Development and Testing of Fiber-reinforced Composite Space Maintainers

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ABSTRACT

Purpose: The purpose of this study was to develop a clinically acceptable, cheaper, and more expedient alternative to standard stainless steel band and loop space maintainers.
Methods: Loops of fiber-reinforced composites were constructed using polyethylene fiber (Ribbond) and glass fiber (Sticktech). The loops were bonded on extracted third molars and tested for flexural strength before and after thermocycling and following repair of the appliances after initial stress failure. Bacterial colonization on the appliances was also compared. Conventional stainless steel band and loop space maintainers cemented with Ketac were controls.
Results: Ribbond samples demonstrated higher flexural strength than Sticktech and the control ($P<.05$). No differences were noted among the other samples and the control. The repaired Ribbond samples were statistically comparable in flexural strength to the initial samples. Thermocycling resulted in decreased flexural strength of both Ribbond and Sticktech ($P<.05$). Thermocycled Ribbond samples were comparable to the control, but a lower flexural strength was noted for Sticktech samples ($P<.05$). While all space maintainers allowed some bacterial adhesion, Sticktech showed higher *Streptococcus mutans* counts than Ribbond ($P=.06$).
Conclusions: Ribbond space-maintainers are comparable to the stainless steel in terms of physical strength and biofilm formation. The fiber-reinforced composite space maintainers may be a clinically acceptable and expedient alternative to the conventional band-loop appliance.
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KEYWORDS: FIBER-REINFORCED COMPOSITE RESIN, SPACE MAINTAINERS, PHYSICAL PROPERTIES

Band and loop space maintainers are stainless steel appliances used to maintain arch space for a permanent tooth when a primary tooth is lost prematurely and the succedaneous permanent tooth has not erupted. Use of a band and loop space maintainer requires 3 steps. First, an impression of the arch is made. Second, a space maintainer is fabricated in the lab. Lastly, the custom-fabricated appliance is cemented in place with cement. Use of a space maintainer involves a clinician and a laboratory technician. Moreover, the procedure is time and labor intensive and, therefore, expensive. Presently, there are a few commercially available alternatives to this treatment, such as those by DENOVO and Unitek, which might not be suitable for all clinical situations.

Composites that are reinforced with polyethylene fibers or glass fibers can result in materials with enhanced mechanical properties.[1,2] Fibers produce a load-enhancing effect on brittle composite materials by acting as the stress-bearing component and as crack-stopping or crack-deflecting mechanisms.[2,3] Ramos et al[4] demonstrated that composite test bars containing Ribbond fibers (polyethylene fibers) had significantly higher fracture strength over nonreinforced test bars. Additions of fibers to composite resin have shown significant improvement in stiffness, strength, toughness, and fatigue resistance.

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Some of the clinical applications for these materials include inlay restorations, fixed partial dentures, and rigid splints. Their potential as space maintainers in the primary or mixed dentition has not been fully explored.

The purpose of this study was to develop a clinically acceptable alternative to the standard stainless steel band and loop space maintainer in the form of a fiber-reinforced composite space maintainer (FRCSM) prototype and to test various physical properties for its clinical suitability as an alternative to conventional metallic space maintainers.

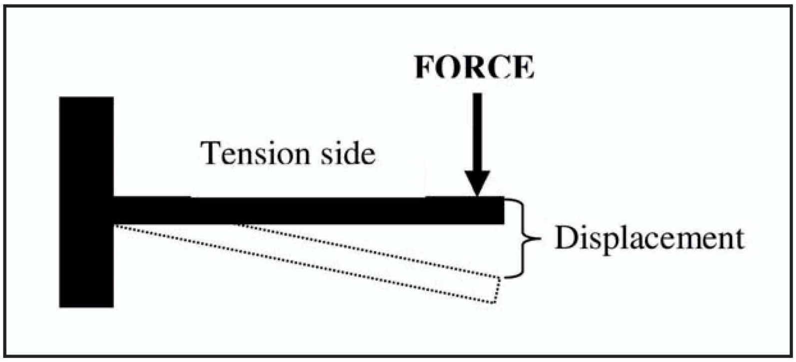

***Figure 1.** Flexural test or cantilever beam test.*

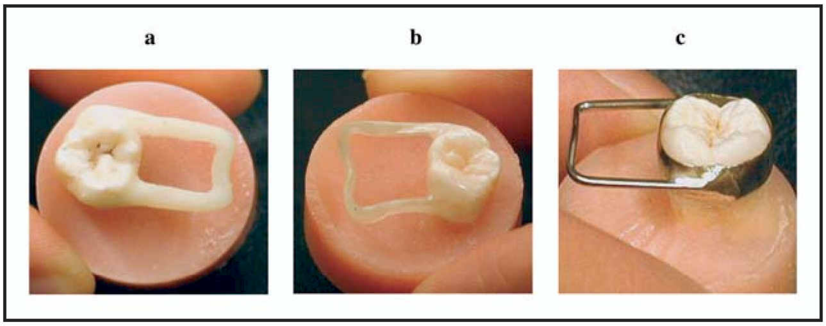

***Figure 2.** (a) Fiber-reinforced composite space maintainer (FRCSM) fabricated with Ribbond. (b) FRCSM fabricated with Sticktech. (c) Stainless steel band and loop space maintainers.*

METHODS

CONSTRUCTION OF FIBER-REINFORCED COMPOSITE LOOPS

Space maintainers were constructed using 2 commercially available fiber systems: (1) polyethylene fiber (Ribbond, Seattle, Wash); and (2) glass fiber (Sticktech, Turku, Finland). For each fiber, 40 mm was used to formulate 10 mm x 10 mm loops, leaving 5 mm of fiber on each end for attachment to extracted third molars. Ribbond fiber system loops 2 mm and 4 mm wide were constructed using a template to standardize the overall loop dimensions regarding length, width, and weight. The polyethylene fibers were wetted with unfilled adhesive resin (3M Scotchbond, 3M Corporation, London, and then covered with composite resin Restorative Z100 (3M Corporation) to produce a rigid surface. The surface was smoothened using finishing burs and soflex discs.

These loops were heat cured for 5 minutes and then attached to the molars via the acid etch technique. Teeth were etched for 30 seconds, rinsed with water, and dried just prior to bonding with Scotchbond. The Sticktech fibers were manually constructed into loops and also attached to the molars via the same acid etch technique. The Sticktech loops were coated with 1 layer of flowable composite resin (Revolution, Kerr, Orange, CA). Stainless steel band and loop space maintainers constructed with 0.8 mm wire were cemented with glass ionomer Ketac cement (N=5) or Duralon cement (N=5) and were used as controls (Figure 1).

FLEXURAL TEST

The samples were subjected to the cantilever beam test or flexural bending test on the Instron machine (Figure 2). The crosshead speed was set at 1 mm/minute and the position force set at 10 mm. The maximum force needed to break or dislodge the sample was recorded. The fractured Ribbond FRCSM were repaired using composite resin Restorative Z100 (3M) and retested on an Instron machine. Some of the samples were thermocycled for 500 cycles with a minimum temperature of 5°C and a maximum temperature of 55°C. The dwell time was set for 30 seconds, air time for 10 seconds, and transfer time for 5 seconds. The thermocycled samples were then subjected to the flexural bending test, and the maximum force needed to break the sample was recorded.

BACTERIAL COLONIZATION

Wild type Streptococcus mutans strain UA159 was cultured overnight in a 2 ml Todd-Hewitt-yeast extract (THYE) buffer. Samples were sterilized and placed in a 12 well plate containing 2 ml of THYE in each well. The samples were inoculated with 10 ml of bacterial culture and placed overnight in an incubator set at 37°C and 5% CO_2. Planktonic cells and the surrounding solution were removed from 3 of the samples in each group. The bacterial biofilm was sonicated off the samples in a 2 ml KPO4 buffer. The solution was then diluted 6 times, and the last 4 serial dilutions were plated on THYE plates. After a 48-hour incubation period, viable cell counts were performed. The other 2 samples in each group were subjected to scanning electron microscope analysis.

STATISTICAL ANALYSIS

Ten samples per group were used for each test. Mean values from all the tests were compared using analysis of variance and pairwise comparisons with Bonferroni corrections.

RESULTS

FLEXURAL TEST

The force needed to fracture the FRCSM or dislodge the stainless steel band and loop appliance was recorded. Examples of the graphs generated upon the flexural test are illustrated in Figure 3. The sudden decrease in force for the Ribbond sample represents the cracking of the composite surface. Since the attachment to the tooth and the polyethylene fibers within the composite remained intact, however, there was a rise in the force again. These samples were repaired with composite and retested and a similar graph was generated. The Sticktech samples never cracked. There was a fair amount of displacement observed before a decrease in force was noted. Furthermore, a separation between glass fiber and composite was observed. The graph for the stainless steel appliance was not completely smooth, due possibly to small amounts of cracking occurring in the cement before complete dislodgment of the band. No statistical difference was noted for the 2 cements used.

The 4 mm Ribbond demonstrated higher flexural strength than the 2 mm Ribbond, Sticktech, and stainless steel samples ($P<.001$, $P<.001$, $P<.002$, respectively; Figure 4). No difference was noted between the other experimental samples and the control. The repaired 2 mm and 4 mm Ribbond were statistically comparable in flexural strength to the initial samples. Thermocycling resulted in a significant decrease in flexural strength of 4 mm Ribbond and Sticktech ($P<.05$). While thermocycled Ribbond samples were comparable to stainless steel, significantly lower strength was noted for Sticktech samples ($P<.05$; Figure 5).

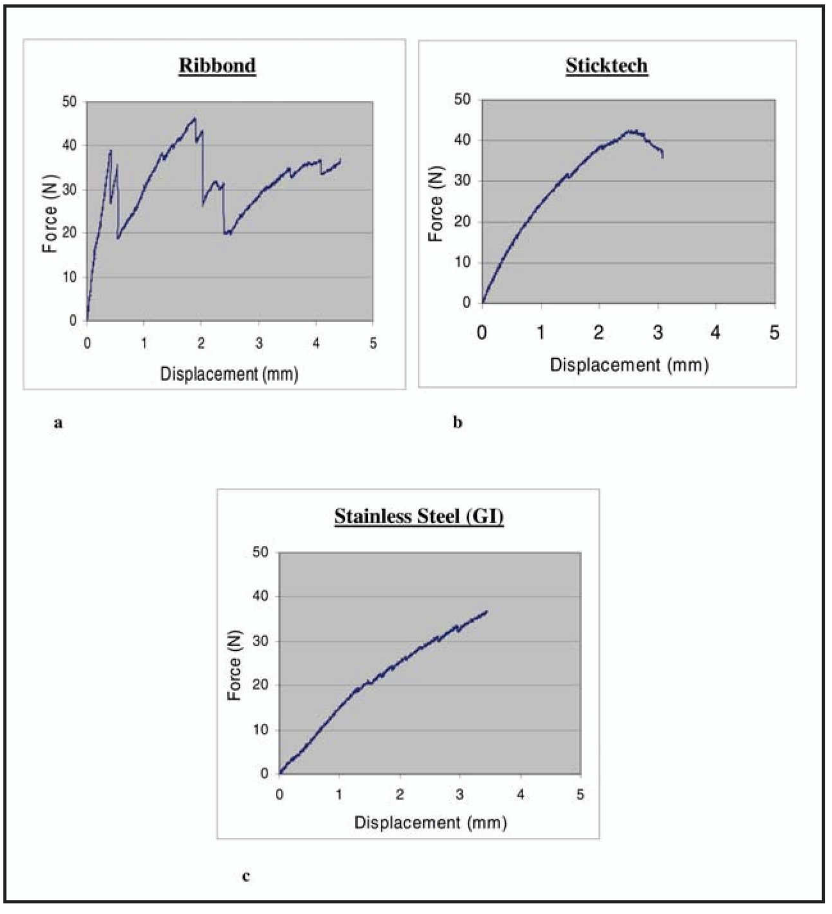

Figure 3. Force vs displacement curves for: (a) Ribbond; (b) Sticktech; and (c) stainless steel.

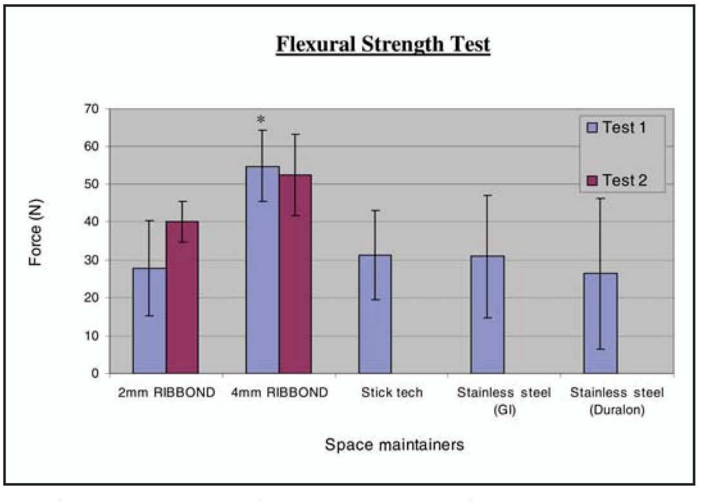

Figure 4. Test 1: 4 mm Ribbond demonstrated higher flexural strength than 2 mm Ribbond, Sticktech, and stainless steel samples (P<.05*).

**** No difference was noted between the other samples and the control. Test 2: The repaired 2 mm and 4 mm Ribbond (test 2) were not statis-tically different compared to their initial strength.***

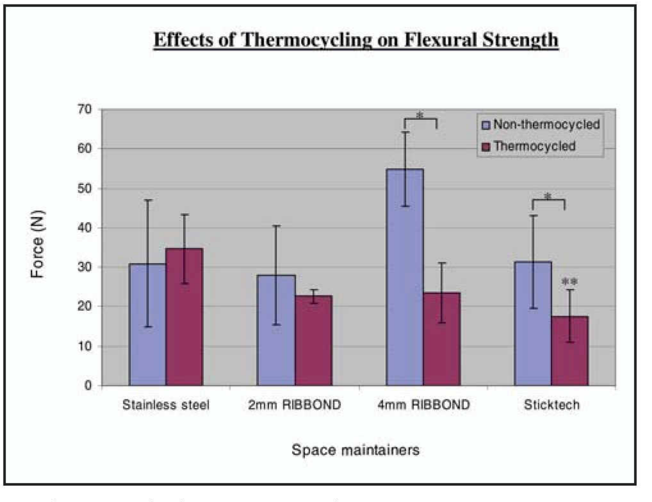

Figure 5. Significant decrease in flexural strength for 4 mm Ribbond and Sticktech after thermocycling (P<.05). Thermocycled Sticktech showed significantly lower strength compared to stainless steel (P<.05).

BACTERIAL COLONIZATION

Qualitative analysis of the samples under SEM revealed comparable amounts of *S. mutans* colonies adhering to the surface (Figure 6). Quantitatively, no difference in *S. mutans* counts were noted between the experimental and control groups. Higher bacterial counts were recorded, however, for Sticktech samples compared to Ribbond samples (*P*<.05; Figure 7).

DISCUSSION

Fiber-reinforced composite's potential as a space maintainer in the primary or mixed dentition has gained popularity in the past years.[5,6] These FRCSMs, however, are often rigidly bonded to teeth, which may adversely influence the growth and development, exfoliation of primary teeth that the maintainers are attached to, and eruption of the succedaneous permanent teeth. Moreover, their failure under stress or ability to form biofilms has not been studied. The FRCSMs in this study were designed to allow free movement of the individual teeth while maintaining proper separation space, simulating the conventional stainless steel band and loop space maintainer.

This study's results suggest that the Ribbond FRCSM is comparable to stainless steel in terms of physical strength and bacterial colonization. Sticktech FRCSM also displayed comparable strengths, however, there were other problems associated with this material. Firstly, the material was flexible and lacked rigidity, resulting in a greater amount of displacement for a given amount of force. Secondly, the glass fibers had separated from the matrix and the FRCSM was deformed. Therefore, it was difficult to repair these samples and the FRCSM was rendered useless. Furthermore, the thermocycling affected Sticktech's bond strength to the tooth considerably, since the flexural loading test resulted in its detachment from the tooth.

As aforementioned, the fibers within composites act as crack-stopping or crack-deflecting mechanisms for the brittle composite materials.[3] The fiber bridges act as toughening mechanisms where the crack permeates the composite matrix but leaves the fibers intact.[7] This coincided with our finding of the Ribbond FRCSM cracking on the surface. These cracks, which would be visible clinically, could easily be repaired using additional adhesive and composite resins, restoring the strength comparable to the initial sample.

Despite the rough surface revealed under the SEM for the FRCSM, the bacterial counts were statistically equivalent to the conventional band and loop appliance. These results suggest that these FRCSM will not attract more plaque compared to the stainless steel space maintainers. Previous studies have shown that polyethylene fiber composite had higher surface roughness and bound significantly more *S. mutans*.[8] This did not coincide with our findings, which could be due to the fact that the degree of polishing of the surface composite can vary and, therefore, result in differing amounts of bacteria adhesion.

LIMITATIONS

Since this was a pilot study to determine feasibility, only 10 samples per group per test were utilized. Future studies would have to be performed using a greater number of samples. Given that there might be differences in the bond strengths between primary as compared to permanent teeth, the results will have to be verified using primary molars. Heat and pressure treatment of the space maintainers prior to bonding on teeth would have improved the performance of the FRCSMs tested. A practical chairside method to reproduce this clinically, needs to be developed to replicate the high flexural strengths noted in in vitro testing.

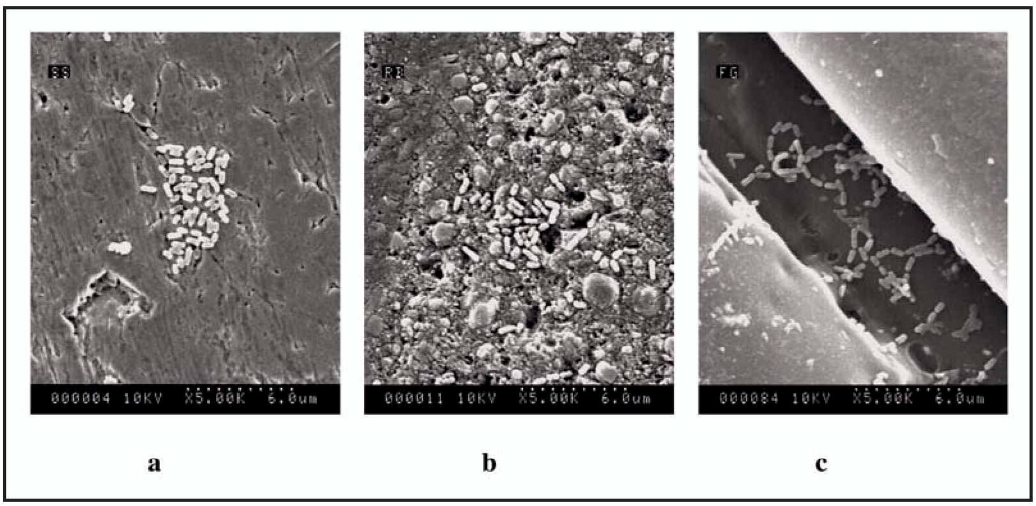

Figure 6. Bacteria adhering to: (a) stainless steel surface; (b) Ribbond fiber-reinforced composite space maintainer (FRCSM); and (c) Sticktech FRCSM (X5000).

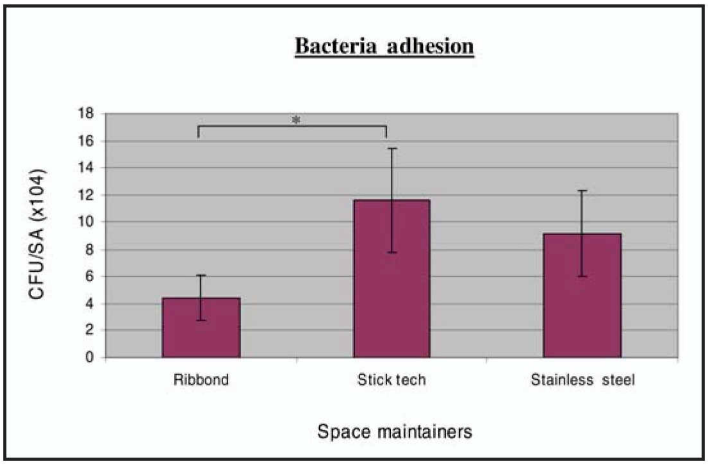

Figure 7. No difference in Streptococcus mutans counts were noted between the experimental and control groups. Higher bacterial counts were recorded for Sticktech samples compared to Ribbond samples (P<.05).

CONCLUSIONS

Based on this study's results, the following conclusions can be made:

1. Ribbond space maintainers are comparable to stainless steel in terms of physical strength and bacterial colonization.
2. Repaired Ribbond samples are comparable to original Ribbond samples in physical strength.

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