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Fiber-reinforced composite prostheses

Martin A. Freilich, DDS*, Jonathan C. Meiers, DMD

Prosthodontics & Operative Dentistry, University of Connecticut School of Dental Medicine, 263 Farmington Avenue, Farmington, CT 06030-2649, USA

Metal-free prosthetic dentistry continues to gain interest. Although the metal alloys contribute great strength and stiffness to restorations and prostheses, they do so at a considerable esthetic liability. Two somewhat divergent metal-free approaches to fixed tooth replacement continue to be developed for a variety of clinical applications. These are all-ceramic and all-polymeric systems. The polymeric prostheses are the subject of this article and generally consist of a particulate composite veneer supported by a fiber-reinforced composite (FRC) substructure. Two maxillary canine to central incisor FRC-supported fixed partial prosthesis are shown in Fig. 1.

FRC-supported polymeric prostheses have undergone much recent testing in the laboratory and the mouth [1–6]. These prostheses can be fabricated by the dental technician in the dental prosthetic laboratory or at chairside by the dentist in the dental operatory. The veneer materials used for the chairside-fabricated prostheses are light polymerized hybrid or microfill composites typically found in the dental office. The laboratory-fabricated prosthesis (including the FRC substructure) also is light polymerized but may have an additional heat polymerization component and may use vacuum or pressure. This provides more complete polymerization for better flexure properties of the substructure and wear resistance and color stability of the veneer [7].

The FRC material is a combination of fiber and a resinous matrix. A variety of FRC materials exhibiting a wide variety of mechanical flexure properties are commercially available. The mechanical properties of FRC materials are primarily dependent upon fiber type, ratio of fiber to matrix resin, fiber architecture (ie, unidirectional, woven, or braided), and quality of impregnation of fiber and resin. Examples of different fiber architecture are shown in Figs. 2, 3, and 4. Examples of different quality of fiber impregnation are shown in Figs. 5 and 6.

* Corresponding author.
E-mail address: freilich@nso2.ichc.edu (M.A. Freilich).

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Fig. 1. Two anterior full-coverage (three-unit) fixed partial dentures replacing the maxillary lateral incisors. These prostheses are made in the dental laboratory with a FiberKor (unidirectional pre-impregnated glass) substructure and Scupture composite veneer. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

Some manufacturers produce a dry fiber that requires hand impregnation by the technician or dentist (eg, Ribbond, [Ribbond, Inc., Seattle, Washington]; GlasSpan, [Glas Span, Inc., Exton, Pennsylvania]; Construct [SDS/Kerr, Orange, California]). Some of the commercially available FRC materials are machine impregnated with resin by the manufacturer (eg, everStick, [StickTech, LTD, Turku, Finland]; FiberKor, [Pentron, Inc., Wallingford, Connecticut]; Vectris [Ivoclar/Vivaclent, Amherst, New York]). These machine-impregnated materials are also known as ‘‘pre-impregnated’’ FRC materials. The flexure properties and characteristics of a number of different commercially available FRC materials are shown in Table 1. This table demonstrates the wide variety of flexure properties dependent upon the aforementioned characteristics. This is particularly true for the properties of elastic modulus (rigidity) and elastic limit (strength at permanent deformation). Rigidity of the FRC substructure is critical to the integrity of

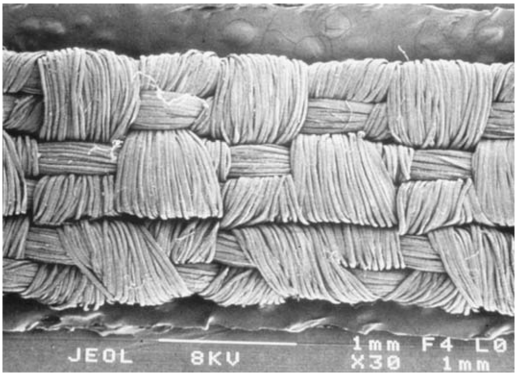

Fig. 2. Magnified view of Ribbond, nonimpregnated woven polyethylene fiber. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

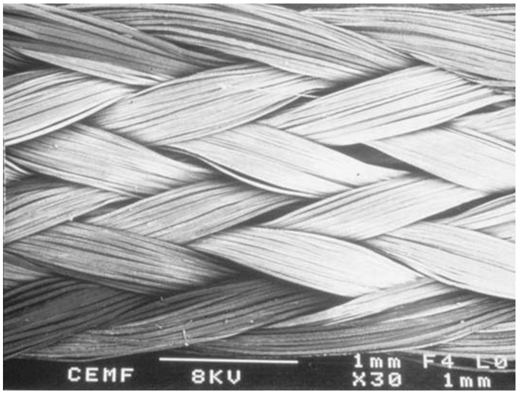

Fig. 3. Magnified view of Connect, nonimpregnated braided polyethylene fiber. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

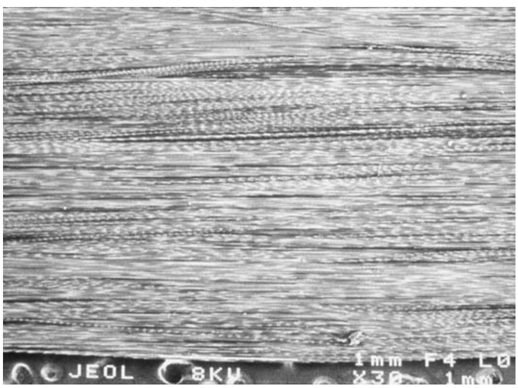

Fig. 4. Magnified view of a unidirectional pre-impregnated FRC.

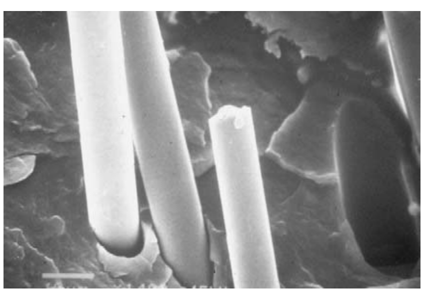

Fig. 5. Unidirectional glass fiber poorly wetted (impregnated) by surrounded resin matrix resulting in very poor flexure properties. (*From* Freilich MA, Duncan JP, Alarcon EK, Eckrote KA, Goldberg AJ. The design and fabrication of fiber-reinforced implant prostheses. J Prosthet Dent 2002;88:449–54; with permission.)

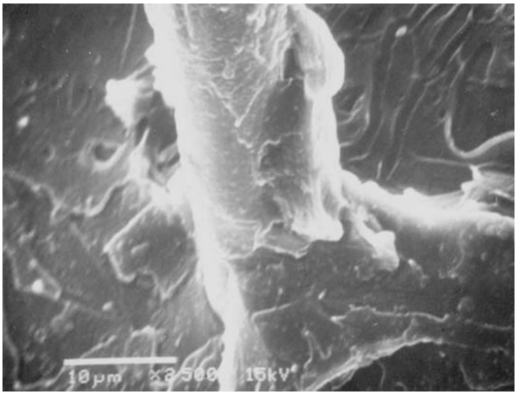

Fig. 6. Unidirectional glass fiber properly wetted (impregnated) by surrounded resin matrix resulting in good flexure properties. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

the veneer made from a fairly brittle material, such as particulate composite. The ultimate flexure strength of manufacturer-impregnated (also known as pre-impregnated), unidirectional, glass FRC materials range from over 500 to 1000 Mpa. This is greater than the flexure strength of noble ceramic alloys [8]. In this article, the clinical tooth replacement applications of FRC-supported prostheses are organized into two categories: laboratory-fabricated prostheses and chairside prostheses.

Laboratory-fabricated prostheses

Laboratory-fabricated FRC prostheses can be retained by teeth or implants. The polymer prostheses include a surface that does not wear opposing tooth enamel, and the substructure does not require waxing, casting, or soldering procedures during fabrication. Supported by a strong, metal-free substructure, the esthetic qualities of the FRC polymer prostheses

Table 1
Flexure properties of FRC products

Product	Flexure modulus (GPa)	Strength elastic limit (MPa)	Strength ultimate (MPa)
FibreKor	28.3	471	539
everStick	24.3	605	739
Vectris	28.9	516	614
GlasSpan	13.9	266	321
Construct	8.3	59	222
Ribbond	3.9	56	206

Abbreviation: FRC, Fiber-reinforced composite.

Fig. 7. Tooth preparations for posterior intracoronal (inlay) FRC prosthesis. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

can be outstanding. Potential concerns for these prostheses are water sorption, loss of surface luster and fatigue resistance over time, and the technique sensitivity associated with an adhesive luting approach at delivery.

For tooth-retained FRC prostheses, the composite retainers can be bonded to abutment teeth. This allows enhanced retention for available axial wall height. This also permits the use of a "conservative" tooth replacement prostheses where intracoronal (inlay) preparations are made on minimally restored abutment teeth. This inlay bridge design has proven unsuccessful where a metal alloy substructure is used and retainers have not

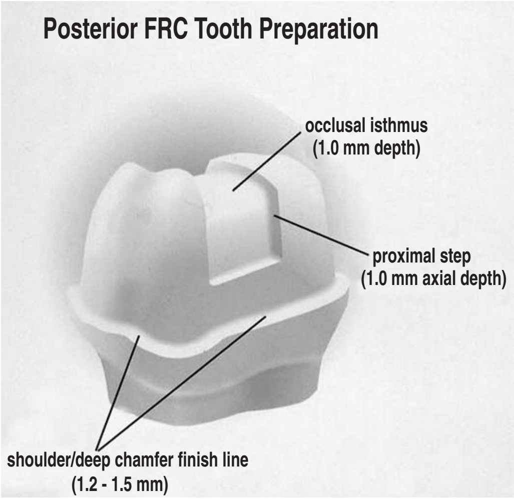

Fig. 8. Drawing of full-coverage posterior tooth preparation exhibiting consistent axial depth of preparation to the finish line around the entire circumference of the tooth, the proximal step (on the side adjacent to the edentulous space), and the occlusal isthmus. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

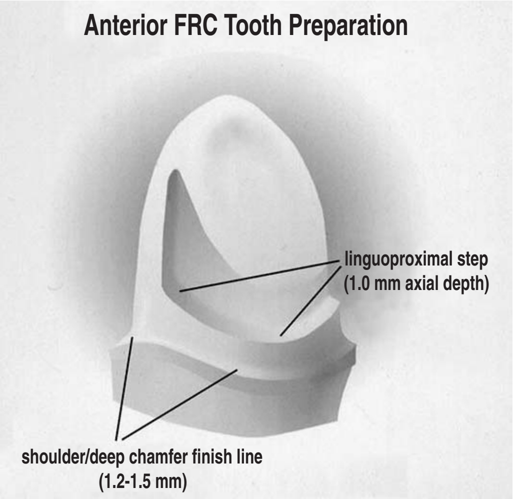

Fig. 9. Drawing of the full-coverage anterior tooth preparation also exhibiting consistent axial depth of preparation around the entire circumference of the tooth and the linguoproximal step. The proximal aspect of the step is only needed adjacent to the edentulous area. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

been bonded to the abutment teeth. Tooth preparation designs of full and partial coverage FRC prostheses are shown in Figs. 7, 8, and 9.

Data have shown that substructure design is a key ingredient of the clinical success of FRC prostheses. Increased substructure bulk added at the pontic region (‘‘high volume’’ design) provides additional rigidity along with greater vertical support of the veneer material. Successful chemical bonding of the veneer composite to the FRC substructure is another critical element of clinical success. The maintenance of the air-inhibited layer on the external surface of the completed substructure seems to be a crucial element in

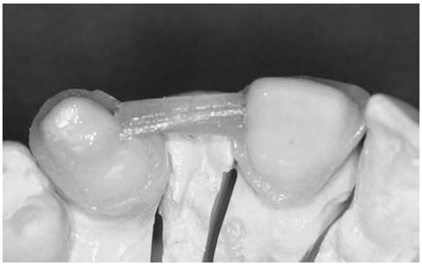

Fig. 10. Full-coverage retainer FiberKor unidirectional glass substructure with less than adequate bulk placed in the edentulous region. (*From* Freilich MA, Meiers JC, Duncan JP, Eckrote KA, Goldberg AJ. Clinical evaluation of fiber-reinforced fixed bridges. JADA 2002;133:1524–34; Copyright © 2002 American Dental Association. All rights reserved. Reprinted by permission.)

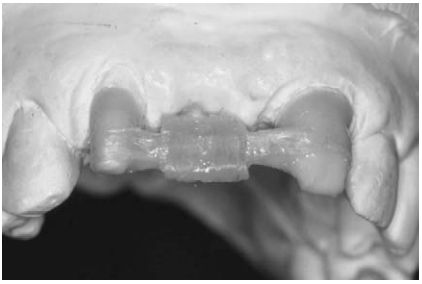

Fig. 11. Full-coverage retainer FiberKor unidirectional glass substructure with optimal bulk (''high-volume design'') placed in the edentulous region. This design results in better substructure rigidity and better support of the composite veneer material. (*From* Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber-reinforced composites in clinical dentistry. Chicago: Quintessence; 2000; with permission.)

achieving this bond. Examples of FRC substructures are shown in Figs. 10, 11, and 12. Two separate clinical studies of FRC prostheses made with Stick (StickTech LTD, Turku Finland) and FiberKor (Pentron Corp, Wallingford, CT) have demonstrated >90% survival of partial and full coverage prostheses for up to 5 years [4,6]. Examples of various prosthesis designs are shown in Figs. 13, 14, and 15.

Implant-retained FRC prostheses can be screw retained or luted to the implant abutment. In contrast with tooth-supported prostheses, the component of the FRC prosthesis retainer that provides an attachment to the implant abutment can be premanufactured. This is because the implant abutment is generally not custom made but is machined by the manufacturer. For luted prostheses, a woven FRC coping can be used to make this underside or foundation of the retainer. The remainder of the FRC substructure can be bonded directly to these copings. An example of a luted FRC substructure can be seen in Fig. 16. For screw-retained FRC prostheses, a cylinder with a screw channel that fits directly to the implant

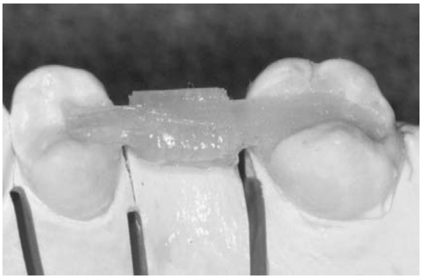

Fig. 12. Partial-coverage retainer (intracoronal) FiberKor unidirectional glass substructure with high-volume design placed in the edentulous region.

Fig. 13. Underside of FRC-supported, full-coverage retainer prosthesis before delivery.

abutment becomes an integral component of the substructure. An example of a titanium ceramic cylinder with horizontal grooves on the facial and lingual surfaces and proximal boxes is shown in Fig. 17. These design characteristics of the cylinder enable the FRC to be reliably attached. The horizontal grooves provide macro-mechanical retention and the proximal boxes provide vertical support to the FRC. The etched and silanated ceramic coating (titanium ceramic; Vident, Brea, California) provides an opaque mask of the alloy and micro-mechanical retention to the FRC.

These fixed partial and complete FRC implant prostheses continue to be developed and tested by our research group. The implant prosthesis substructure exhibits the ''high volume'' design features and external surface air-inhibited layer mentioned previous. An example of a complete arch implant prosthesis substructure is shown in Fig. 18. For the partial prostheses, a light/heat/vacuum polymerized particulate composite veneer is placed over the FRC substructure. For complete, fixed detachable (hybrid) prostheses, polymethylmethacrylate (PMMA) and denture teeth are used to provide final form and occlusal function. These materials are applied using many widely accepted fabrication techniques commonly used by the dentist and laboratory technician. These include procedures for the verification of the accuracy of the master cast, wax try-in of the denture teeth, and the processing of the PMMA prosthesis supra structure [9,10]. Examples of completed FRC implant prostheses are shown in Figs. 19 and 20. The advantages of using fiber-reinforced polymer materials to fabricate implant prostheses are listed in Box 1.

Chairside prostheses

One of the most exciting and potentially useful applications for pre-impregnated FRC technology is its use in replacing missing teeth in a timely and cost-effective manner. The ability to deliver a functional, esthetic tooth replacement with no to minimal tooth preparation to the adjacent abutment teeth in a single visit is a realistic treatment option with our current adhesive technologies and reinforced composites. The increase in physical properties

Fig. 14. Posterior three-unit FRC prosthesis seen in situ.

Fig. 15. Completed intracoronal retainer FRC prosthesis.

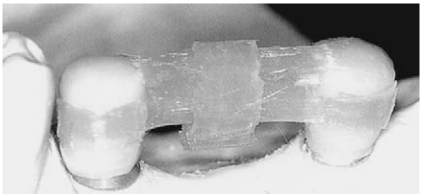

Fig. 16. Luted implant prosthesis substructure made with pre-impregnated unidirectional (FiberKor) and woven glass (Sticknet) components. (*From* Freilich MA, Duncan JP, Alarcon EK, Eckrote KA, Goldberg AJ. The design and fabrication of fiber-reinforced implant prostheses. J Prosthet Dent 2002;88:449–54; with permission.)

that fiber reinforcement provides to particulate composites allows for an improved approach over earlier methods that used denture teeth as pontics [11,12]. This new approach eliminates the disadvantages posed by the incompatibility of the different chemistries between the particulate luting composite and the acrylic pontic and results in a much stronger connector between the pontic and the abutment teeth when compared with particulate composite alone. This provides the potential for long-term clinical service [13]. Consequently, what was once thought of as a purely short-term or temporary solution can sometimes be considered as a more definitive remedy for those patients who cannot afford a conventional fixed-tooth replacement. Potential clinical applications for chairside-fabricated FRC prostheses include situations where the abutment teeth may be of

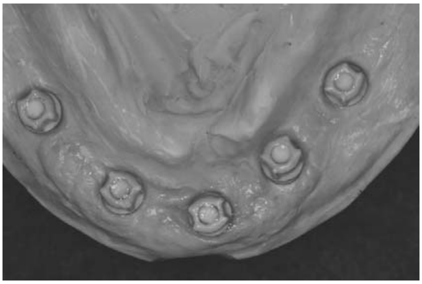

Fig. 17. Screw-retained titanium ceramic cylinders placed on implant abutment replicas located within a master cast. In addition to the ceramic surface that provides an opaque mask and resin adhesion, the grooves on the facial and lingual surfaces and proximal boxes exhibited by the cylinders provide macro-mechanical retention and support, respectively, to the incorporated FRC.

Fig. 18. Completed screw-retained implant prosthesis substructure including titanium ceramic cylinders and pre-impregnated unidirectional glass FRC.

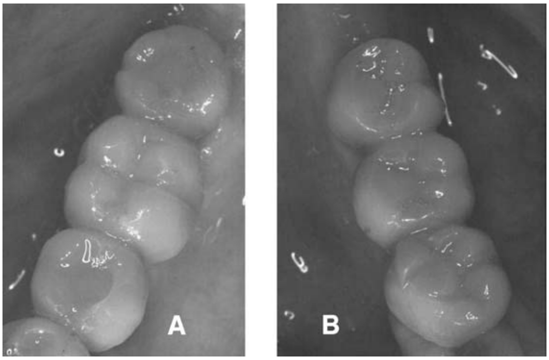

Fig. 19. (*A*) Completed three-unit, screw-retained FRC implant prosthesis. (*B*) Completed three-unit luted FRC implant prosthesis.

Fig. 20. Completed full-arch fixed detachable (hybrid) FRC-supported implant prosthesis beforeplacement in mouth. (*From* Freilich MA, Duncan JP, Alarcon EK, Eckrote KA, Goldberg AJ. The design and fabrication of fiber-reinforced implant prostheses. J Prosthet Dent 2002;88:449–54; with permission.)

questionable stability or in place of a provisional removable prosthesis immediately after anterior implant placement but before loading. Additionally, this technology can be used for immediate fixed-tooth replacement after extraction, after traumatic loss of a tooth, or for space maintenance in pediatric or adolescent patients.

We have investigated the concept of designing pre-formed substructures that can be used to quickly provide a platform for creating a bridge at chairside rather than having to fabricate a chairside bridge from scratch using particulate composite and FRC components [14–16]. This approach helps reduce time and technique sensitivity in the delivery of chairside bridges. We have developed this concept to provide the clinician with the ability to replace a missing tooth in the same way that the fabrication of a provisional crown can be expedited by using a preformed shell.

FRC can easily be manipulated into a pre-formed (pre-fabricated) substructure that has polymerized and nonpolymerized elements. The "wing" element is not polymerized and provides an attachment to the adjacent abutment teeth as they are adapted, polymerized, and bonded to the facial or lingual surfaces. The "pontic" element is rigid because it is already polymerized and consists of unidirectional FRC but in greater bulk. After attaching the wings to the abutment teeth, the dentist veneers the pontic element with light polymerized particulate (restorative) composite. These prefabricated substructures (frameworks) can be designed to have one

Box 1. Why use FRC in Implant prosthodontics?

- Good flexure properties of some FRC materials
- Saves time and cost because no casting or soldering
- Chemical bond of resin veneer to substructure
- No need for opaque application to substructure
- Avoids concerns of corrosion and toxicity

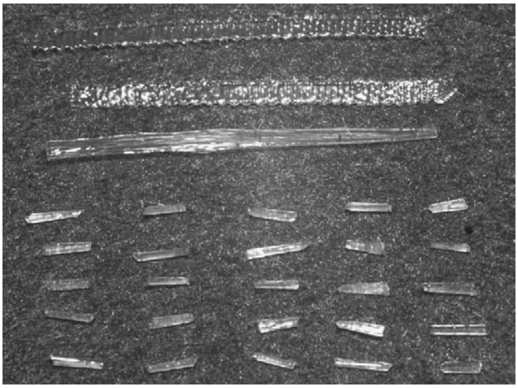

Fig. 21. Layout showing the pieces of Splint-Itmaterial required to fabricate the first generation of prefabricated FRC framework shown in Fig. 22. (*From* Meiers JC, Freilich MA. Chairside prefabricated fiber-reinforced resin composite fixed partial dentures. Quintessence Int 2001;32:99–104; with permission.)

or two wings to allow double abutment or a cantilever approach and only replace a single tooth. Figs. 21 through 25 show the basic design concepts of FRC prefabricated frameworks and how they can be used. The basic construction consists of pieces of FRC that are cut to provide the wing attachments to the abutment teeth and a support for the pontic tooth shape (Figs. 21 and 22). During this development process there have been three generations of basic designs. The first had a nearly fully completed pontic for the particular missing tooth (Fig. 23-1). The second design featured only a basic pontic body that required chairside veneering to finish the shape (Fig. 23-2). These two designs used Splint-It unidirectional and woven pre-impregnated glass fibers (Pentron) in their fabrication. The current design features just a basic framework support for the pontic requiring a total

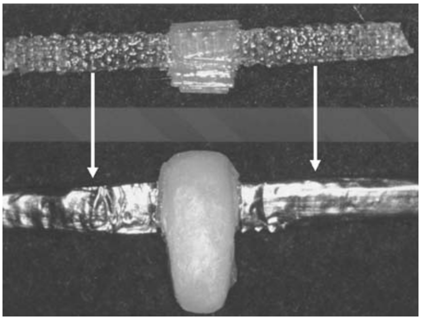

Fig. 22. The pre-fabricated FRC framework formed from the Splint-It pieces shown on Fig. 1 and then the finished product ready for chairside use. The pontic in this design was designed to fit specific spaces. This one was for a mandibular incisor. The foil protects the wings from premature polymerization and allows for flexibility in adapting them to the tooth surfaces.

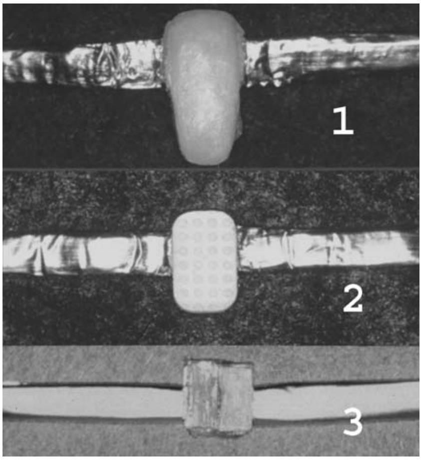

Fig. 23. The three generations of pre-fabricated FRC bridges: generations 1 and 2 used Splint-It as the pre-impregnated FRC material, and generation 3 is designed from everStick. Generation 1 is the first design using a fully formed pontic shape duplicating the replacement tooth. Generation 2 used a partial pontic form that required more chairside work to develop the final pontic form. Generation 3 had only an FRC pontic substructure that required complete development of the pontic shape after placement. Each had its own advantages and disadvantages.

placement of the pontic shape at chairside (Fig. 23-3). This scaled-down design allows for a more universal application of pre-fabricated frameworks and reduces the work involved in their fabrication. EverStick unidirectional pre-impregnated glass fibers (StickTech) have been used to create this

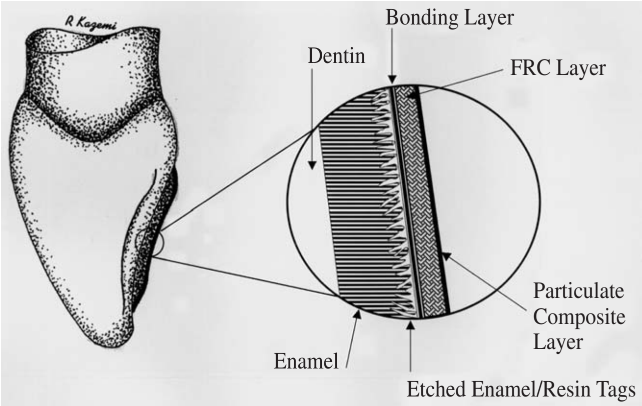

Fig. 24. Cross-sectional diagram showing the concept of a cohesive unit of adhesive resin/particulate luting resin and FRC at the etched tooth interface. (*From* Meiers JC, Freilich MA. Chairside prefabricated fiber-reinforced resin composite fixed partial dentures. Quintessence Int 2001;32:99–104; with permission.)

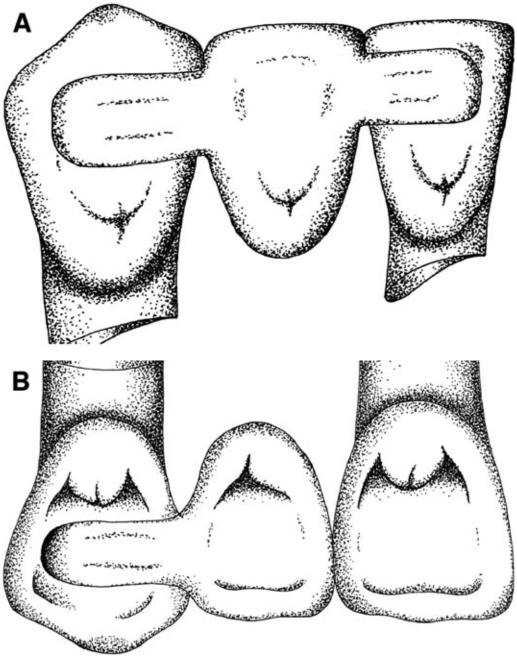

Fig. 25. Diagrams depicting tooth replacement options. (*A*) A dual-wing pre-fabricated FRC approach to replacing a missing tooth. (*B*) A cantilever approach involving only one abutment tooth. These can be placed on the facial or lingual surfaces of the abutment teeth, depending on occlusion. (*From* Meiers JC, Freilich MA. Chairside prefabricated fiber-reinforced resin composite fixed partial dentures. Quintessence Int 2001;32:99–104; with permission.)

framework. These pre-fabricated frameworks are made for maxillary and mandibular anterior and premolar designs and stored in a light-safe foil wrap to be used when needed. Covering the wings in a light-protected foil allows them to be kept in a flexible, nonpolymerized state until they are placed and light polymerized by the operator at chairside. The pre-impregnated matrix of the Splint-It and everStick FRC material allows for a strong chemical cross linking between it and the air inhibited layer of the adhesive resin/luting resin/enamel interface, which creates a unified resin/glass fiber network from the etched enamel surface to the external surface of the FRC wing (Fig. 24). This is achieved by having the wings in a nonpolymerized state (protected by the foil layer when the framework is created) when they are placed on the abutment surface. We have not seen any failures with these bridges at the wing/enamel interface. This indicates that a strong attachment between the enamel and FRC framework can be obtained with no mechanical preparations created in the abutment teeth for additional support. The frameworks can be adapted for dual-wing or single-wing abutment support (Fig. 25), depending on the clinical situation (ie, a full permanent or temporary crown on one of the potential abutment teeth

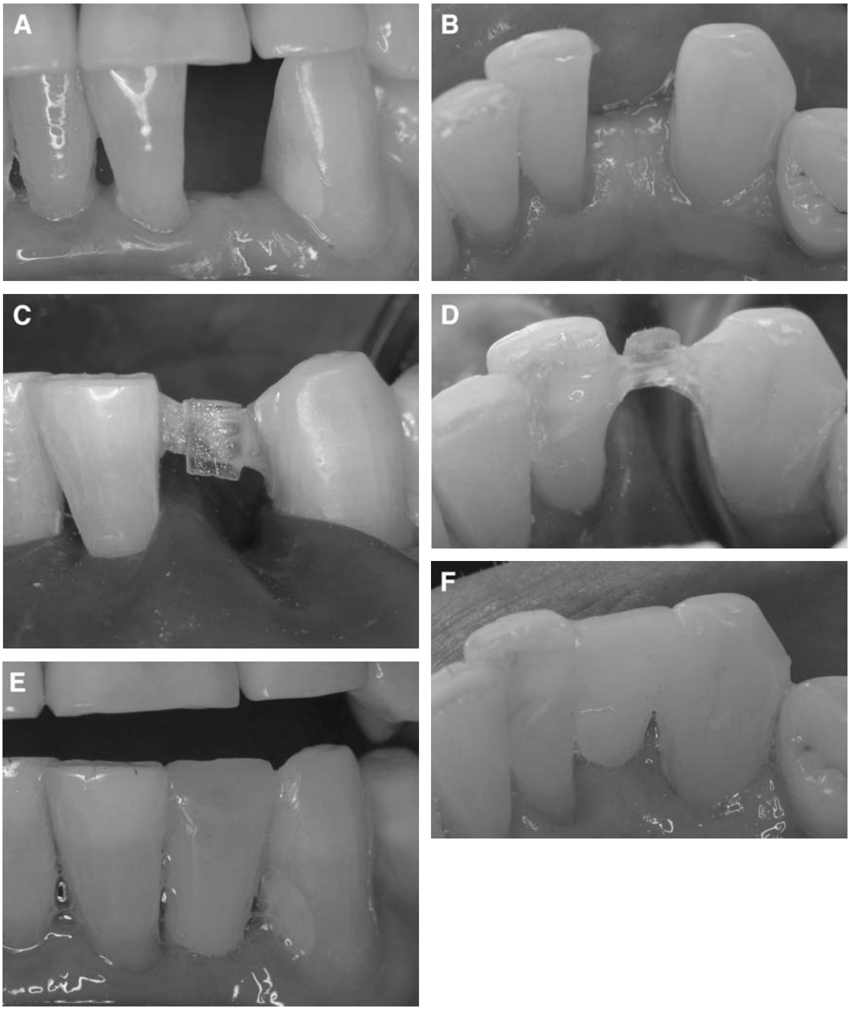

Fig. 26. Dual-wing pre-fabricated chairside FRC bridge. (*A*) Patient with missing #23, facial view. (*B*) Patient with missing #23, lingual view. (*C*) Appearance of pre-fabricated FRC framework (everStick) showing pontic support, facial view. (*D*) Lingual view of pre-fabricated FRC framework. Note the lack of bulk on the lingual and the good adaptation of the wings to the lingual contour of the abutment teeth. Compare with (*B*). (*E*) Facial view of completed pontic on pre-fabricated FRC framework. (*F*) Lingual view of completed pontic. Compare with Fig. 26B and D.

or for short-term use). The wings are intended to be placed without mechanical preparation on the abutment teeth. The ability to thin the FRC with pressure along with its translucency allows the wings to be placed in a labial position, if lingual occlusion does not permit this approach, and they can be easily masked with a thin facial veneer.

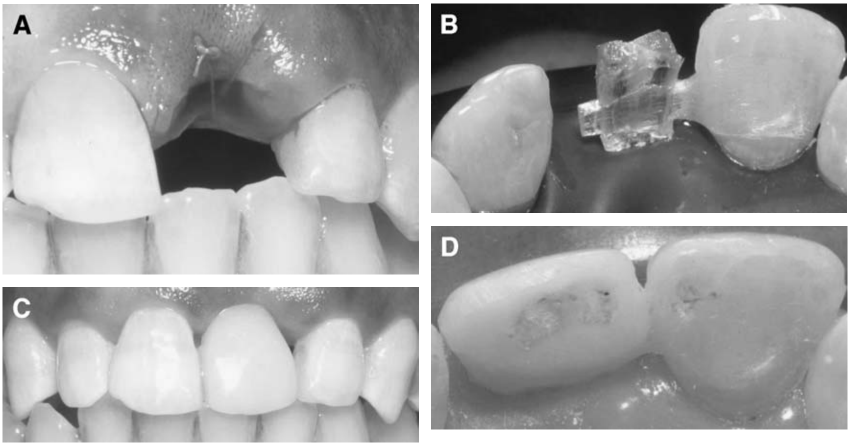

Fig. 27. Cantilever pre-fabricated chairside FRC bridge. (*A*) Patient with extracted #9 and bone augmentation awaiting future implant placement. An immediate cantilever FRC bridge was treatment planned to replace #9 until implant placement. (*B*) Lingual view of pre-fabricated framework (everStick) showing wing adapted to lingual surface of #8. (*C*) Facial view of finished pontic #9 on cantilever chairside FRC bridge. (*D*) Lingual view of finished cantilever chairside FRC bridge showing intimate adaptation of lingual wing on #8.

Clinical cases

Figures 26 through 28 show some examples of chairside bridges made from pre-fabricated FRC frameworks.

Dual-wing anterior chairside bridge

Fig. 26 (A–F) shows the replacement of a missing mandibular lateral incisor with a dual-winged pre-fabricated bridge approach. The abutment teeth are isolated and the pre-fabricated framework modified to have the wings shortened to fit the proximal surfaces of the two abutment teeth. The abutment teeth are etched, adhesive is applied, the framework is placed using a hemostat holding the pontic in position, and the wings compressed with a gloved finger to intimately adapt to the lingual contours of the abutment teeth, after which the compressed FRC wing with the luting resin composite is light cured (Fig. 26C and D). The external pontic surface is then built using particulate composite to the desired shape (Fig. 26E and F).

Cantilever anterior bridge over a healing extraction site

Fig. 27 shows a cantilevered bridge series. This approach is appealing to patients and clinicians because it allows a rapid solution to tooth replacement that involves only one abutment tooth. The added strength imparted at the connector area by the FRC allowed for the concept of this design, and it has proven to be predictable for up to 6 months. This approach is

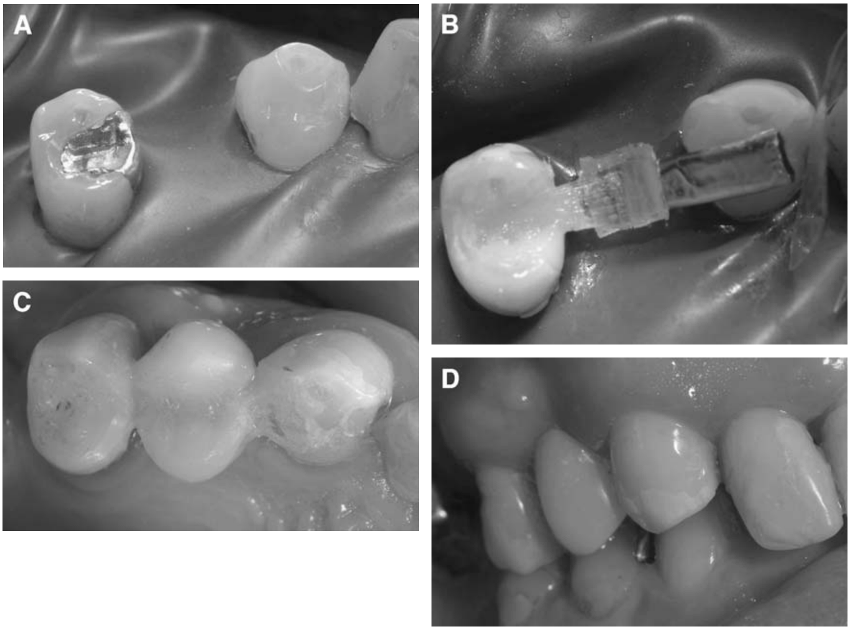

Fig. 28. Premolar FRC pre-fabricated chairside bridge. (*A*) Patient with missing #5. The mesial-occlusal amalgam in #4 will be removed to allow room to place a wing of the pre-fabricated bridge into the preparation. (*B*) The pre-fabricated framework (everStick) has been placed onto the abutment teeth. The wing placed into the mesial-occlusal preparation of #4 has been polymerized in a bed of flowable resin. The foil on the lingual of #6 has protected this wing from polymerization and will be removed next to allow adaptation and attachment. (*C*) Occlusal view of completed FRC chairside bridge showing pontic and wing adaptation to the abutment teeth. (*D*) Buccal view of completed FRC chairside bridge showing good esthetics and functional relationships.

normally used when the bridge is to function for a short period of time. Examples of its use include the edentulous area that is a future implant site and as a tooth replacement covering the implant immediately after placement but before loading. In both of these cases, the usual removable provisional prosthesis (“flipper”) is replaced by a fixed prosthesis. Preparation of the abutment tooth surface receiving the wing is not needed, and when the bridge needs to be removed, the removal of the FRC wing from the abutment has proven to be easily accomplished with essentially no loss of enamel.

Replacement of a missing premolar

Fig. 28 illustrates a posterior application. We have used these frameworks to replace premolars. In these situations, the premolar or molar abutments are prepared with an occlusal slot to receive the wing(s). If a canine is one of the abutments, the wing is placed on the buccal or palatal surface with no preparation.

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