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Review Article

Applications, benefits, and limitations of fiber-reinforced composites in fixed prosthodontics

Ali S. Alfaer[1]*, Yahya S. Aljabri[2], Areej S. Alameer[2], Mohammed J. Abu Illah[2], Hamed A. Thubab[2], Abdulaziz Y. Thubab[2], Weaam R. Naseeb[2], Sana E. Ageel[2], Asayil K. Juraybi[2], Wejdan M. Marwahi[2], Atheer H. Khawaji[2]

[1]Department of Prosthodontic, Rabigh General Hospital, Rabigh, Saudi Arabia
[2]College of Dentistry, Jazan University, Jazan, Saudi Arabia

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***Correspondence:**
Dr. Ali S. Alfaer,
E-mail: dr.alfaer@gmail.com

ABSTRACT

This study offers a comprehensive evaluation of the efficacy, benefits, and limitations of fiber-reinforced composites (FRCs) in fixed prosthodontics. Emerging as a substitute for conventional dental materials such as metals and ceramics, FRCs are now used in a variety of applications, from dental crowns and bridges to veneers. The study is based on an exhaustive literature review and explores various properties of FRCs, such as mechanical, optical, viscoelastic, adhesive, and thermal attributes. The strength and rigidity of constructions made from FRC are dependent on the polymer matrix of the FRC and the type of fiber reinforcement. In dental appliances of relatively small sizes, the quality of the load bearing FRC sub-structure is very important. A special emphasis is placed on the clinical applications and future potential of these materials. The advantages of using FRCs include their biocompatibility, light weight, durability, and aesthetic superiority. However, there are limitations, such as higher costs and concerns about long-term clinical performance, specifically related to interface degradation. The study concludes that FRCs hold significant promise in the domain of fixed prosthodontics, although further research is needed for optimizing their long-term effectiveness.

Keywords: Efficacy, Benefits, Limitations, Fiber-reinforced composites

INTRODUCTION

Traditional dental materials such as metals and ceramics, aside from their several properties, have several disadvantages, such as significant damage to dental tissues caused by grinding to make space for metal and ceramic crowns and fixed dental prothesis. There have also been concerns about releasing metal ions from restorations, which can be potentially harmful.

Conversely, the fields of restorative and prosthetic dentistry have shifted towards using adhesively secured restorations more frequently instead of solely depending on mechanically interlocked methods for restoration.[1] Fiber-reinforced composites (FRCs) are a novel group of dental materials characterized by non-metallic, fibrous fillers that are being increasingly used in place of traditional prosthodontic materials. Dental FRCs have been studied and developed since the 1960s.[2] FRCs allow the use of minimally invasive adhesive tooth-colored restorations with light weight but durable and biocompatible materials. FRC consists of a polymer matrix blended with reinforcing fibers, as shown in Figure 1.

When pressure is exerted on the composite material, the fibers serve as the component that provides reinforcement. This force is then distributed to be supported by these fibers.[3]

These reinforcing fibers can vary in their arrangement: they can be aligned in a single direction and continuous (known as rovings), woven in two directions and continuous (known as weaves), continuously arranged in a random fashion (referred to as mats), or short and randomly placed.

Of the many types of fibers available, those that have proved most clinically suitable are glass fibers that can be silanized and adhered to the resin matrix of the FRC.[4-6]

Glass fibers vary according to their composition; the most commonly used are E-glass and S-glass, which offer chemically stable and durable glass in the pH range 4–11.[7] The strength and rigidity of constructions made from FRC are dependent on the polymer matrix of the FRC and the type of fiber reinforcement.

In dental appliances of relatively small sizes, the quality of the load bearing FRC sub-structure is very important. All factors influencing the properties of the FRC must therefore be carefully taken into consideration. This is especially important because the masticatory system produces cyclic loads on dental appliances. The appliance must therefore not only have adequate static strength but also adequate dynamic (fatigue) strength.

It is important to highlight that dental structures are composed of multiple phases. Take, for instance, the FRC-reinforced root canal post-system, which includes dentine, composite resin cement, core build-up composite resin, and the FRC root canal post as the load-bearing element. Each of these components needs to be sufficiently strong and must adhere well to one another.

The advancement of FRCs featuring a novel resin formulation, along with an improved grasp of the design guidelines that dictate how devices are built, has expanded the use of FRCs across multiple fields and uses, particularly in fixed prosthodontics and in repairing broken porcelain veneers.[8-10]

METHODS

This study is based on a comprehensive literature search conducted on 11 September 2023, in the Medline and Cochrane databases, utilizing the medical topic headings (MeSH) and a combination of all available related terms, according to the database. To prevent missing any possible research, a manual search for publications was conducted through Google Scholar, using the reference lists of the previously listed papers as a starting point. We looked for valuable information in papers that discussed the applications, benefits, and limitations of fiber-reinforced composites in fixed prosthodontics. There were no restrictions on date, language, participant age, or type of publication.

DISCUSSION

Fixed prosthodontics includes the replacement and restoration of teeth through crowns, bridges, and implants. For many years, materials like metals, ceramics, and polymers have been commonly used. However, FRCs have emerged as an alternative material, combining high strength and aesthetic appeal. They are made by combining resins with different types of fibers such as glass, carbon, or Kevlar.

Properties of reinforced glass fiber materials

Certainly, a table summarizing the properties of fiber-reinforced glass (often glass fiber-reinforced composite, or GFRC) materials would be a useful way to quickly understand the key features of these materials. Here is how you could organize this information. Table 1 is intended to serve as a quick reference guide to the properties of glass fiber-reinforced materials, citing the relevant research for each category for those who wish to delve deeper into the subject.

Table 1: Properties of glass fiber-reinforced materials.

Property category	Summary
Mechanical properties	Influenced by the shape of reinforcing fibers and interactions between fibers and resin. Factors like strength, stiffness, resilience, and resistance to static and dynamic forces are significantly impacted. Treating with silane enhances hardness and tensile strength. The orientation of fibers is also important.[11-13]
Optical properties	The refractive index of glass fibers is similar to resin, allowing for efficient light transmission. They can be incorporated into dental composites without impacting the resin matrix's rate of conversion.[14,15]
Viscoelastic properties	Polymers strengthened with glass fibers show a viscoelastic performance of 15.32 GPa, closely aligned with the 17 GPa characteristic of dentin.[16]
Bonding qualities	In dentistry, glass fiber-reinforced posts showed zero instances of adhesive failure, outperforming titanium and carbon fiber-reinforced composite posts.[17]
Heat-related characteristics	The directionality of glass fibers affects the linear thermal expansion coefficient. Unidirectional fibers have different thermal expansion coefficients when measured parallel and perpendicular to the direction of the fibers.[11]
Biocompatibility	Materials reinforced with glass fibers show less microbial adhesion to Streptococcus mutans compared to natural dental substances like dentin and enamel.[3]

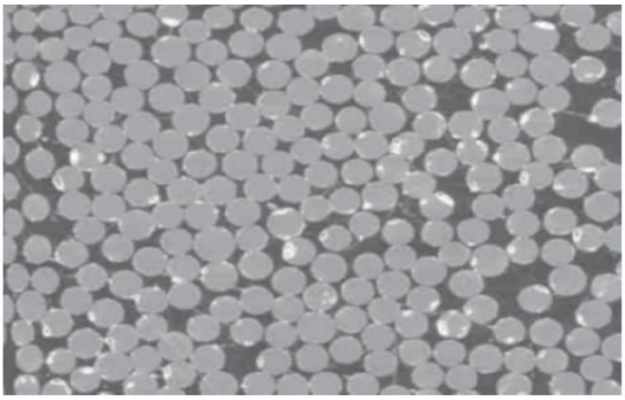

Figure 1: Cross-sectional view of glass fibre-reinforced composite showing good impregnation of the fibres with the resin matrix.[8]

Factors affecting the properties of glass fiber-reinforced dental materials

A complex set of variables impacts the physical and mechanical attributes of GFRCs. The chemical composition, especially the content of alkali and alkaline earth metals, plays a pivotal role in defining the hydrolytic stability and strength of the fibers. Impregnating these fibers with polymers as a solution to the corrosion issue is another significant aspect.[11]

The direction in which these fibers are arranged in the polymer matrix is another crucial factor affecting the material's characteristics. While unidirectional fibers provide maximum reinforcement in one direction, bidirectional fibers offer benefits when the force direction is unknown. Similarly, random fiber orientation contributes to isotropic properties. Notably, fiber orientation directly correlates with thermal behavior, wear resistance, and polymerization shrinkage. The distribution of these fibers is equally crucial. A uniform distribution augments fatigue strength, while concentration in specific areas enhances stiffness. This is particularly important in applications like dental bridges, where fiber positioning significantly affects the mechanical stability of the prosthetic device. Fiber amount is also key; an overly high concentration can lead to poor fiber bonding and, consequently, reduced efficacy.

Essential factors to consider also include the critical fiber length and the fiber aspect ratio. A fiber should be long enough to transmit stress efficiently from the matrix, with an optimal length-to-diameter ratio to achieve maximum reinforcement. Lastly, the connection between the fibers and the polymer matrix is crucial for the efficient distribution of stress. Poor bonding results in inferior mechanical properties, such as low flexural strength. Several elements play a role in forming this bond, such as van der Waals forces, chemical interactions, and mechanical engagement. Methods like etching and silanization can considerably strengthen this connection, leading to an overall improvement in the material's characteristics.

Clinical applications of FRCs in prosthodontics

The main application of FRCs in dentistry is related to provisional or definitive prosthodontics. Using FRCs and veneers allows for minimally invasive procedures by employing a mix of different types of adhesive and retentive components.[18] A resin-bonded FRC prosthesis may contain inlays or onlays, surface-bonded wings, and crowns. FRC can be created as surface-anchored, inlay-supported, or fully-covered crown-supported dental prosthetics.[19] The fabrication could be realized directly in the mouth or include prefabricated pontics, simplifying the fabrication technique and providing more predictable outcomes. The results of the mechanical and adhesion properties of FRC frameworks appear to be encouraging.[20,21] In addition, FRCs can be used in the repair of existing conventional prosthetic devices. Repairs of porcelain-fused-to-metal restorations with resin composite veneers can be made using woven glass fiber reinforcement, thus increasing the strength of the repair.[9,10] In addition, removable devices could be reinforced using FRCs.[22] FRCs can be used in indirect pontic fabrication and also in combination with CAD/CAM-based technologies.[23-25] FRCs can be used as a framework for crowns and bridges, offering a lighter, yet durable structure compared to traditional metals. FRCs can be used to fabricate periodontal splints and connectors, offering flexibility while maintaining sufficient strength.[26] Since their introduction in the 1960s for use in denture foundations, GFRCs have become a significant material in dental care. Their uses have expanded to encompass not only denture foundations but also fixed partial dentures, as well as temporary bridges and crowns. When glass fibers are incorporated into the base of the denture, they improve various mechanical characteristics like transverse strength, elastic modulus, and impact resistance. This addition also minimizes the transfer of stress, contributing to more durable dental prosthetics. However, some research has pointed out that GFRCs may exhibit reduced flexural modulus, suggesting that their performance can differ based on the specific application and manufacturing process. In terms of aesthetics and bonding, glass fibers have been shown to provide superior outcomes compared to other materials like carbon or aramid fibers. GFRCs have also proven effective for repairing broken dentures, enhancing the longevity and functionality of the prosthesis. For fixed partial dentures, they offer a metal-free, low-cost, and low-risk option with high success and survival rates. New technologies, such as FRC CAD/CAM, have further confirmed the reliability of GFRCs, especially in bearing physiological masticatory loads in the molar region.

In the case of connectors, it is crucial for the fibers that run in a single direction to have a cross-sectional structure capable of withstanding biting forces effectively. Research has demonstrated that the connector's thickness is a more critical factor for achieving optimal rigidity and durability than its width. The cross-section of the connector normally has the maximum quantity of fiber, but if there is excess space, the greatest strength can be achieved by placing the fiber on the tension side.[8] Full coverage crown-retained FPDs are made by layering woven FRC on prepared abutments. Abutments are connected by continuous unidirectional fiber, with additional pieces of FRC added to support the cusps of the pontics. FRC structure is designed to be completely enveloped by a composite resin containing lab-grade particulate filler for veneering. This allows for a surface that can be polished and matched to the color of natural teeth. Special attention needs to be paid to the interproximal regions. If the FRC framework is not properly covered by the veneering composite.

Advantages of the use of FRCs

The main advantages of using FRCs over conventional materials are mainly due to their easy manipulation and high mechanical properties, especially in dynamic loading conditions. For numerous FRC uses, little to no lab work is required, and the structures can frequently be set up right at the dental chair, inside the patient's mouth.[27] Another advantageous feature is the superior visual appeal of these materials compared to metal-reinforced options.[28] Finally, the lack of metal components in the FRC framework enables its application even for patients who have allergies to nickel or various other metals. Noteworthy is that FRCs can be indicated in patients who need to undergo nuclear magnetic resonance exams.[29]

Limitations of the use of FRCs

One of the key drawbacks of using FRC in a clinical setting is the insufficient long-term clinical data, despite numerous in vitro studies. The primary vulnerability lies in the bond between the fiber and the organic matrix. This interface is susceptible to weakening due to intraoral hydrolysis and degradation, potentially leading to device failure. This issue may also contribute to the absence of long-term performance results. The most common modes of failure for FRC devices include fractures and layers separating (delamination), although these problems can generally be fixed easily using resin composite materials.[30] Finally, the higher cost than unreinforced or metallic materials is a factor that has to be considered for a global evaluation of FRC employment.

New features and future applications

Future research on FRCs needs to focus on many aspects, such as optimization of the design of the frameworks in FRC devices, incorporation of bioactive minerals into the reinforced resin composites, and the change of fiber binding matrix from resin base to inorganic type.[31,32] Another improvement is related to nanotechnology, with the production of functional structures in the range of 0.1100 nm by various physical or chemical methods. Dental nanocomposites provided a cosmetically acceptable result with excellent mechanical properties.[33,34] The main point involved with this new trend is the addition of nanofillers to resin-based dental materials.[35] The utilization of continuous and discontinuous nanofillers has been proposed in conjunction with FRCs.[36,37] FRC utilization has also been proposed in combination with computer-aided design and computer-design/computer-aided-machining (CAD/CAM) technologies. The interaction between the two technologies seems promising based on limited information.[25] One other field where FRCs are starting to be utilized is implantology. Implant applications could benefit from certain biomechanical properties of FRCs, and the possibility of incorporating additional bioactive components into the implant structure may open new research fields.[38] FRCs have been suggested for tissue engineering for orthopaedic scaffolds.[32] Given the encouraging findings on biocompatibility, FRC biomaterials that have been developed could serve as an enhanced alternative to existing materials for craniofacial bone defect reconstruction.[39] The research options with FRC materials are open, and future reports about the topic are expected to widen FRC utilization in both dental and medical fields.

CONCLUSION

FRCs have revolutionized the field of fixed prosthodontics by offering a blend of mechanical strength and aesthetic appeal. Their unique properties, such as biocompatibility, minimally invasive application, and durability, make them a compelling choice over traditional materials like metals and ceramics. While FRCs have shown promising results in various applications, concerns about their long-term stability, cost, and interface degradation warrant further investigation. Nonetheless, their current applications and future prospects, including integration with nanotechnology and CAD/CAM technologies, indicate that FRCs are poised to play an increasingly vital role in dental restorations and beyond.

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