylene fiber systems, such as Dyneema polyethylene fibers (Holland), Spectra system (USA) and Connect (USA), which have been prepared in woven form and modified with cold gas-plasma application on the surface [58].

Continuous parallel aramid fiber (Kevlar) acrylic resin has been reported to increase durability with fatigue resistance. It has been stated that by adding 20% by weight of aramid fiber acrylic resin, the durability is increased by 200%. However, aramid fibers are not as aesthetic as carbon fibers [10]. Nowadays they are not used to increase the durability of complete dentures.

Agha *et al*. [60] reported that placement of the glass fiber close to the tensile stress side surface of the bar increased the resistance to elastic deformation and the stress level needed for flexural fracture. In addition, more energy was absorbed by reinforced specimens before fracture occurred.

Yu *et al*. [61] stated in their study about reinforcing effect of glass fiber mesh on complete dentures, the glass fiber mesh groups showed higher fracture load and toughness than the unreinforced control group.

In the study of the effect of the silane applicator, it was observed that silanized glass fibers incorporated in continuous parallel form into 7.39 wt.% glass, 2.08 wt.% carbon and 2.3 wt.% aramid fiber acrylic resin significantly enhanced acryl resistance [62].

Reinforcement of PMMA with different combinations of fiber types with different metal oxides and ceramics, and fibers with metal oxides, or ceramic materials. Hybrid fiber reinforcement significantly increased the flexural strength and toughness of reinforced acrylic resin. In addition to improving surface roughness, tensile strength, flexural modulus, hardness, and thermal conductivity, and radiopacity as well as reducing shrinkage, it has antibacterial properties without showing cytotoxicity [63]. Nagakura *et al*. [64] developed non-metal clusp denture materials made from E-glass fiber-reinforced polyamide-6 and showed in their study that the density and flexural properties of GFRTP were greatly improved by changing the fiber content of the GFRTP.

c. Repair of Broken Facets In Fixed Prosthetic Restorations

There is little chance of long-term success, especially since it is difficult to attach to the fractured surface of the repair material in case of large fractures that have been exposed to the metal substrate. To overcome this problem, the idea of strengthening the repair material with glass fibers in the form of a net has come to the forefront. Mechanical retention is increased by the use of filler composite and fiber layer in the repair of the facet [65]. Turkaslan and Mutluay [66] reported that 1.5 mm diameter glass fiber was added to the Empress 2 material with a bending strength of 407±45 MPa, which increased it to 1144±99.9 MPa, with the addition of fiber changing the direction of the progress of the fracture or progressively slowing down. Fractured facet repair with fiber attachment is an easy application that has low cost, reduces the time spent nearby the patient and satisfies the patient esthetically.

d. Application In The Connection Interface of The Restorations:

The ability to bond the fiber-reinforced material to the tooth depends on the strength of the fiber-reinforced material and the connection between the restorative material and the fiber-reinforced material. Stresses or cracks in the restoration are stopped or changed the directions by the fibers [43]. When fibers with different directions are used in the restoration interface, by changing the dynamics of the link interface, it reduces the stresses on the interface during loading and can cause link failures to occur on different surfaces (in the fiber reinforced composites instead of the restoration-thread interface).

It has been reported that studies on evaluating the effects of restorations on bonding strength of composite resin, amalgam, ceramics, laminate veneer restorations and glass fiber placement on the tooth interface did not increase the bonding strength of the fiber in the interface but changed the fracture type in restoration or in dentition and could strengthen tooth structure or restoration [67-70].

e. Post-Core Restorations

Simple, fast, high resistance, direct and inexpensive restorations should be performed to ensure success in root canal treatment. Adhesive technology is evolving day by day and the restorations that can meet conservative and high esthetic expectation are directly adhered to the tooth. Teeth are restored by supporting intra coronal post structure with composite resin material in the root canal treated teeth with low fracture strength. Strengthening the composites with fiber materials increases the fracture strength.

Fiber reinforced composite (FRC) posts are used to strengthen the core. Previously metal cast post and cores, prefabricated metal and zircon posts were used. FRC posts that have higher bending strength and higher fatigue resistance, close to elastic modulus of dentin, stick to the root canal system to form a one-piece complex structure, and increase the aesthetic when used with full ceramic crowns. The aim is to support the root part, to distribute the incoming forces evenly, and to prevent the formation of root fractures. Fiber-reinforced posts have elasticity modulus of about 20 GPa, cast metal alloy posts and prefabricated metal posts are about 200 GPa, and ceramic posts have an elasticity modulus of about 150 GPa. Thus, fiber posts have similar mechanical properties to natural dentin (having a flexural modulus of about 18 GPa). Akkayan and Gülmez [71] have shown that the teeth restored by fiber show positive and repairable fractures, and that titanium and zirconia posts bring tooth irreparable fractures to the teeth. Habibzadeh *et al*. [72] pointed out that fiber-glass posts with composite cores showed the highest fracture resistance values (915.70±323 N), Ni-Cr casting post and cores was reported as 780.59±270 N and the zirconia post system showed the lowest resistance (435.34±220 N). The fracture resistance of zirconia post-and-core systems was found to be significantly lower than those of fiberglass and cast Ni-Cr post systems.

Seefeld *et al*. [73] compared the fragility and structural properties of different fiber posts. In the study, bending strength over 800 MPa was seen in most fiber-post types, but only one of the bends showed bending strength below 565 MPa. Rigid metal posts: forces transmit a long axis of the tooth, creating a wedge effect on the tooth structure. Fiber posts with a modulus of elasticity similar to that of dentin, however, significantly overcome this. In cases where endodontic treatment is required to be done again, fiber posts allow the dentist to provide further treatment options by removing the posterior part from the canal without performing tooth extraction.

The glass fiber posts are the first to be used in clinical use because of the fact that glass fiber posts can be used in a wide range of teeth, good connection to the channel, good retention with resin material [74]. Fiber-reinforced posts consist of resin matrix with saturated carbon fiber or glass/quartz fiber. Black carbon fiber reinforced composite posts are poorly aesthetized when used in translucent full ceramic restorations due to poor optical properties. Cloet *et al*. [75] compared the clinical outcomes of prefabricated glass fiber posts, custom-made glass fiber posts and gold cast posts and cores (control). After 5 years of follow-up success probabilities were 81.6% for fiber posts, 87.8% for custom-made posts and 86.9% for the control, while the survival probabilities were 91.4% for fiber posts, 92.1% for custom-made posts and 91.2% for the control group, without statistical differences.

The good optical properties of fiber posts (glass and quartz fibers) such as the reflection of light like natural teeth, increase the success of full ceramic restoration. At the same time, the dentin walls are supported by plastic composite construction, as it is a procedure that does not damage the remaining dental structures. Furthermore, the underlying areas can be stored and used as plastic composite restorations as areas of additional retention [29]. The fiber posts used should be cementated to the root canal system with either dual cure or self cure resin based cements [74,76]. It is stated that fiber post cementations made with self-adhesive resin cements require less technical precision and achieve higher success [77].

Surface treatment with hydrofluoric acid or aluminum oxide particles is recommended *in vitro* to improve the adhesion of fiber posts (except Everstick post) to the resin core material [78]. In another study, it was evaluated how surface treatments using laser technology affected the light transmittance of fiber posts and noted that there was no negative effect on light transmittance, unlike surface treatments with hydrofluoric acid or sandblasting [79]. Elnaghy *et al*. [80] showed that the use of M10 (etching with CH_2Cl_2 for 10 min) as a surface treatment to methacrylate resin- based glass fiber post improved the adhesion between the fiber post and dual-cure self-adhesive luting agent. On the other hand, hydrofluoric acid etching and airbone particle abrasion treatments compromised the adhesion of fiber posts. The surface treatments performed did not compromise the flexural properties of the fiber posts.

Aksornmuang *et al*. [81] studied fiber post surface etching using hydrofluoric acid and hydrogen peroxide with various alternative protocols and pointed out that no adverse effects on the flexural properties were found for three tested types of commercially available fiber post.

There was no significant difference in the study of glass fiber and metal post compared to primary teeth with large tissue loss [82]. In another study, it was stated that the aesthetic success was increased by the use of polyethylene fiber post in the primary teeth with large tissue loss, and post retentions were sufficient during the 30 months of observation [83].

Sungur *et al*. [84] pointed out in their study about the reinforcement of the core part in the post systems: reinforcement with fiber chips showed the highest fracture resistance and 50% retrievability, while no reinforcement showed the lowest fracture resistance with 62.5% retrievability. It can be concluded that the use of fiber chips may be an effective and practical method for reinforcement of the core material.

f. Short Fiber Reinforced Restorations:

Particle filling composite resins predominantly used in the anterior regions but now can be used not only in postendodontic applications, but also in full crowns and fixed prostheses, because particulate filler composite resins enhance the mechanical properties.

Short fiber reinforced resins were introduced as dental restorative composite resins. Composite resins are intended to be used especially in high stress areas.

According to the results obtained from laboratory mechanical stress tests, it is stated that the load lifting capacity, bending strength and fracture toughness of composite resin reinforced with short glass fiber fillers are superior to those of conventional composite resin composites. Polymerization shrinkage is controlled by fiber distribution in short fiber reinforced composite resins. Thus, marginal micro-sealing is further reduced compared to conventional composite resins. Hypothesis can be made that fiber-reinforced composite structures in particle filling composite resins improve static loading capacity [29]. In the study, it was stated that short fiber reinforced composite resins showed successful clinical performance in the areas of high stress where they were used as support in the base of the cavities with composites containing occlusal cavities filler, and no fracture occurred in the restoration [85]. Sharafeddin *et al*. [86] worked out the effect of short polyethylene fiber with different weight percentages on diametral tensile strength of conventional and resin modified glass ionomer cements, and pointed out that the polyethylene fiber was shown to have a significant positive influence on diametral tensile strength of two types of glass ionomers.

g. Usage as Implant Material and Implant Superstructures:

Clinical trials have shown that one-way FRCs can be used in implant superstructures [87,88]. The implant prosthesis materials must be biocompatible with the tissue, be precisely connected to the implant system, have adequate mechanical resistance, be aesthetically pleasing and cost effective. When metal-alloyed frameworks are prepared in implant-supported overdenture prostheses, the time spent in the lab increases, opaque material must be used for the framework, metal corrosion risk occurs, and potential toxicity of Cr-Co and Ni-Cr alloys arises. With the use of fiber, these disadvantages are eliminated. The fiber-reinforced composite is chemically and mechanically bonded to the framework resin and increases the flexural strength of the prosthesis resin [89]. Menini *et al*. [90] pointed out that carbon fiber-reinforced implant supported overdenture frameworks exhibit very high mechanical properties compared to the metal substructures and that the carbon fiber biocompatibility is good. Li *et al*. [91] stated at their study that the addition of carbon or glass fibers between two abutments in the All-on-Four provisional fixed denture base resin may clinically increase the fracture resistance significantly.

Bergendal *et al*. [92] it has been found that the carbon fiber supported PMMA framework in the restoration of hybrid type prostheses showed 70% success in clinical trials with a mean of 44 months.

In another study comparing titanium (ITI) implant superstructures with Vectris FGK (Ivoclar Vivadent) superstructure, FGK implants were found to have lower fracture resistances than the superstructures placed on the titanium superstructure (1300 N) was reported to be sufficient for clinical application [87]. In the study, it was stated that acrylic resin added glass fiber increased the fracture strength in implant supported overdentures using thin layer acrylic resin [93]. Aktaş *et al*. [94] pointed out that fracture resistance is increased by reinforcing the broken acrylic resin on the implant with bi-directional glass fiber. Bassi *et al*. [95] have shown that glass fiber-reinforced abutments exhibit higher fracture and deformation resistance than titanium abutments and that fiber-reinforced abutments absorb transverse loads due to flexural capacity and reduce stress on the implant-bone interface. It was emphasized that glass fiber-reinforced abutments could be used in patients with parafunctional habit, such as bruxism or grinding.

Mechanical tests are performed on the use of glass fibers as implant material, the biocompatibility and osseointegration in soft tissue and bone are evaluated by animal studies [43,96].

CONCLUSIONS

The fibers are biocompatible, have high modulus of elasticity, fracture strength and high tensile-compression strength reinforcing biomaterials. In addition to natural and aesthetic images, these structures possess the characteristics of adhesives when missing teeth are placed in their places. Their resistance, aesthetic and adhesive properties make fiber-reinforced composite restorations acceptable. In prosthetic applications, fracture formation can be reduced, resistance can be increased and restorations can be made with their negative features removed. *In vitro* and *in vivo* fiber reinforcement studies are needed to better understand in use and limitations of fiber in clinical practice.

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