International Journal of Scientific Research and Management (IJSRM)
||Volume||10||Issue||03||Pages||MS-2022-41-48||2022||
Website: www.ijsrm.in ISSN (e): 2321-3418
DOI: 10.18535/ijsrm/v10i3.ms03

Fiber Reinforced Composite a forgotten sword in prosthodontics

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Abstract

Prosthodontics is a constantly evolving branch of dentistry as a result of innovative treatment options based on new materials, treatment techniques, and technologies, with composite material revolutionised everything. With the advent of fiber reinforcement, it has further increased the potential uses of composites within dentistry. Fiber reinforced materials have highly favourable mechanical properties and their strength to weight ratios are superior to those of most alloys. When compared to metals they offer many other advantages as well, including non-corrosiveness, translucency, good bonding properties and ease of repair. They also offer the potential for chairside and laboratory fabrication. This article describes the use of fiber reinforced composites in Prosthodontics and also in other disciplines in dentistry.

Introduction

Composite resin material has completely revolutionized the field of dentistry and have now become the material of choice of most clinicians. The earliest work to use fibre reinforcement in clinical dentistry began more than 60 years ago. In the late 1960s, researchers sought to reinforce polymethyl methacrylate (PMMA) dentures with glass or carbon fibres.[1] Some of the earliest of these experimental preimpregnated fiber-reinforced composites (FRCs) designed for dental applications were based on glass-reinforced thermoplastics by Goldberg et al. [2] in the year 1994. Fibre-reinforced composite restorations are resin-based restorations containing fibres aimed at enhancing their physical properties. This group of materials is a very heterogeneous one depending on the nature of the fibre, the geometrical arrangement of the fibres and the overlying resin used. The fibres within the composite matrix are ideally bonded to the resin via an adhesive interface The resin matrix acts to protect the fibres and fix their geometrical arrangement, holding them at predetermined positions to provide optimal reinforcement. The interface between the two components plays the vital role of allowing loads to be transferred from the composite used to replace missing tooth structure.

Review of Literature

In 1994, Altieri et al [3] evaluated the use of preimpregnated glass-reinforced polycarbonate as the framework for acid-etched fixed partial dentures (FPDs).[2] Fourteen 3 unit restorations were placed both in anterior and posterior regions using adhesive techniques and without tooth preparation. On evaluation after 9 years showed that, three restorations were still in service. Rest all 11 failures were associated with separation in the region of the tooth restoration interface indicating the need for adequate mechanical properties of FRCs for use in prosthodontic applications. These problems were addressed by switching to bisphenol glycidyl methacrylate based resin as the matrix for the FRCs.

In 1997, Samadzadeh et al. [4] studied the effect of the addition of high modulus polyethylene fibers on the fracture resistance of FRC. They concluded that the fracture resistance remarkably improved with addition of polyethylene fibers.

In 2002, Freilich et al. [5] evaluated 39 light and heat polymerized fixed partial bridges made with a substructure of preimpregnated, unidirectional FRC, veneered with a hybrid particulate composite. Each of the prosthesis was assessed for surface integrity, anatomical contour, marginal integrity, and structural integrity. The results showed that survival was associated primarily with substructure design volume. The survival rate was 95% for prostheses made with a high-volume substructure, when patients with severe parafunctional habits were excluded. This study shows that a unidirectional, preimpregnated FRC can be used successfully to make bridges of variable retainer designs that last up to 4 or more years when a high-volume substructure is used.

In 2003, Li et al [6] studied the mode of failure and failure locations of the direct FRC dental bridge structures with and without adjacent teeth. The experimental results proved a good agreement with the clinical observations. It was found that the bonded interface is indeed the weakest region in the composite bridges. Also, it suggested that the composite resin reinforced with high modulus polymer fibers and the presence of adjacent teeth could significantly increase the structural strength and stiffness of the bridge and therefore improve its clinical performance.

In 2003, Li et al. [7] did a finite element study on FRC bridges. The model adopted was constructed from computer tomography images of a physical bridge specimen. The peak stresses and their variations with the different bridge designs were evaluated. The analysis showed stress concentration at the pontic-abutment interface, which resulted in failure at the interface. The numerical analysis of the bridge structure revealed that a high stress concentration occured around the incisal portion of the adhesive interfaces between the pontic and abutment.

In 2005, Visser and Rensburg[8] did a study to review FRC as an alternative to tooth replacement. Since it wasn’t necessary to prepare adjacent teeth, so it made more sense to conserve as much tooth structure as possible. Additionally, as this technique is reversible it allows other restorative options to be evaluated at a later time. They concluded that these restorations offered a viable alternative to more expensive fixed or removable prostheses.

In 2008, Shinya et al [9] studied the stress distribution in anterior adhesive fixed dental prosthesis and at tooth/framework interface. The design of FPD consists of retainers in maxillary central and canine and pontic lateral incisor. Two different materials were compared: Isotropic Au-pd alloy and anisotropic continuous unidirectional E-glass FRC. A three-dimensional FE model of 3 U FPD with 154 N loading was analyzed to determine the stress distribution at FPD and adhesive interface. The general observation was that the FRC-FPD provided more even stress distribution from the occluding contact point to cement interface than did metal-FPD.

In 2010, Matheus et al [10] used optical coherence tomography (OCT) compared to scanning electron microscopy and optical microscopy to evaluate qualitatively crack propagation and final fracture in restorative composite materials with fiber-reinforcement after cyclic loading. The failures were analyzed using the three methods described. OCT permitted good characterization of internal crack propagation. The results indicated that the deformation occurred in the dental composite and fiber in the direction of the force.

E-glass fiber (“E” stands for electric) is a recent advancement in FRC. E-glass fiber is made of aluminoborosilicate glass with less than 1 wt% alkali oxides. Recent studies by Zhang and Matinlinna in 2011 have proved that E-fibers are able to maintain strength properties over a wide range of conditions, they also concluded that these fibres are relatively insensitive to moisture and also chemical-resistant.[11]

Physical and Mechanical Properties

FRCs are structural materials that have at least two distinct constituents. The reinforcing component provides strength and stiffness, while the surrounding matrix supports the reinforcement and provides workability. One of the constituents may be metal, ceramic or polymer; in dental applications, polymeric or resin matrices reinforced with glass, polyethylene or carbon fiber are most common. The fibers may be arranged in various configurations: unidirectional fibers-long, continuous and parallel are the most popular, followed by braided and woven fibers. Typically, fibers are 7 to 10 nm in diameter and span the length of the prosthesis or appliance toughness, as well as other mechanical properties.[12] However, an increase in fracture toughness can be achieved by adding reinforcing fibers to a polymer to prevent or slow down crack growth.

The type of fiber used to make an FRC depends on how it is intended to be used and the characteristics that are needed for that purpose. Glass fibers of various kinds are commonly used in dental lab products, while polymeric reinforcements, such as polyethylene, are often used for chairside applications. Posts are made of carbon or glass fibers. Table 1 lists the types of fiber and architecture found in various products; products are classified according to their clinical uses and whether the fiber bundles are pre-impregnated with resin by the manufacturer or resination is required by the dentist or laboratory technician. Dental manufacturers use only standard industrial fibers; however, there is wide variation between products in fiber surface treatments, methods for incorporating the fibers into the polymeric resin, and chairside and laboratory processing methods.

Product	Company	Fiber type	Fiber Architecture
Pre-impregnated dental laboratory products			
Fibrekor	Jeneric / pentron	Glass	Unidirectional
Vectris pontic	Ivoclar	Glass	Unidirectional
Vectris frame and single	Ivoclar	Glass	Mesh
Preimpregnated chairside products			
Splint-it	Jeneric / pentron	Glass	Unidirectional
Splint-it	Jeneric / pentron	Glass	Weaved
Splint-it	Jeneric / pentron	Polyethylene	Weaved
Impregnation required, chairside products			
Connect	Kerr	Polyethylene	Braid
DVA fibers	Dental ventures	Polyethylene	Unidirectional
Fiber-splint	Inter dental distributors	Glass	Weave
Fiber flex	Biocomp	Kevlar	Unidirectional
Glasspan	Glasspan	Glass	Braid
Ribbond	Ribbond	Polyethylene Leno	Weave
Pre-impregnated prefabricated posts			
C-post	Bisco	Carbon	Unidirectional
Fibrekor	Jeneric / pentron	Glass	Unidirectional

Table 1: Classication of fiber-reinforced composite Dental products

Water Sorption - Water sorption of material includes both water adsorbed on the surface and water absorbed into the body of the material during preparation and while the material is in service. Polymethylmetacrylate (MMA) absorbs water because of the polarity of the water molecule and because it is smaller than the interchain distance in the polymer. The volume of water uptake by a polymeric material is determined by polymer structure, the content of various polar and hydrophilic groups in the polymer structure, temperature, concentration of various additives, presence of voids within the matrix, physicochemical, and mechanical properties can be affected by absorbed water.[13]

Flexural Strength - These materials are often tested in the laboratory, although the mode of failure and many other properties affect clinical performance. Researchers emphasize the importance of fatigue and fracture toughness in predicting the clinical performance. It is important to note that test methods, procedures for preparing the samples, and, in particular, the geometry of the test specimens all affect the calculated flexure strength. Flexure strength for commercial laboratory processed FRCs may range from approximately 300–1000 MPa, depending on the specimen preparation and geometry.[14]

Linear Coefficient of Thermal Expansion - The variation of the coefficient of thermal expansion between different materials is important because a mismatch can lead to strains, resulting in stress formation and adverse effects on the interface. Therefore, thermally induced strains and stresses adversely affect the long-term stability of intraoral multiphase materials. By adding fibers to a polymer, the coefficient of thermal expansion decreases. In general, the thermal coefficient varies with the direction of the fibers in a composite rigid fibers appear to prevent the expansion of the matrix in the longitudinal direction, so the matrix is forced to expand in the transverse direction.[15] One of the major concerns in the development of dental materials is physical and chemical durability.

Solubility Over time - components such as stabilizers, plasticizers, monomers, residuals of initiators, and degradation products may be released to the oral environment. Thus, the quantity of such components should be as small as possible, ensuring that the polymer retains its characteristic properties and that no components adversely influence biocompatibility.[16]

Residual Monomer - Biological features, as well as mechanical properties of polymeric materials, are highly influenced by the monomer-polymer conversion. Residual monomer will alter the property and may leach out to pulp if a protective layer of base is not given.[16]

Cytotoxicity - Some substances released from materials are cytotoxic and residual monomers leached out into the oral environment may induce toxic and allergic reactions.[17]

Prosthodontic Applications

The properties of fibre-reinforced composites (FRCs) that make them well suited for various clinical applications include strength; desirable esthetic characteristics; ease of adaptability to various shapes; and potential for direct bonding to tooth structure.

Conservative treatment of missing tooth replacement

Chair side tooth replacement is an excellent application for fibre reinforcement composite technology. Previous attempts at chair side tooth replacement involved the use of pontics derived from extracted teeth, acrylic resin denture teeth with or without lingual wire reinforcement, and resin composite. These were attached to abutment teeth with acid-etched bonded particulate composite. The abutment teeth used for these approaches were usually not prepared; most often, tooth replacement was only for the anterior region and the procedure was considered a short-term solution. The chair side fibre reinforced composite prosthesis offers a fast, minimally invasive approach for tooth replacement that combines all of the benefits of the fibre reinforced composite material for an esthetic, functional, and potentially durable result. A denture tooth or a natural tooth (in the case of an extraction of a periodontally involved incisor) can be used as the pontic.

Selection criteria for this tooth replacement approach include:

1. A patient who desires an immediate, minimally invasive approach

2. A patient who requires an extraction in an esthetic area and desires an immediate replacement

3. Abutment teeth with a questionable long term prognosis

4. Anterior disarticulation during mandibular protrusive movements

5. A non-bruxing patient

6. Cost considerations

Post Endodontic Restorations: To prevent the failure of root canal treatment, a simple, quick, high strength, direct and cost effective restorative procedure may be desirable. Adhesive technology is advancing by leaps and bounds every day, making it possible to create conservative and highly aesthetic restorations with direct bonding to the teeth. A significant increase in the fracture resistance of root filled teeth was observed when they were intra coronally restored with a resin composite material. Reinforcing composites with polyethylene fibres and glass fibres has successfully provided superior resistance.

Endodontic Fibre Reinforced Composite Posts: FRC posts are a recent addition to the systems traditionally used to retain a core in severely broken down, endodontically treated teeth: custom-made metal or cast posts and cores and prefabricated metal and zirconium posts. The FRC posts offer greater flexure and fatigue strength, a modulus of elasticity close to that of dentin, the ability to form a single bonded complex within the root canal for a unified root post complex, and improved aesthetics when used with all-ceramic or FRC crowns as compared to custom-made cast or metal-prefabricated posts.[18],[19] The properties of this post design have the potential to reinforce a compromised root and to distribute stress more uniformly on loading to prevent root fracture moreover, the FRC post will yield prior to catastrophic root failure better than will custom- made cast metal or prefabricated metal post systems.[20] Two categories of FRC posts are available: chair side-fabricated and prefabricated. Chair side fabricated posts are custom designs that use polyethylene non preimpregnated woven fibres (Ribbond, Connect) or glass fibres (Glass Span) to reinforce the root and hold a composite core. 18 Prefabricated posts are constructed of two kinds of fibre: carbon fibres embedded in an epoxy matrix (C-Post, U-M CPost, and Aestheti-Post) and S-type glass fibres embedded in a filled resin matrix (FibreKor Post). [21] Fibre-reinforced composite posts consist of a resin matrix, in which structural reinforcing carbon fibres or quartz/glass fibres are embedded. Black carbon fibre-reinforced composite posts are, on the one hand, poorly suited for combination with translucent full ceramic restorations due to their unfavourable optical properties. On the other hand, carbon fibre posts also have unfavourable biomechanical properties The favourable optical properties of tooth-colored fibre posts (glass- and quartz-fibre), which are consistent with natural teeth in their ability to conduct light, facilitate the goal of esthetic, high-quality restorations when they are combined with full ceramic materials. The posts can be processed in one time-saving surgery visit that eliminates the laboratory step, due to the direct technique in combination with an adhesive composite build-up. They also permit a procedure that is gentle to the tooth substance: Thin dentin walls are stabilized by the plastic build-up composite and the composite cement. Moreover, the areas underneath can be saved and maintained as additional retentive areas for the plastic build-up composite restoration.

Repair of Acrylic Resin Prosthesis Both unidirectional and woven light-polymerized FRC strips can be used effectively for chair side repairs of fractured acrylic resin prostheses. As mentioned earlier, FibreKor (Jeneric/ Pentron) and Vectris (Ivoclar/ Williams) are unidirectional materials available for laboratory use. Splint-It (Jeneric/Pentron), another chairside material, is available either as a unidirectional or a woven fibre. All of these materials have significantly greater flexural properties than unreinforced resin. As explained earlier, woven FRC has a shorter memory than unidirectional FRC, which makes it easier to handle; however, unidirectional FRC has superior flexural properties and will likely provide a stronger repair. Virtually any acrylic resin prosthesis or appliance can be repaired with light-polymerized FRC, like complete dentures, acrylic bases of partial dentures, provisional removable partial dentures, provisional FPDs, obturators, palatal lift appliances, orthodontic retainers, occlusal splints and night guards.

Short Fibre Reinforced Composite: A New Alternative for Direct Onlay Restorations Particulate filler composite resin (PFC), at one time considered only as a treatment option for anterior teeth, has steadily been found to have wider applications. With the improvements in the mechanical properties of PFCs, their use has been widened not only to the posterior intra-coronal area, but also to extra-coronal restorations, and even complete crowns and fixed partial dentures.30 Many studies have been undertaken to investigate the filler phases, resin compositions, and curing conditions to improve the mechanical properties of PFC.[22],[23] However, further significant improvements are needed in order to extend the use of PFC to high stress-bearing applications such as direct posterior restorations involving cusps and indirect restoration, inlays and onlays.[24],[25] Recently, short fibre reinforced composite FC resin was introduced as a dental restorative composite resin.[26],[27] The composite resin is intended to be used in high stress bearing areas especially in molars. The results of the laboratory mechanical tests revealed substantial improvements in the load bearing capacity, the flexural strength and fracture toughness of dental composite resin reinforced with short Eglass fibre fillers in comparison with conventional particulate filler composite resin.[26] The short fibre composite resin has also revealed control of the polymerization shrinkage stress by fibre orientation and, thus, marginal micro leakage was reduced compared with conventional particulate filler composite resins.[28]

Implants: Dental implants have become a standard of care for tooth replacement in both partially and completely edentulous arches. Implants are routinely restored with overdentures, fixed partial dentures (FPDs), or hybrid (fixed-removable) prostheses. Short edentulous spans can be successfully restored with fiber-reinforced FPDs. Despite the short-term success that has been achieved in restoring short edentulous spans, the standard metallic or cylinder form abutment is less than ideal because of its esthetic and bonding limitations and because it has proven unacceptable for restoring a hybrid type of prosthesis.

Overdenture frameworks : Overdentures retained by implants or with attachments to natural dentition are routinely reinforced with a metal framework. This metal framework is time-consuming to fabricate, costly, unesthetic, and requires the use of alloys that can present health dangers to the technicians who routinely use them. They have developed a method for creating on FRC framework to replace the traditional metal for overdentures. This process requires no special abutments or cylinders other than those routinely used to restore an overdenture with a metal framewok

Discussion

The advantages of FRCs include lower treatment costs, single visit immediate tooth replacements, suitable for transitional and long-term provisional restorations, readily repaired and time saving. It is a completely metal free restoration with improved aesthetics and can be produced in a simple manner in the laboratory without the need for waxing, investing and casting. Also it is a conservative option which requires minimal or no tooth preparation. The studies even suggest that wear of the opposing dentition is much reduced in comparison to traditional metal-ceramic restorations. The associated drawbacks of fiber reinforced composites are wear of the overlying veneering composite material especially in patients with significant parafunctional habits. The material is not ideally indicated for long span bridges as it may lack sufficient rigidity. The clinical use of FRCs is very technique sensitive as it requires excellent moisture control required for adhesive technique. The diagnostic evaluation of case selection should be careful as space requirements are greater in posterior occlusal situations in comparison to metal occlusal surfaces so to allow sufficient space for fibres and also an adequate bulk for veneering composite overlay. The longevity of FRC prosthesis is always questionable I comparison to traditional or conventional treatment options

Conclusion

FRC prosthesis may prove to be a successful modality for fixed tooth replacement, providing the natural esthetic appearance of a metal free prosthesis and the inherent adhesive nature of polymer materials. The strength, aesthetics and versatility of these materials will allow for the development of new applications as well as the enhancement of existing techniques. The future holds great promise for FRC prostheses in all areas of clinical and laboratory procedures.

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