Fiber-Reinforced Composites in Orthodontics

CHARLES J. BURSTONE, DDS, MS
ANDREW J. KUHLBERG, DMD, MDS

We are entering a new era of orthodontics in which fiber-reinforced composites can change the concept, mechanics, and application of fixed appliances through the use of a pre-impregnated material or "pre-preg"—a partially polymerized fiber-matrix complex that is later fully polymerized in a clinical setting. The advantages of a pre-preg are a significant enhancement of mechanical properties, better control of the final cross-sectional shape, and simplification of steps performed by the clinician.[1-3]

This article describes a new approach to the use of polymers in orthodontics, using a long-fiber-reinforced composite (Splint-It*). Passive applications, such as bonded cuspid-to-cuspid retainers or bonded bridges to replace missing lateral incisors, are the most obvious. The greatest clinical potential, however, lies in active applications, where long-fiber composites can be used as adjuncts for active tooth movement.

Organic fibers such as Kevlar have been used in previous FRC applications, but they are weak in compression. Splint-It uses the stronger S-glass fibers, which also make the connecting bar clear or translucent, and thus more esthetic for the patient. The matrix is a light-cured thermoset bisGMA,[4-6] which allows superior bonding, since it is identical to adhesives that are commonly used in orthodontics. Using a commercial manufacturing process, the fibers are correctly oriented and an excellent coupling is achieved, followed by an initial stage of polymerization of the matrix. This initial polymerization makes the matrix flexible and adaptable, so it can be easily contoured to the teeth. The result is a user-friendly polymer that is as easily manipulated as any plastic, but as structurally strong as a metal.

The modulus of elasticity in flexure of Splint-It is 70% greater than that of a highly filled dental composite.[7-10] Even more significant, the yield strength is six times greater. Splint-It also has 24 times greater resilience than a dental composite. The modulus of resilience is the mechanical parameter that determines the ability of an appliance to withstand stresses (energy absorption before permanent deformation).

*Jeneric/Pentron, Inc., 53 N. Plains Industrial Road, Wallingford, CT 06492.

Dr. Burstone

Dr. Kuhlberg

Dr. Burstone is an Associate Editor of the *Journal of Clinical Orthodontics* and a Professor, Department of Orthodontics, School of Dentistry, University of Connecticut Health Center, 263 Farmington Ave., Farmington, CT 06030. Dr. Kuhlberg is Assistant Professor and Clinic Director, Department of Orthodontics, University of Connecticut Health Center.

Clinical Use of FRC

Three configurations of Splint-It are available (Fig. 1). The rope type, being round, can be adapted around the corners of an arch and thus is useful in such applications as cuspid-to-cuspid retainers. The 2mm-wide strips are available with the fibers in a unidirectional parallel configuration or in a woven pattern. Unidirectional strips have the best mechanical properties for bending, although the other configurations can be successfully used in many applications to make appliance fabrication easier or to improve shear-loading properties.

Applying the FRC pre-preg to a tooth involves a straightforward technique, either direct

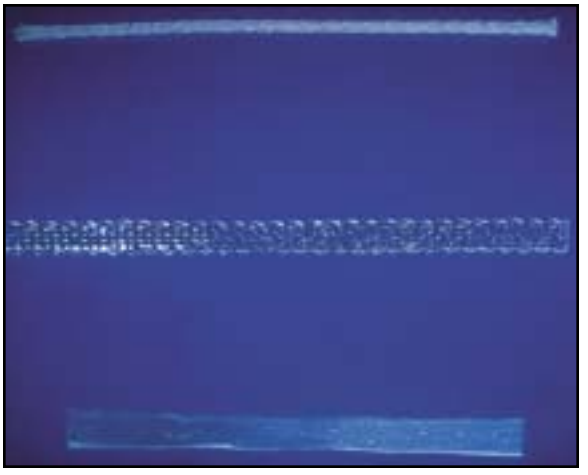

Fig. 1 Splint-It configurations: rope, woven strip, unidirectional strip.

or indirect.[11] The FRC rope or strip is cut to length, and the protective transparent foil is gently removed. The tooth is prepared for bonding with the conventional polishing and etching. The FRC is placed in position and contoured to the tooth, then light-cured to form an effective connecting bar.

When the FRC is adapted to the embrasures, a memory phenomenon can be observed as it tries to reestablish its original straight shape before curing. If more contour is required, it may be necessary to isolate an FRC area by protecting it from the light source, so it can be cured later. At any rate, it is probably not desirable to place the FRC too far into the interproximal embrasures, since too much curvature may weaken the material. Adhesive can be added between the FRC and the embrasures to fill in spaces.

If attachments such as brackets, tubes, or hooks are needed, they can be directly bonded to the FRC. The adhesive should then be only partially cured on initial placement, and the attachments bonded before final light-curing of the bar.

Once the bar has been completed, a low-viscosity adhesive can be added to form a protective layer over the bar. The FRC can be easily removed by a peeling action using a scaler or other suitable instrument.

An FRC bar can also be prepared indirectly from a study cast, using either a hand-held light or a light-curing oven. One of the advantages of an indirect technique is that it avoids the longer curing time needed for direct bonding in the mouth. After the indirect light-curing, the finished bar with attachments can be bonded in the mouth as with any conventional technique. Bond strength is enhanced with either the indirect or the direct technique, because the polymeric matrix is the same as the bonding adhesive.

Active Applications

A full-arch FRC can be constructed between the first or second molars (Fig. 2). In some cases, however, it is more convenient to divide

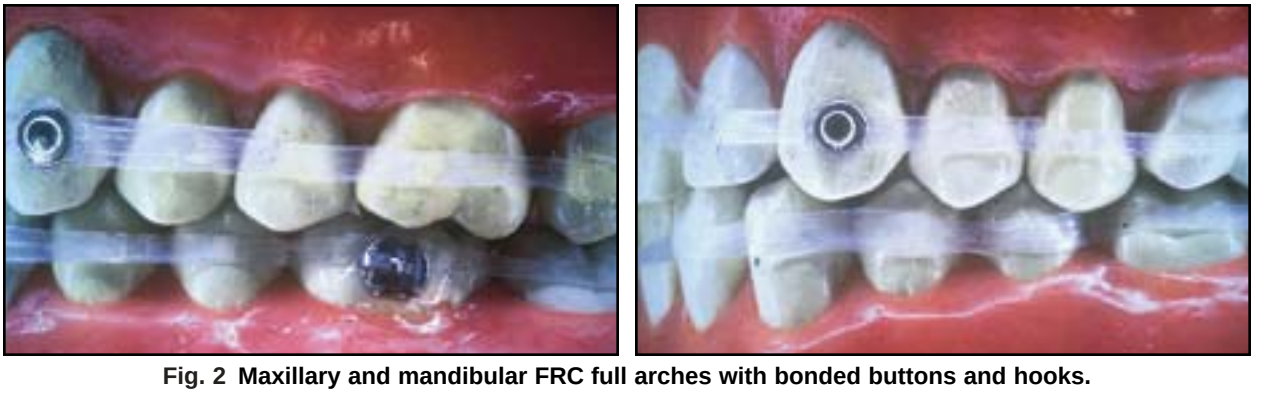

Fig. 2 Maxillary and mandibular FRC full arches with bonded buttons and hooks.

the FRC into three segments (Fig. 3). One of the advantages of using an FRC is the ability to join pieces together with an adhesive to make a strong structural unit. Although the appliance is esthetic when placed labially, it is possible to make a three-piece full arch with a lingual crossover from cuspid to cuspid.

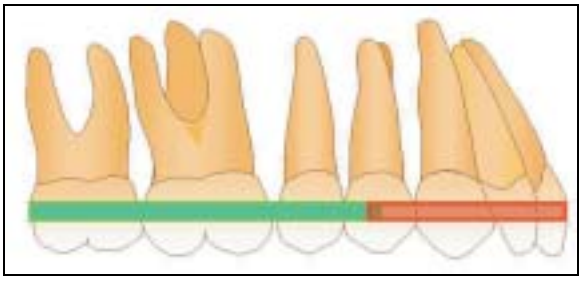

Fig. 3 FRC arch can be fabricated in sections that are bonded together to form a full arch.

Attachments can be added for intermaxillary tooth movement (Fig. 4). Class II or Class III elastics can be applied without bands or brackets, making it simple to position the hooks with the ideal direction and point of force application respective to the maxillary and mandibular centers of resistance (Fig. 5).

Vertical elastics, if indicated for the closure of an open bite, can be applied directly to the maxillary and mandibular FRC bars (Fig. 6). The hook positions can be easily controlled and changed during treatment, if necessary, to produce the desired center of rotation for movement

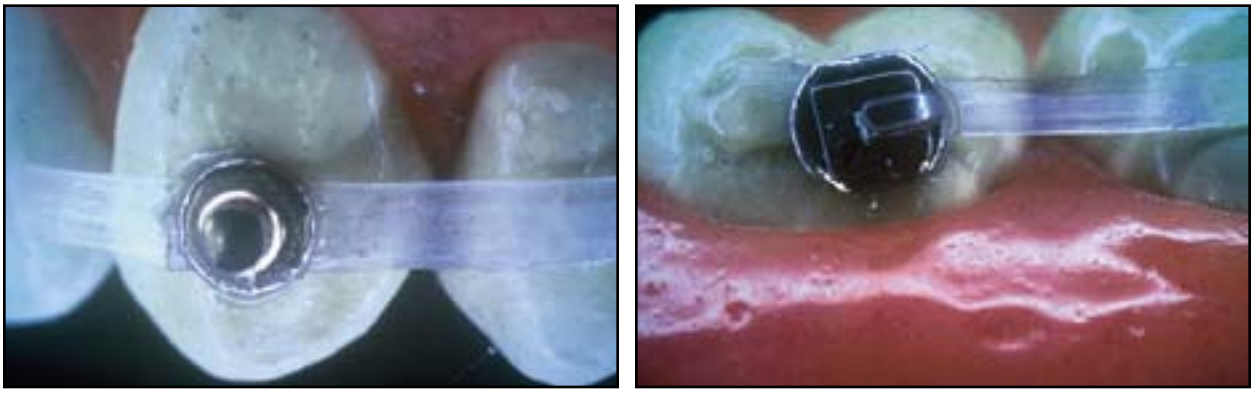

Fig. 4 Hooks, brackets, and buttons can be bonded before final light-curing or added later.

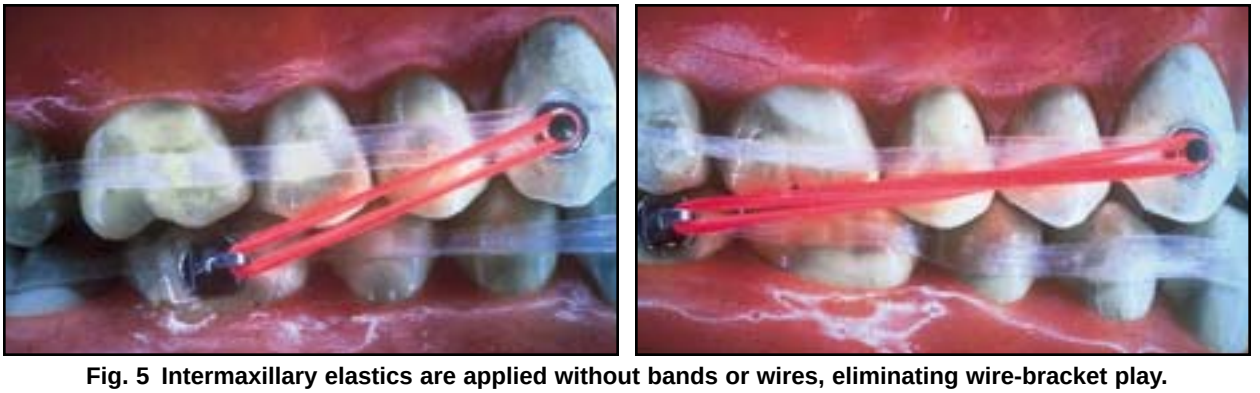

Fig. 5 Intermaxillary elastics are applied without bands or wires, eliminating wire-bracket play.

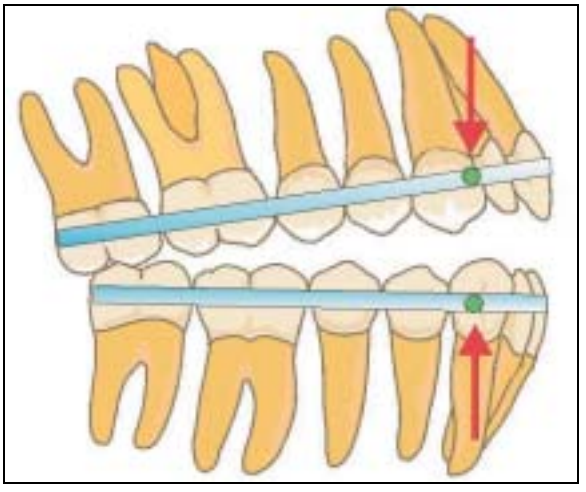

Fig. 6 Full FRC arches used with vertical elastics to close open bite when incisor extrusion is indicated.

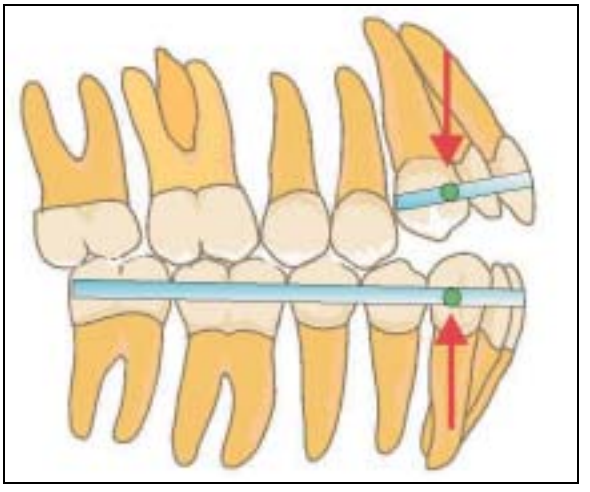

Fig. 7 Extrusion only of maxillary incisor segment for open-bite closure, using mandibular full connecting bar as anchorage unit. Hook positions can be varied to produce translation or tipping.

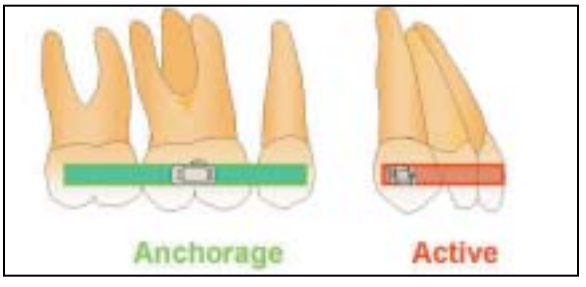

Fig. 8 Posterior anchorage unit (green) and active anterior unit (red), with bonded attachments used for esthetic space closure or other intersegmental movements.

of each arch. Some patients may only require movement of one segment to close an open bite (Fig. 7).

A full-anchorage connector from mandibular molar to molar can be used for extrusion of the maxillary anterior segment. This technique is preferable to leveling the arch first with brackets and wires, which would produce some undesirable side effects. After the eruption of the maxillary anterior teeth, brackets can be placed for detailed tooth movements. As with the application of vertical elastics in deep-bite cases, the FRC bar can be combined with a maxillary or mandibular bite plate.

Intra-arch tooth movements can also be performed with FRC appliances. For example, two connectors can be used for space closure by retraction of the anterior teeth (Fig. 8). FRC bars with bonded tubes form the posterior anchorage units; unlike with conventional appliances, the tubes can be moved to increase the effective interbracket distance. Similarly, brackets are attached to the anterior segments to form the active units (Fig. 9). Plastic or ceramic brackets can be used for esthetic reasons (Fig. 10A). Space closure can also be effected with a T-loop between the anterior and posterior FRC bars, or with a wire segment from molar to cuspid and a chain elastic (Fig. 10B).

Second molars often erupt in poor positions after orthodontic treatment has been completed. Rather than resuming treatment with brackets and wires, the clinician can upright a second molar by using a full-arch FRC as an anchorage unit, combined with either a straight wire segment or a wire with a differential bend or T-loop (Fig. 11). Brackets are placed anywhere in the anterior anchorage segment, and a tube or brack-

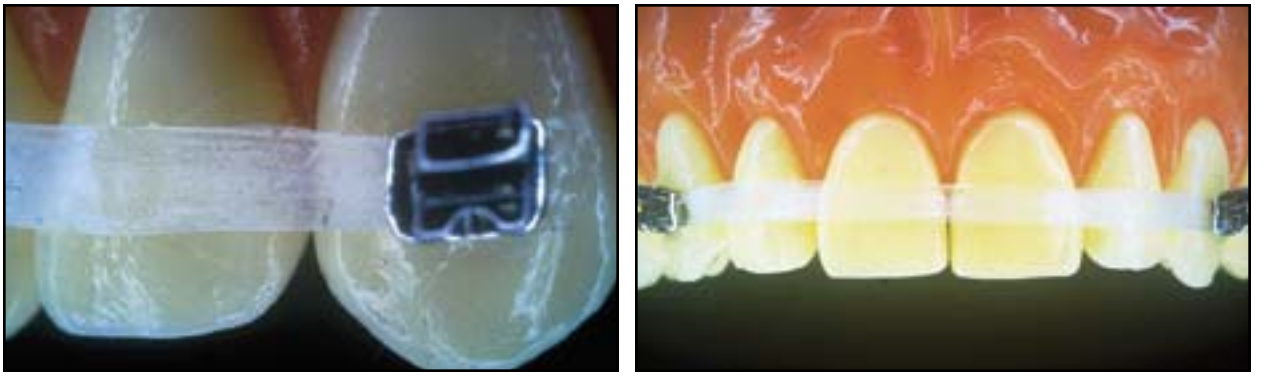

Fig. 9 Cuspid bracket-tubes bonded to esthetic anterior connector.

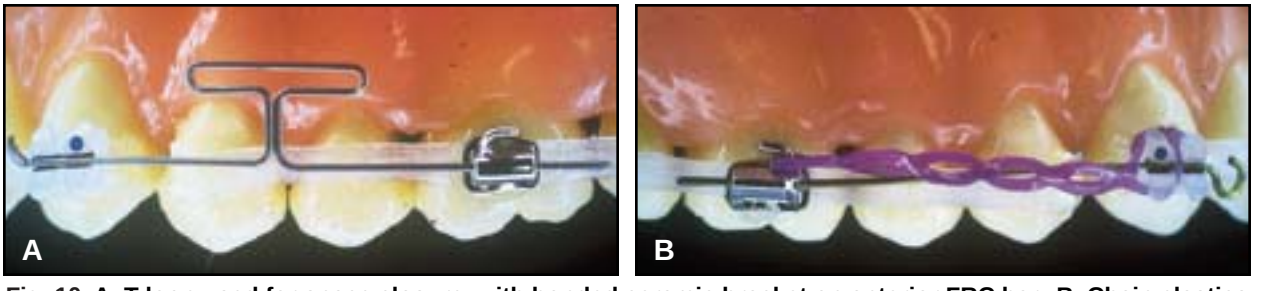

Fig. 10 A. T-loop used for space closure, with bonded ceramic bracket on anterior FRC bar. B. Chain elastics used for space closure, with stainless steel wire for control.

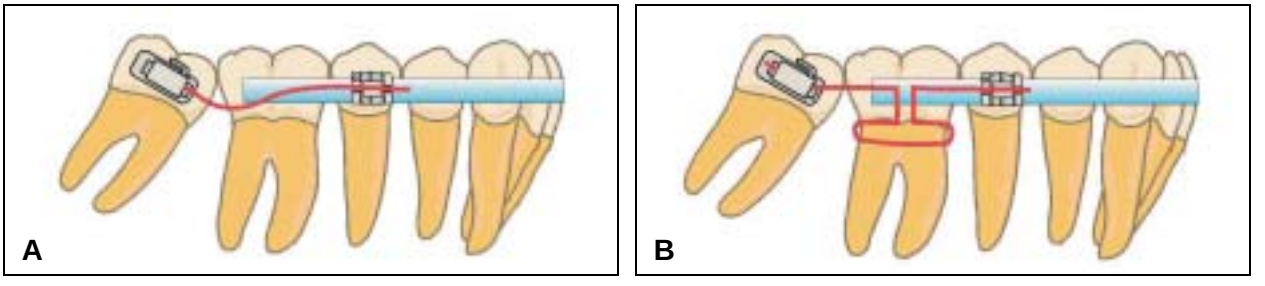

Fig. 11 Uprighting second molar with a full FRC arch from first molar to first molar. Absence of brackets allows greater, more efficient interbracket distance between bonded attachments. A. With straight archwire segment. B. With T-loop.

et is bonded to the second molar. A large interbracket distance can be created, increasing the efficiency of the appliance.

When a posterior segment in either the maxillary or mandibular arch is tipped forward, a tipback spring to a tube on the posterior FRC segment can be used to tip the segment back as a unit (Fig. 12). A wire is placed through a bracket or tube on the anterior segment to engage the tipback spring as it is brought occlusally, producing

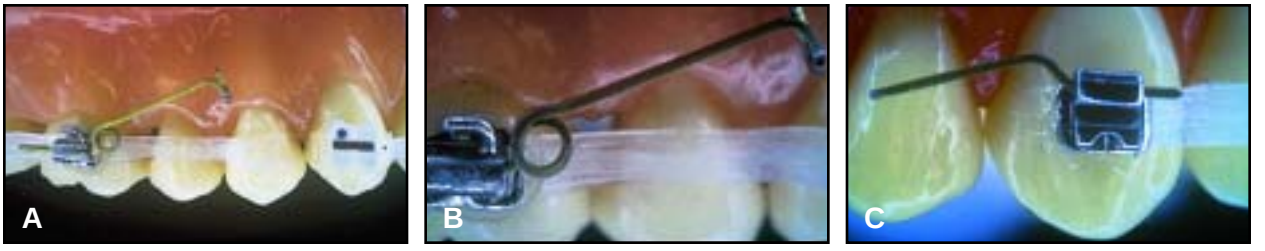

Fig. 12 A,B. Uprighting posterior segments with tipback spring (anterior wire not shown). C. Distal wire extension from bonded bracket-tube on anterior FRC bar.

the tipback moment.

En masse lingual root movement of the six anterior teeth can be accomplished with a helical root spring to a bonded tube on the anterior FRC (Fig. 13). A continuous metal archwire from a posterior tube is needed to hook the spring occlusally and prevent the anterior teeth from erupting or flaring.

For patients with deep overbite, a continuous metal intrusion arch can be attached to a bonded tube on a posterior FRC anchorage bar (Fig. 14). The intrusion arch delivers a single force at a hook bonded to the anterior segment. Following the overbite correction, whether by incisor intrusion or by extrusion of the posterior teeth, brackets may have to be placed to continue the orthodontic treatment; in any case, it is advantageous to correct the deep overbite before proceeding with fully bracketed appliances.

In cases with flared incisors, a three-piece intrusion arch may be preferable to the continuous intrusion arch. A bracket can be placed in the region of the lateral incisor, with a metal posterior extension to direct the force through the center of resistance. This posterior extension wire can also be angled to direct the force through and parallel to the long axes of the incisors.

Another approach for anterior intrusion is to place round wire segments between the incisors before curing the anterior FRC bar. These wires will create channels for metal ligatures to tie the intrusion arch in place (Fig. 15), eliminating the need for a bonded hook.

Various forms of interdisciplinary treatment are possible with FRC arches. The patient

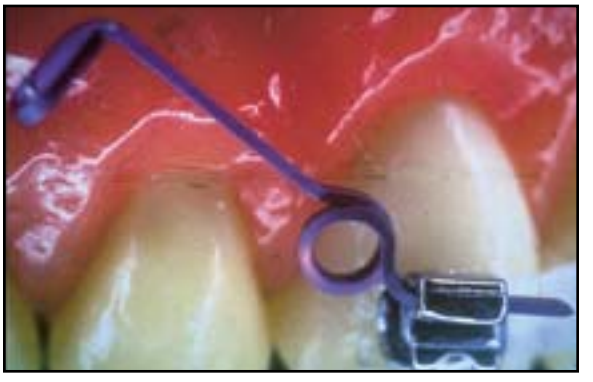

Fig. 13 Anterior lingual-root-torquing spring used in combination with stainless steel archwire to prevent incisor flaring or extrusion.

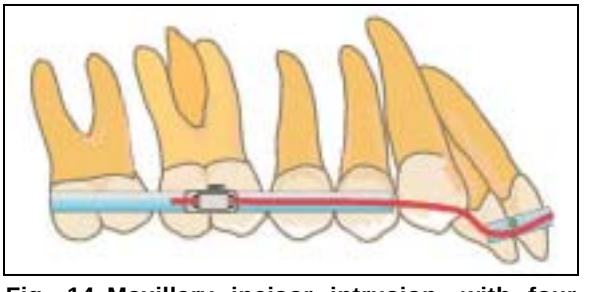

Fig. 14 Maxillary incisor intrusion, with four incisors joined to form active connector. Tube is placed on posterior connector, and continuous TMA intrusion arch applies force at bonded button or hook on anterior segment.

in Figure 16 had a devitalized maxillary right cuspid that was to serve as the distal abutment of a six-unit anterior bridge. The crown was

Fig. 15 Mandibular incisor intrusion arch. A. Vertical wires placed before curing incisor FRC bar to form channels for ligature wires. B. FRC bar after curing. C. Intrusion arch tied into place.

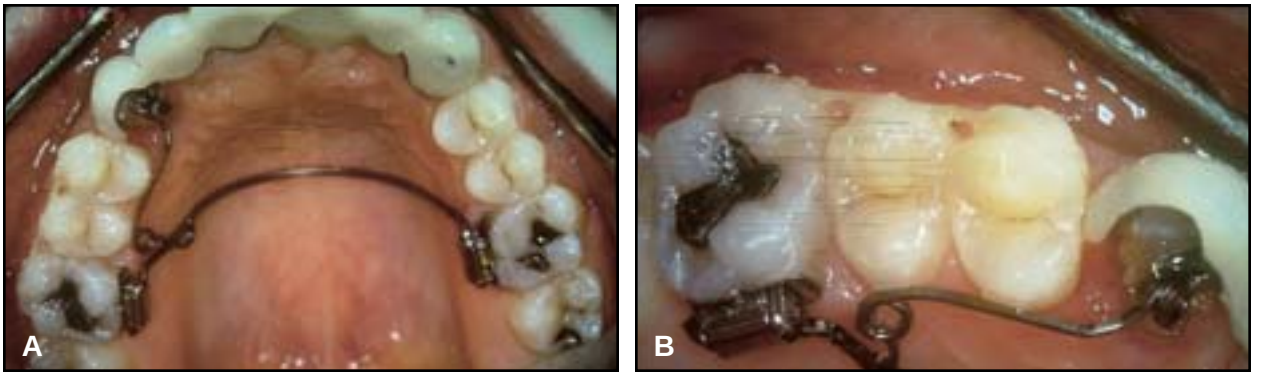

Fig. 16 A. Bonded posterior anchorage bars and bonded precision lingual arch used to erupt cuspid root and enhance crown replacement. B. Finger spring attached to lingual arch.

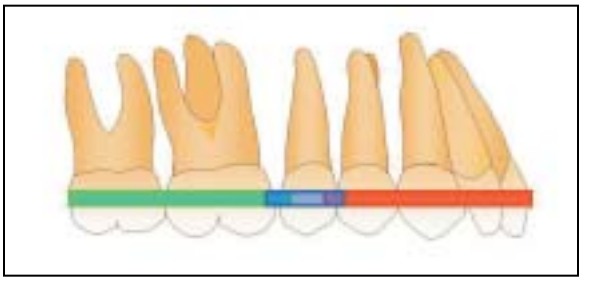

Fig. 17 FRC bars can be repaired or modified by removing section and bonding replacement connector between segments (green = posterior segment; red = anterior segment; blue = new connector).

removed, and the root had to be extruded occlusally so that a more satisfactory crown could be made. No bands were used; instead, posterior FRC anchorage bars were bonded from the first bicuspids to the first molars. A bonded precision lingual arch was placed to further enhance anchorage, and a cantilever spring to a bonded hook on the cuspid was used to extrude the cuspid root.

One of the advantages of an FRC is its ease of modification. If greater rigidity is required, more layers can be added. Attachments can easily be repositioned or replaced with entirely new attachments of different designs. Part of an FRC can be cut off with a bur, and a new FRC strip can be bonded to connect the remaining segments into a continuous unit (Fig. 17).

Passive Applications

The ease of use and mechanical properties of the FRC also make it suitable for purely passive applications. One of the most common is a bonded tooth-to-tooth retainer (Fig. 18). The FRC assures good esthetics—unlike a metal

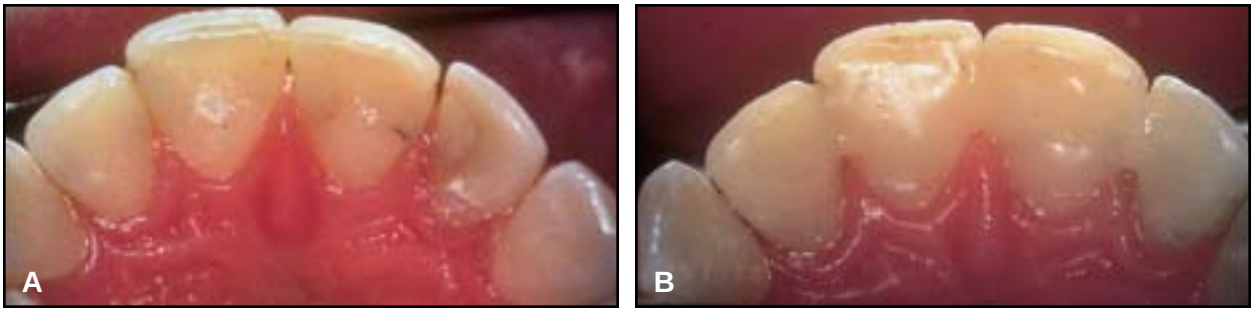

Fig. 18 Maxillary lingual bonded FRC retainer. A. Patient after closure of diastema. B. After bonding of 2mm-wide unidirectional strip.

wire, which is not only visible from the lingual, but can affect the translucency of the teeth as observed from the labial.

Bonded metal bridges, sometimes called Maryland bridges, have been used to replace missing lateral incisors. These bridges are technique-sensitive, however, so that bond failures are often observed. A bonded FRC bridge is more esthetic and, because of its greater resilience, is more stable and less sensitive to procedural errors. A framework is built to connect the pontic to the abutment tooth (Fig. 19A), and the pontic is then attached with a direct composite build-up (Fig. 19B). An alternative approach is to make the bridge indirectly on casts in the laboratory. The indirect procedure has the advantages of saving chairtime and allowing a better color match of the replacement pontic to the adjacent teeth.

Discussion

Long-fiber-reinforced composite materials have the potential to replace metals in clinical orthodontics. Unlike metals, an FRC has good bonding characteristics not only to the tooth, but to the appliance itself. An FRC can be bonded to another FRC, and attachments can be added directly. Biocompatibility is not a concern, as it can be with stainless steel and other metals.

FRC materials are superior to polymers alone, because they offer a structural material of improved rigidity and strength as well as a reduction in stress relaxation. They are highly form-

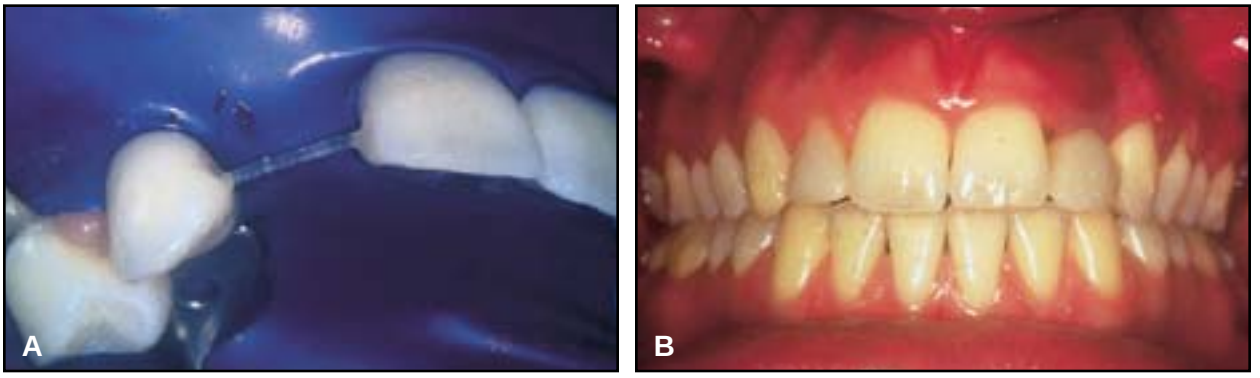

Fig. 19 Bonded FRC bridge replacing missing lateral incisor. A. Connecting FRC framework uses lingual bar, to which pontic is attached by direct composite build-up. B. Finished bridge. (Case courtesy of Dr. Martin Freilich.)

able and can be fabricated in complex shapes. While it is almost impossible to bend an archwire to be perfectly passive, an FRC can be easily contoured into either a passive or an active unit. Layers can be added to change the shape or to improve rigidity. Bars and other appliance shapes can be precisely contoured to the teeth, so that the adhesive layer is uniformly thin and hence stronger.

A light-cured FRC pre-preg provides a user-friendly means of appliance construction. FRC appliances can be fabricated either directly in the mouth or indirectly on models. If an appliance needs to be modified, portions can be cut away and a new FRC connector can be bonded. This allows quick and easy repair of broken appliances and enhances customization.

Although passive applications of retainers and bridges are somewhat obvious, FRC materials also have the potential to radically alter some of our current methods of active treatment. The glass fibers are so translucent that they are difficult to see even on the labial surfaces of the anterior teeth, making the FRC an esthetic alternative to lingual orthodontics. In adults with bridges or other fixed prostheses, FRC connectors can be placed without bridge removal.

There is much to be said for using an FRC in an initial phase of treatment, before bracket placement, to alleviate problems such as deep overbite or open bite and eliminate many of the undesirable side effects of leveling. Additionally, if problems develop after brackets have been removed, an FRC appliance offers an alternative to minimize or to eliminate further bracket placement.

Patients who need only partial or compromise treatment are good candidates for FRC appliances. For example, if anterior or posterior tooth alignment is relatively good, segments can be joined with a connector, and only one tube or bracket may be needed. Similarly, mixed-dentition cases may be better handled with an FRC appliance than with a multibracketed technique.

What are the limitations of fiber-reinforced composites? Although FRC bars are extremely strong and rigid in tension, and somewhat less so in the bending mode, they are weakest in shear and torsion. Unlike metals, these are not homogeneous materials; therefore, shear loads should be minimized as much as possible. As with bracketed appliances, a good bonding technique is required. Bridges and retainers, which must serve for long periods of time, require especially good bonding conditions.

This article is only an introductory glimpse at some of the possibilities of treatment using state-of-the-art polymers and the potential for development of new techniques and procedures.

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