Fracture Characteristics of Fiber Reinforced Composite Bars Used To Form Rigid Orthodontic Anchorage Units

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Abstract:

Objective: The aim of this study was to evaluate fracture characteristics of rigid two-tooth segments splinted with fiber reinforced composite (FRC), with and without application of simulated masticatory forces.

Material and Methods: In this experimental study, 80 extracted maxillary bicuspids were joined in pairs from the buccal aspect using FRC. The specimens were divided into two groups. In group A, the fracture load of FRC was measured. The 20 specimens of group B were initially loaded in a chewing simulator machine for 4 × 10^5 cycles to simulate a two-year chewing period. Samples that withstood these loads were assessed for fracture load. The results were compared using student t-test. Stereomicroscopic evaluation of fracture areas was performed to determine the fracture pattern.

Results: None of the specimens in group B failed during application of simulated masticatory forces, meaning that the survival rate was 100%. Mean (standard deviation) of fracture loads in groups A and B were 195.80 (14.345) and 190.57 (24.027), respectively. No significant difference was found in mean fracture loads between the two groups. The overall fracture pattern was similar in both groups.

Conclusions: FRC bars demonstrated sufficient durability to withstand chewing forces within the chewing simulation period. The fracture loads were higher than the mean mastication forces and remained almost unchanged after application of these forces.

Key Words: Fiber reinforced composites; Fracture load; Masticatory forces

INTRODUCTION

Fiber reinforcement was introduced to clinical dentistry for the first time in the 1960s, when investigators attempted to reinforce polymethyl-methacrylate dentures with glass or carbon fibers [1,2]. It has recently been shown that crowns, bridges and posts made of FRC can be used successfully in dental practice and they possess adequate flexural modulus [3], flexural strength [3,4] and fracture strength [5,6].

Initial application of FRC in orthodontics was limited to bonded lingual retainers [7]. In a clinical study, Rose et al [8] found that retainers made of plasma-treated woven polyethylene ribbons remained in place for approximately 11.5 months. Fallis and Kusy [9] introduced a novel esthetic glass fiber-reinforced composite wire for specific purposes with reasonable patient acceptance and structural integrity. Burstone and Kuhlberg [10] presented a new clinical use of FRC to make an esthetic connecting bar utilized as an adjunct for active tooth movement. In this application, teeth were
connected by FRC to form anchorage or movement units and attachments such as brackets, tubes and hooks were directly bonded to the FRC as needed (Fig. 1). Although this design can not be used in all stages of comprehensive orthodontic treatment, its great advantages such as simplicity, esthetics, biocompatibility, obviating the need for a full set-up and reducing the need for bonded attachments and wires, make it a good candidate for partial or adjunctive orthodontic treatment. In this application, bonding and fracture characteristics of FRC under masticatory forces would be of great importance. Meiers [11] and Freudenthaler [12] showed a good bond strength of FRC to enamel and an excellent bonding of orthodontic attachments to FRC, respectively.

On the other hand, a problem with rigid connection of teeth is independent physiologic tooth movement during function in contrast to the inherent brittleness and rigidity of composites. Thus the results of clinical reports on direct splinting of dental segments with composite were consistently discouraging, demonstrating breakage or fracture of the adhesive within a few weeks or months [13,14]. Addition of fibers to composites has improved their flexural properties to an extent that has made FRC a good candidate even for prosthetic bridges [3,4]. Different bonding locations and loading conditions have been reported for FRC when used for splinting teeth from the buccal aspect; therefore further investigation is required in this field.

The aim of the present study was to determine if FRC bars joining adjacent teeth would remain intact under forces simulating a 2-year period of intraoral function. The influence of simulated masticatory forces on the fracture characteristics of FRC bars was also evaluated.

MATERIALS AND METHODS

In this in vitro study, 80 intact and recently extracted maxillary bicuspidis with normal anatomy were collected and stored in a normal saline solution (sodium chloride, 0.9%). Forty plastic cylinders (25mm in diameter x 20mm in height) and self curing polymethyl methacrylate (PMMA) resin (Acropars, Iran) were used for mounting the teeth in pairs. The size and shape of all premolars were similar and each pair was positioned in full proximal contact so that their marginal ridges were in full contact and their central grooves aligned. To create an artificial PDL, the roots were covered with a 0.1-0.2 mm-thick layer of polysiloxane impression material (Speedex, Coltene, Switzerland), before mounting to allow for physiologic tooth movement under masticatory forces [15]. Measurements were made using a thickness gauge (Iwanson caliper, Hu Friedy Mfg. co, Chicago, Ill).

The buccal surfaces were cleaned with a brush and pumice powder, then etched with 35% phosphoric acid (Ultra-Etch, USA) for 20 seconds, rinsed for 10 seconds and dried. To limit and unify the etched areas in all teeth, a 2.5 x 4 mm rectangle was punched in PVC tape and fitted on the center of the buccal surfaces before etching.

A thin layer of bonding resin (Excite, Ivoclar-Vivadent Inc, Liechtenstein) was applied and cured with a light curing unit (Astralis-7, Ivoclar-Vivadent Inc, Liechtenstein) at low power mode (LOP, 400 mW/cm²) for 20 seconds, followed by application of the composite (Tetric-Ceram, Ivoclar-Vivadent Inc, Liechtenstein). A 3-mm-wide and 12-mm-long reinforcement strip (Ribbond; Ribbond Inc, Seattle, Washington) was saturated with a bonding agent.
(Excite, Ivoclar-Vivadent Inc, Liechtenstein) and firmly adapted onto the underlying composite and enamel surface according to the manufacturer’s instructions. By this approach, maximal contact along with a minimal thickness of composite was obtained. Ribbond is a commonly used and commercially available FRC and was therefore employed in the present study. Any excess composite expressed outside the strip was removed.

Next, a thin layer of flowable composite (Tetric-Flow, Ivoclar-Vivadent Inc, Liechtenstein) was applied on the fiber/composite combination, and cured with the same unit at high power (HIP, 750 mW/cm²) for 40 seconds from the buccal aspect of each tooth. The procedure was repeated for all teeth, resulting in 40 specimens, each consisting of 2 teeth splinted with FRC.

After 24 hours storage in normal saline, the samples were randomly divided into two equal groups. In group A, fracture load of FRC was measured with a universal testing machine (Instron corp, Canton, Mass) at a crosshead speed of 5 mm/min. The specimens were oriented in the positioning jig, so that the blade of the crosshead loaded the FRC bar vertically, on the mid point of the FRC bar in the interdental area (Fig. 2). The blade was positioned exactly in the mid point, between the teeth to apply similar flexural forces on each tooth.

The specimens in Group B were placed in a chewing simulator machine operated for $4 \times 10^5$ cycles at 14 N loads with a frequency of 3 Hz and duration of 0.2 seconds. This was equivalent to two years of mastication [16] (Fig. 3). After mechanical loading, all samples were evaluated for bond failure or fracture. The ratio of intact teeth to the total number of specimens was considered as the survival rate. Intact specimens were then evaluated for fracture load similar to group A, and data was recorded in Newton. The results were statistically analyzed and compared between the two groups using Student $t$-test.

Fracture pattern was evaluated by a stereomicroscope (Olympus SZH10, Tokyo, Japan) at ×10 magnification and classified into 4 categories [11]:
1) Adhesive failure at the enamel surface when more than 75% of the enamel was exposed.
2) Cohesive failure in the composite material between FRC and the enamel surface when more than 75% of the composite was exposed on both fractured surfaces.
3) Adhesive failure at the FRC interfaces when more than 75% of FRC was exposed on one of the fractured surfaces.

![Fig. 2: Location of cross head and force application for the measurement of fracture load.](image)

![Fig. 3: Teeth under simulated masticatory forces.](image)
4) Cohesive failure within the FRC when more than 75% of FRC was exposed on both fractured surfaces.

RESULTS
None of the specimens in Group B showed bond failure or fracture after mechanical loading. In other words, a 100% survival rate was encountered in Group B. Means (standard deviations) of fracture loads in groups A and B were 195.80 N (14.345) and 190.57 N (24.027), respectively. Student t-test showed no significant difference in mean fracture loads between the two groups (P > 0.05).

Figure 4 presents the distribution of different fracture patterns in the two groups. The overall fracture pattern was similar in both groups and occurred in the following order: on the enamel surface, the FRC interface and on the composite material between the FRC and enamel surface. No fracture was observed within the FRC.

DISCUSSION
Anchorage units or units for active tooth movement can be formed by rigidly joining dental segments using fiber reinforced bars [12]. This study was designed to test the efficacy of fiber-reinforced bars when used for anchorage reinforcement or segmental tooth movement.

Previous reports on FRC restorations have demonstrated sufficient fracture strength and favorable durability of FRC fixed partial dentures under chewing forces [6]. However no similar study seems to have evaluated the survival rate of splinted posterior segments made by FRC.

In the present investigation, none of the specimens developed fracture under simulated masticatory forces. This means that, despite the fact that all teeth could have independently moved within their artificial PDLs, the FRC connecting bars did not show evidence of fracture or bond failure under these forces. Therefore it appears that FRC connecting bars have sufficient flexural properties and durability. Fallis and Kusy in a short-term clinical study found no fracture in fiber reinforced composite wires used for retainers [9]; but in another report, the survival time of lingual orthodontic retainers made by FRC was only 11.5 months [8]. These investigations were conducted on lingual retainers and are not comparable to the current study. This is due to the fact that force application on the buccal surfaces of posterior segments is completely different from those applied on the lingual surfaces of lower anterior teeth.

We tried to assess fracture strength of FRC bars under chewing forces. According to Freilich et al [4], these forces are completely different from those applied by orthodontic appliances or delivered to the brackets attached to the FRCs by elastics or archwires.

Mean values for fracture load of FRC bars, with and without application of masticatory forces were 195.8 N and 190.57 N, respectively (P>0.05).

Various studies have described different average forces during mastication; for example, amounts of 14 [16], 45 [17] and 120 N [18] have been reported in the literature. It is
conceivable that FRC bars used for connecting teeth can tolerate such forces. On the other hand, maximum biting forces of more than 500 N have been described [19,20] which is extremely higher than the fracture load of FRC. It can be concluded that FRC bars normally have sufficient and acceptable strength for clinical application under average mastication loads; however heavy biting forces can break them, a situation which is also true for bonded orthodontic brackets [21].

Stereomicroscopic evaluation of fracture areas showed that in both groups, fractures occurred mainly at the enamel-composite interface. Therefore, it may be postulated that application of masticatory forces does not change the fracture pattern or the fracture load.

It should be mentioned that in new generations of pre-impregnated FRC bars, fibers and matrices are commercially integrated and therefore chair-time is shorter than that required for non pre-impregnated FRCs.

Based on the findings of the present study, the authors suggest further investigation on the clinical properties of FRC for integrating dental segments, especially in oral environments.

CONCLUSION

Within the limitations of this experimental investigation, the following conclusions were drawn:

1- FRC bars joining teeth had sufficient flexural properties and durability to withstand chewing forces simulating a two-year intraoral function.

2- Fracture loads of FRC bars were higher than the mean masticatory forces and remained almost unchanged after application of simulated masticatory forces.

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