Fracture characteristics of fibre reinforced composite bars used to provide rigid orthodontic dental segments

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Background: Fibre reinforced composites (FRC) can be used to join teeth as a rigid unit for anchorage purposes and/or for tooth movement. The utility of FRCs for these applications depends on the fracture characteristics and durability of the material under masticatory loads.

Aims: To evaluate the effect of simulated masticatory loads on the fracture characteristics of FRC bars joining two bicuspids.

Methods: Eighty extracted maxillary bicuspids were used. Pairs of bicuspids were joined with FRC bars on the buccal surfaces. The specimens were divided into two equal groups. In group A the fracture loads of the FRC bars were measured, and in group B the specimens were placed in a simulator and subjected to 4×10^5 chewing cycles, simulating a 2-year period of mastication. At the conclusion of this test the fracture loads of the FRC bars were measured in the intact specimens. All specimens were examined stereomicroscopically to determine the fracture pattern.

Results: There were no bond failures in group B during the simulated masticatory forces. The mean fracture loads in groups A and B were 195.8 N and 190.6 N, respectively. Stereomicroscopic examination showed that most fractures occurred at the enamel-composite interfaces in both groups. There were no significant differences between the groups in the fracture loads and fracture patterns.

Conclusions: Fibre reinforced composite bars bonded to bicuspids had sufficient durability to withstand the loads simulating a 2-year period of function. The fracture loads and fracture patterns of the FRC bars were not affected by the loads exerted by the simulator.

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Introduction

Glass and carbon fibre reinforced polymethylmetacrylate dentures were introduced to clinical dentistry in the 1960s.[1,2] Previous studies have reported that FRC has an appropriate flexural modulus,[3] flexural strength[3,4] and fracture strength[5,6] for fixed partial dentures. Fibre reinforced composites have been used in bonded lingual retainers,[7,8] in a novel but seldom used glass fibre reinforced composite 'wire',[9] to join adjacent teeth as an anchorage unit or for en masse movement[10–12] and in space maintainers.[13,14] Fibre reinforced composite is relatively straight-forward to use, it is biocompatible and tooth-coloured, and brackets, tubes and hooks can be directly bonded to it.[12] It is a material suited to partial or adjunctive orthodontics, particularly in adult patients with advanced periodontal disease or patients who are concerned about the appearance of conventional fixed orthodontic appliances.

Although FRC bonded to enamel has acceptable bond strength[15] and orthodontic attachments can be bonded to it,[16] further information is needed on the behaviour of FRC bars under masticatory loads. During mastication, adjacent teeth often move independently of each other and, as a result, composite bars without fibre reinforcement either fracture or debond.[17,18] The addition of fibres to composites has been shown to improve the physical behaviour of the material to such an extent that FRCs are used in prosthodontic bridges.[3,4]

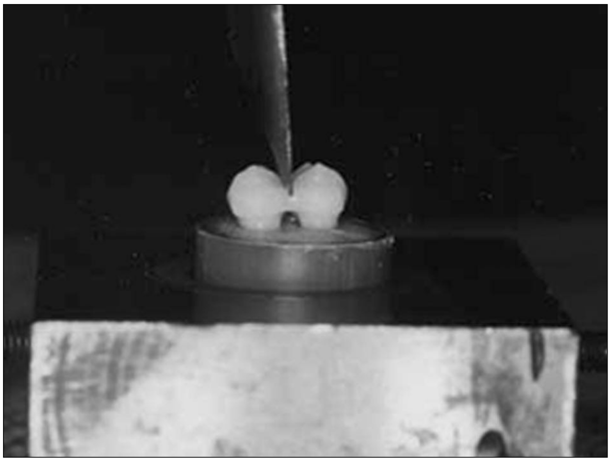

Figure 1. Location of the crosshead on the FRC bar.

Figure 2. A specimen in the simulator.

The aims of this study were to determine if FRC bars bonded to adjacent teeth will remain intact under the loads simulating a 2-year period of intra-oral function, and to determine if the fracture characteristics of FRC bars are affected by simulated masticatory forces.

Materials and methods

In this in vitro study, 80 recently extracted intact maxillary bicuspids with normal anatomy were collected and stored in normal saline solution until required. The teeth were removed from the saline, allowed to dry in air and the roots covered with a 0.1–0.2 mm thick layer of vinyl polysiloxane impression material (Speedex, Coltene AG, Alstatten, Switzerland). The intention was to create a flexible layer, simulating the periodontal ligament, that would allow the teeth to move independently under simulated masticatory loads.[19] Pairs of bicuspids were matched in shape and size and mounted in plastic cylinders (25 mm x 20 mm) with an autopolymerising resin. The bicuspids were mounted with their proximal surfaces in contact, with the marginal ridges at the same level and the central grooves aligned.

The buccal surfaces of the bicuspids were cleaned with a rotating prophylaxis brush, pumice and water and the buccal surface of each tooth masked with PVC tape. A 2.5 mm × 4 mm rectangular window in the tape left the central area of the buccal surface clear for etching. The teeth were etched with 35 per cent phosphoric acid for 20 seconds, rinsed for 10 seconds and dried with air. A thin layer of bonding resin (Excite, Ivoclar-Vivadent, Schaan, Liechtenstein) was applied and cured with a light unit (Astralis-7, Ivoclar-Vivadent, Schaan, Liechtenstein) using the low power program (400 mW/cm^2) for 20 seconds. Tetric-Ceram composite (Ivoclar-Vivadent, Schaan, Liechtenstein) was then applied to the resin. A 3 mm × 12 mm strip of Ribbond (Ribbond Inc, Seattle, Washington) saturated with the bonding resin was adapted to the composite. Any composite expressed outside the strip was removed. Next, a thin layer of a flowable composite (Tetric-Flow, Ivoclar-Vivandent, Schaan, Liechtenstein) was applied to the fibre/composite combination and cured with the Astralis-7 unit using the high power program (750 mW/cm^2) for 40 seconds. The curing unit was placed on the buccal aspect of each tooth. The procedure was repeated for all specimens.

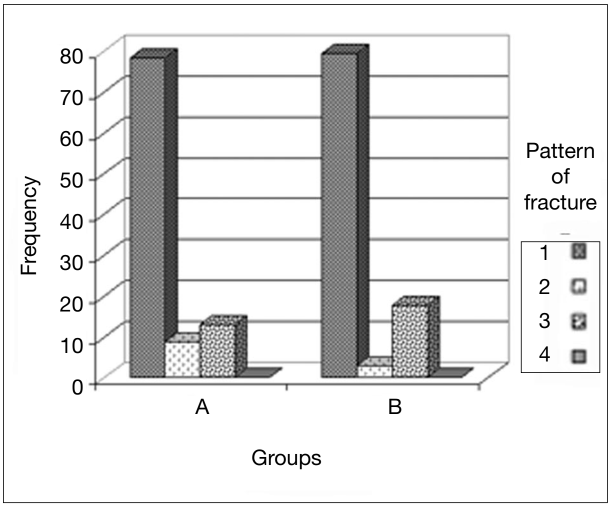

Figure 3. Pattern of failure.
1. Adhesive failure at the enamel-composite interface.
2. Cohesive failure in composite between enamel surface and FRC.
3. Adhesive failure at the FRC interface.
4. Cohesive failure in the FRC.

Table I. Fracture strengths of the FRC bars linking two bicuspids.

Group	Total	Mean (N)	SD (N)	SEM (N)
A	20	195.8	14.34	3.21
B	20	190.6	24.03	5.37

Student *t*-test, not significant

After 24 hours storage in normal saline, the specimens were randomly divided into two equal groups. In group A, the fracture load (N) of each FRC bar 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 at the midpoint interdentally (Figure 1). The specimens in Group B were placed in a chewing simulator machine operated for 4×10^5 cycles at 14 N loads with a frequency of 3 Hz and duration of 0.2 seconds. This simulated two years of mastication (Figure 2).[20] At the conclusion of this test specimens were inspected for bond failure or fracture, and the ratio of intact specimens to initial specimens reported as the survival rate. The load (N) required to fracture each intact specimen was then determined using the methods described for group A. The data obtained for the groups were compared with the Student *t*-test.

Each specimen was then examined with a stereomicroscope (Olympus SZH10, Tokyo, Japan) at ×10 magnification and the fracture pattern classified as follows:

1. Adhesive failure at the enamel surface (enamel exposed on more than 75 per cent of one of the fractured surfaces).

2. Cohesive failure in the composite material between FRC and enamel surface (composite exposed on more than 75 per cent of both fractured surfaces).

3. Adhesive failure at the FRC interface (FRC exposed on more than 75 per cent of one of the fractured surfaces).

4. Cohesive failure within the FRC (FRC exposed on more than 75 per cent of both fractured surfaces).

The fracture patterns in the groups were compared with the Chi-square test.

Results

As all specimens in Group B were intact at the end of the test simulating the forces of mastication the survival rate of the FRC bars was 100 per cent. The mean loads required to fracture the specimens in groups A and B were 195.8 N (SD: 14.34) and 190.6 N (SD: 24.03) respectively (Table I). There was no significant difference between the mean fracture loads of the two groups ($p > 0.05$).

The distributions of the fracture patterns in the two groups are shown in Figure 3. In both groups most fractures occurred at the enamel-composite interface. The Chi-square test revealed that the fracture pattern was independent of the groups: i.e. the fracture pattern was similar in both groups.

Discussion

Fibre-reinforced composite bars can be used to join teeth to form rigid anchorage units or units for active tooth movement. This study was designed to determine if FRC bars bonded to adjacent bicuspids would survive the loads simulating two years of mastication, and to determine if the fracture characteristics of the FRC bars were affected by the simulated masticatory forces. The results indicated that FRC bars linking the bicuspids had sufficient durability to withstand the simulated masticatory forces, and these forces did not have adverse effects on the fracture characteristics of FRC bars. Although previous studies have demonstrated the durability of FRC fixed partial dentures under chewing forces,[6] no similar study has been carried out on the survival rate of posterior teeth joined with FRC.

In our study, we attempted to reproduce the periodontal ligament by covering the roots of the teeth with a thin layer of vinyl polysiloxane impression material. We assume the flexible layer allowed the teeth to move independently of each other under the simulated masticatory loads. The FRC connecting bars had sufficient strength and durability to remain intact for the entire period of the study. Fallis and Kusy,[9] in a short-term clinical study, found no fractures in fibre reinforced composite wires used for retainers, but Rose et al.[8] reported that the survival time of FRC lingual orthodontic retainers was only 11.5 months.

The FRC bars had fracture loads between 190 and 195 N, which compares favourably with the range of forces (45 to 120 N) experienced during mastication.[21,22] We consider that FRC bars may have sufficient fracture strength to tolerate normal masticatory forces but not maximum biting loads, which can be more than 500 N.[23,24] Patients should be warned that FRC bars are likely to fail if they are subjected to heavy biting forces that may occur during bruxism and clenching. The same situation applies to most bonded attachments and retainers.[25]

Stereomicroscopic examination of the fracture areas in both groups showed that the majority of fractures occurred at the enamel-composite interface (Figure 3). The patterns of failure were estimated so one must acknowledge that some bias may have occurred in our judgements of the sites of failure. Using the data we collected we were unable to demonstrate any significant difference in fracture pattern.

It is noteworthy that in the latest generation of preimpregnated FRC bars, the fibres and the resinous matrix are coupled during the manufacturing process. This process results in a higher concentration of fibres, more complete wetting, fewer voids and reduced chair time when placing FRC bars, as compared with the FRC method we used.[26] Based upon the results of the present study we suggest clinical investigations are now needed to determine the value of FRC bars bonded to two or more teeth.

Conclusions

Fibre reinforced composite bars linking bicuspids had sufficient durability to withstand the loads simulating a 2-year period of function. The fracture loads and fracture patterns of the FRC bars were not affected adversely by the loads exerted by the simulator.

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