

The effect of box preparation on the strength of glass fiber–reinforced composite inlay-retained fixed partial dentures

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Statement of problem. Nonstandardized box dimensions for inlay-retained fixed partial dentures (FPDs) may result in uneven distribution of the forces on the connector region of such restorations.

Purpose. The objective of this *in vitro* study was to evaluate the effect of box dimensions on the initial and final failure strength of inlay-retained fiber-reinforced composite (FRC) FPDs.

Material and methods. Twenty-one inlay-retained FPDs were prepared using FRC (everStick) frameworks with unidirectional fiber reinforcement between mandibular first premolars and first molars. Boxes were prepared using conventional inlay burs (Cerinlay), and small and large ultrasonic tips (SONICSYS approx). Box dimensions were measured after preparation with a digital micrometer. All restorations were subjected to thermal cycling (6000 cycles, 5°C-55°C). Fracture testing was performed in a universal testing machine (1 mm/min). Acoustic emission signals were monitored during loading of the specimens. Initial and final fracture strength values (2-way ANOVA, Bonferroni post hoc tests, $\alpha=.05$) and failure types (Fisher exact test) were statistically compared for each group.

Results. Significant differences ($P=.0146$ and $P=.0086$) were observed between the groups in the dimensions of the boxes prepared using conventional burs buccolingually (2.8-3.0 mm in molars, 3.1-4.3 mm in premolars) and the small size (2.5-2.9, 2.9-3.8 mm) or large size (2.6-3.8, 3.2-4.9 mm) ultrasonic tips for the premolars and the molars, respectively. No significant differences were found at the initial and final failures between the conventionally prepared group (842 ± 267 N, 1161 ± 428 N) and those prepared with either small (1088 ± 381 N, 1320 ± 380 N) or large ultrasonic tips (1070 ± 280 N, 1557 ± 321 N), respectively. The failure analysis demonstrated no significant difference in failure types but predominant delamination of the veneering resin (85%) in all experimental groups. According to acoustic emission tests, a higher energy level was required for final failure of the FRC FPDs with boxes finished using small ultrasonic tips.

Conclusion. Standardized box dimensions showed no significant effect on fracture strength at either initial or final failure of the fiber-reinforced FPDs. The FRC FPDs with boxes refined with small ultrasonic burs required a greater energy level before failure. The type of failure observed after the fracture tests was primarily delamination of the veneering resin. (J Prosthet Dent 2005;93:337-45.)

CLINICAL IMPLICATIONS

In this in vitro study, the static initial strength of inlay-retained fiber-reinforced fixed partial dentures exceeded 900 N, which is reported as the maximum occlusal force in the molar region. The weakest features of such restorations remain the pontic area and the low resistance of the veneering resin composite against occlusal forces.

Resin-bonded fixed partial dentures (FPDs) with metal frameworks are considered a practical and conser-

vative approach in dentistry, but no documentation of long-term success, especially for the replacement of posterior teeth, could be identified.^{1,2} Repeated stresses can predispose these restorations to fatigue failures of the adhesive joint. By selecting materials with a lower modulus of elasticity than those of cast metal alloys, stress at the interface can be diminished.³ Currently, clinicians have a wide range of fiber-reinforced composites (FRC) to choose from. Fabrication of reinforcing polymers is not as simple as placing a fiber into a plastic. Factors affecting the durability of FRC restorations include the properties of the fibers, matrix, and polymer, impregnation of fibers with the resin, adhesion of fibers to the matrix, the

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quantity of fibers, and the direction, orientation, location, construction, distribution, and position of the fibers.^{4,5}

Clinicians are expected to satisfy the expectations of patients who seek safe, biocompatible, affordable, and esthetic restorations. However, clinicians are restricted by factors such as type of preparation, fiber frame design, span length, and the resin composite or luting agent.⁶ The few reports of successful use of FRC restorations in the peer-reviewed literature include clinical reports⁷⁻⁸ and a study with short-term follow-up.⁹ The primary failure types identified were either bulk fracture at the connector or pontic area, debonding of the veneering composite, or fiber exposure.

FRC restorations are expected to withstand masticatory forces. Different testing methods and the difficulty in measuring masticatory forces result in a wide range of force values. Stress applied during mastication may range between 441 N and 981 N, 245 N and 491 N, 147 N and 368 N, and 98 N and 270 N in the molar, premolar, canine, and incisor regions, respectively.¹⁰ A restoration should be able to withstand stress to approximately 500 N in the premolar region and 500 N to 900 N in the molar region.¹⁰

The mode of fracture is a good indicator of the path of crack propagation.¹¹⁻¹⁴ In general, stress concentrations within the resin and the interface are relieved by initiation of a crack and propagation of the crack through the resin until it meets the fiber,¹⁵ resulting in debonding of the resin composite. Failure of the FRC due to external force may occur by the cracking of the polymer matrix, the fiber, or the interface.^{16,17}

Internal cracking and fracturing of material can be evaluated by means of acoustic emission (AE) signals from the material.¹⁸⁻²⁰ AE, also known as “stress wave emission,” is the term that describes the acoustic stress waves that result when energy is rapidly released due to the occurrence of microstructural changes in a material during sudden movements.¹⁷ AE signals, which usually have broadband characteristics, can be collected by sensors in the AE transducers with an amplifier during the loading event.¹⁶ In a composite material, AE is highly sensitive and does not only detect crack growth and material deformation but also solidification, friction, impact, flow, phase transformations, and the stress released when matrix crazing, fiber breakage, debonding, or any other microstructural failure occurs.¹⁷ Advantages of using the AE method to test and analyze FRC include the ability to obtain real time data and the method’s high sensitivity to a process or mechanism within a composite material that generates AE signals.^{18,19}

The strength of FRCs is often reported as the ultimate flexural strength of the final fracture.^{21,22} A number of factors affect the strength of inlay-retained FPDs, one of which is the dimension of the preparation.²³⁻²⁵ Recently, instruments based on oscillating

principles have been introduced.²⁶ These instruments are coated with diamond on only one side, which helps to guide the instrument at the proximal areas, preventing accidental damage of the adjacent tooth as may occur with rotary instruments. Moreover, the coated side has a defined shape; for example, it is possible to prepare reproducible preparations with excellent margins.²⁷

This *in vitro* study evaluated whether a standardized approach to box preparation using ultrasonic burs would have an effect on the initial and final failure strengths and failure locations of inlay-retained FRC FPDs compared with the conventional preparation technique using conventional inlay burs. Also, the failure type and behavior of crack formation was evaluated with an acoustic emission test by recording audible sounds of cracking.

MATERIAL AND METHODS

The experimental design consisted of *in vitro* simulation of a typical clinical scenario in the mandibular right quadrant. Forty-two caries-free, restoration-free human mandibular right first premolars (N = 21) and first molars (N = 21) were embedded in autopolymerized poly(methyl methacrylate) (Palapress Vario; Heraeus Kulzer, Hanau, Germany). A distance of 7 mm was established between the 2 abutment teeth. The teeth were stored in 0.01% *n*-chloro-*para*-toluene sulfonamide sodium salt (Chloramine-T; H&S Chemical Co, Covington, Ky) for approximately 3 months prior to the experiment.

Two operators prepared the teeth, one using the conventional inlay burs and the other using ultrasonic tips. The first operator did not know the aim of the study but was instructed to make the preparations for the purpose of placing a direct inlay-retained FRC FPD using conventional fine diamond inlay burs (model number 011, Cerinlay; Intensiv, Grancia, Switzerland) with a high-speed handpiece (KaVo K9, handpiece type 950; KaVo, Biberach, Germany) utilizing water spray. A new set of burs was used after every 7 preparations. Boxes, on the distal surface of 7 premolars and the mesial surface of 7 molars, with margins in enamel, at least 1 mm above the cemento-enamel junction, were prepared by the first operator. The second operator prepared the boxes first, using conventional fine diamond inlay burs (model number 011, Cerinlay; Intensiv) followed by small or large ultrasonic tips (SONICSYS approx, micro torpedo; KaVo) for the premolars and the molars, respectively (Fig. 1, A). The linear oscillation speed was 6.5 kHz. Subsequently, the dimensions of the boxes were measured at buccolingual (BL), mesiodistal (MD), and cervico-occlusal (CO) directions with a digital micrometer (accurate to 0.005 microns) (Mitutoyo Ltd, Andover, UK). The preparations were cleaned with water spray and dried with an air syringe

(Fig. 1, B). Thirty-five percent orthophosphoric acid (3M Scotchbond; 3M Dental Products, St. Paul, Minn) was applied on the enamel and dentin for 15 seconds. The preparations were then thoroughly rinsed with water for 15 seconds and air dried. All the preparation surfaces were first coated with primer (Scotchbond Multipurpose primer; 3M Dental Products) and gently air dried. The adhesive (Scotchbond Multipurpose adhesive; 3M Dental Products) was applied, and after the excess was blown off, the adhesive was subsequently light polymerized (Optilux 501; Kerr, Orange, Calif) for 10 seconds.

After etching and primer/bonding agent application, a total of 21 inlay-retained FPDs (3 experimental groups, $n=7$ FPDs) were fabricated by the second operator. Before fabricating the restorations, 2 mm of wax (Ideal-standard 73100 Modelling Wax; Gebdi Dental Products, Engen, Germany) was placed between the abutment teeth to act as an index to create the identical shape and form of the cervical aspect of the pontic area. A low-viscosity composite (Tetric Flow, Shade A2; Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the gingival and axial walls covering the cervical one third of the box. Then, 1 layer of polymer-monomer gel-impregnated light-polymerizable unidirectional E-glass fiber (everStick; Stick Tech, Turku, Finland) was cut at the appropriate length, placed in position, slightly curved cervically towards the gingiva in the middle of the pontic area, and light polymerized for 40 seconds. The rest of the restoration was incrementally built up using particulate filler composite (Tetric Ceram, Shade A2; Ivoclar Vivadent).

The light output of the polymerizing unit was measured using a radiometer (Optilux 501; Kerr) and was determined to be 770 mW/cm^2 . The irradiation distance between the tip of the polymerization wand and the resin surface was kept to a maximum of 10 mm to obtain adequate polymerization. The thickness of the connectors was maintained at 4 mm in the CO direction at the mesial and distal areas, with the greatest thickness being 6.6 mm at the cusp tip. The pontic width was 5 mm at the BL direction in the mesial and distal areas. The thickness at each location was indicated with a water-resistant pen. After finishing, measurements were made with a digital micrometer to maintain this thickness in all experimental groups. The steel contact ball of the universal testing machine (LRX Material Testing Machine; Lloyd Instruments, Hants, UK) loaded the pontics, which were 6.5 mm in the gingival-occlusal direction and 4 mm in the BL direction. All of the restorations were finished wet. Fine diamond burs (model number 012; Intensiv) were used to remove the excess resin composite. Proximal and occlusal surfaces were further finished with coarse, medium, fine, and ultrafine finishing disks (Sof-Lex; 3M Dental Products).

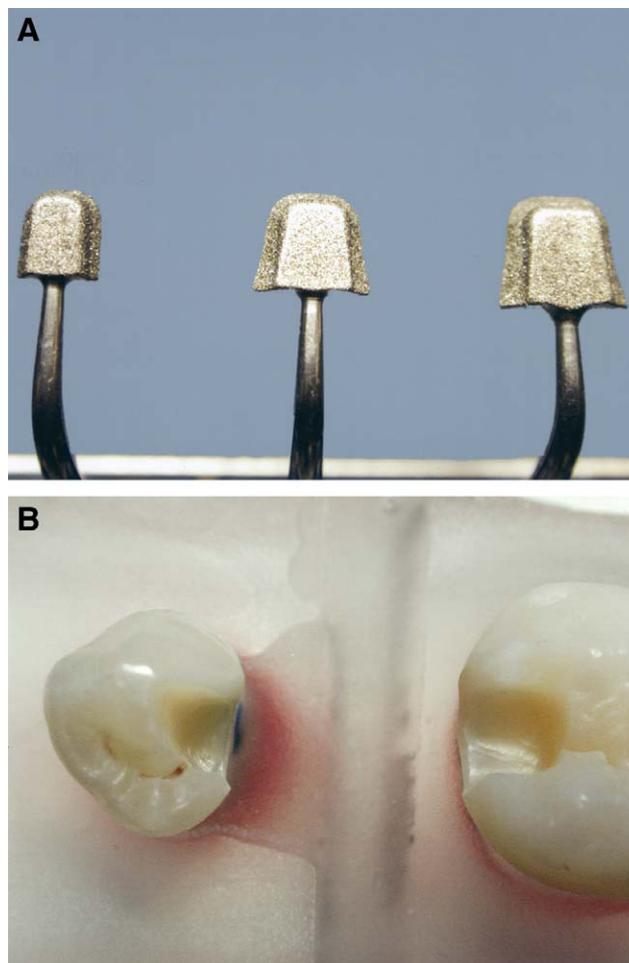


Fig. 1. A, Ultrasonic tips used to finalize box preparations. B, Box preparations on premolar and molar using ultrasonic tips.

The specimens were first stored in water at 37°C for 72 hours and then subjected to thermal cycling (Thermocycler 2000; Heto-Holten A/S, Allerød, Denmark) for 6000 cycles between 5°C and 55°C in deionized distilled water. The dwell time at each temperature was 30 seconds, and the transfer time from one bath to the other was 2 seconds.

After thermal cycling, the load test was performed using the previously mentioned screw-driven universal testing machine (LRX Material Testing Machine; Lloyd Instruments) (1 mm/min), in which the force (N) was applied from the occlusal direction to the central fossa with a steel contact ball, 6 mm in diameter, that started moving from a distance of 2 mm from the occlusal surface.

During loading, AE recording was used to determine the energy levels at the initial and final failure loads. Two AE-signal wideband transducers (Broadband sensor S9225; Physical Acoustic Corp, Princeton Junction, NJ) were attached to the specimen holder and located 18 mm away from the mesial and distal sides of the specimens by means of acrylic resin (Triad Gel; Dentsply,

Table I. Dimensions (mm \pm SD) of boxes in buccolingual (BL), mesiodistal (MD), and cervico-occlusal (CO) direction prepared using conventional burs and ultrasonic tips for both molars and premolars

Cavity preparation systems	Molar			Premolar		
	BL*	MD [†]	CO [‡]	BL [§]	MD	CO [¶]
Conventional inlay burs	3.1 (\pm 0.2)	4.3 (\pm 0.9)	3.8 (\pm 0.2)	2.8 (\pm 0.2)	2.9 (\pm 1.2)	3.0 (\pm 0.4)
SONICSYS <i>approx</i> tips (small)	2.9 (0)	3.8 (\pm 0.5)	3.6 (\pm 0.1)	2.5 (\pm 0.1)	2.7 (\pm 1.0)	2.9 (\pm 0.1)
SONICSYS <i>approx</i> tips (large)	3.2 (\pm 0.2)	4.9 (\pm 0.1)	3.9 (\pm 0.1)	2.6 (\pm 0.1)	3.8 (\pm 0.1)	3.6 (\pm 0.1)

Mean values of box dimensions in each group for initial and final failure were analyzed by 2-way repeated measures ANOVA, with *direction* as repeated-measure factor and *group* as between-group factor. Further analyses were performed with 1-way ANOVA, the Bonferroni correction in multiple comparisons within each direction for molar and premolar specimens ($\alpha=.05$).

*Conventional vs small, $P=.031$; small vs large, $P=.0023$.

[†]Small vs large, $P=.007$.

[‡]Conventional vs small, $P=.028$; small vs large, $P=.0032$.

[§]Conventional vs small, $P=.0024$.

^{||}Small vs large, $P=.021$.

[¶]Conventional vs large, $P=.0003$; small vs large, $P=.0001$.

Table II. Results of 2-way repeated measures ANOVA for molars

Source of variation	df	SS	MS	F	P
Between subjects					
Group	2	3.51	1.75	12.86	.0003
Error	18	2.46	0.14		
Within subjects					
Direction	2	15.62	7.81	63.50	<.0001
Direction * Group	4	1.47	0.37	2.99	.0312
Error	36	4.43	0.12		
Total	62	27.68			

SS, Sum of squares; MS, mean square.

Table III. Results of 2-way repeated measures ANOVA for premolars

Source of variation	df	SS	MS	F	P
Between subjects					
Group	2	4.60	2.30	13.33	.0003
Error	18	3.11	0.17		
Within subjects					
Direction	2	4.17	2.09	11.45	.0001
Direction * Group	4	2.76	0.69	3.79	.0114
Error	36	6.56	0.18		
Total	62	21.20			

SS, Sum of squares; MS, mean square.

York, Pa). With 2 transducers, the source of AE was located in the test specimen and transducers using silicone-based lubricant (Silikonfett Wacker-Chemie, Munich, Germany). Signals detected by transducers were passed through preamplifiers of 40 dB gain, with a band pass of 10 kHz to 2 MHz (Model 2/4/6; Physical Acoustic Corp). AE signals were recorded during the loading cycles with software (MISTRAS 2001; Physical Acoustic Corp) using 4-MHz sample frequencies. After each fracture test, the failure type, veneering composite delamination, catastrophic failure, and combination of failure type and failure location were identified by visual examination, and digital photographs were made from buccal, lingual, and occlusal aspects of the specimen (Nikon Coolpix 990; Nikon, Tokyo, Japan).

Statistical analysis was performed using statistical software (SAS, Windows 8.02; SAS Institute, Inc, Cary, NC). The mean values of box dimensions in each group for initial and final failure were analyzed by 2-way repeated-measures analysis of variance (ANOVA), with direction (BL, MD, CO) as the repeated-measure factor and group as the between-group factor. Because the interaction terms between the groups and dimensions were significant, further analyses

were performed with 1-way ANOVA ($\alpha=.05$), using the Bonferroni correction in multiple comparisons within each direction for molar and premolar specimens. The difference between the fracture-strength values dependent on the preparation techniques evaluated was analyzed with 1-way ANOVA. Furthermore, the Fisher exact test was used to determine the statistical difference in the type of failure between groups in which 3 preparation techniques were used ($\alpha=.05$).

RESULTS

Significant differences were observed between the groups in the dimensions of the boxes prepared using conventional burs and the small or large size ultrasonic tips at the BL, MD, and CO directions for both the premolars (2.8 mm, 2.9 mm, 3.0 mm) ($P=.0029$, $P=.0014$, $P<.0001$) and the molars (3.1 mm, 4.3 mm, 3.8 mm) ($P=.0024$, $P=.0086$, $P=.003$), respectively (Tables I, II, and III).

After thermal cycling, although there was a trend towards increased fracture strength values in the FPDs prepared with the larger size ultrasonic tips, no significant difference was identified for the initial and final failures between the conventionally prepared

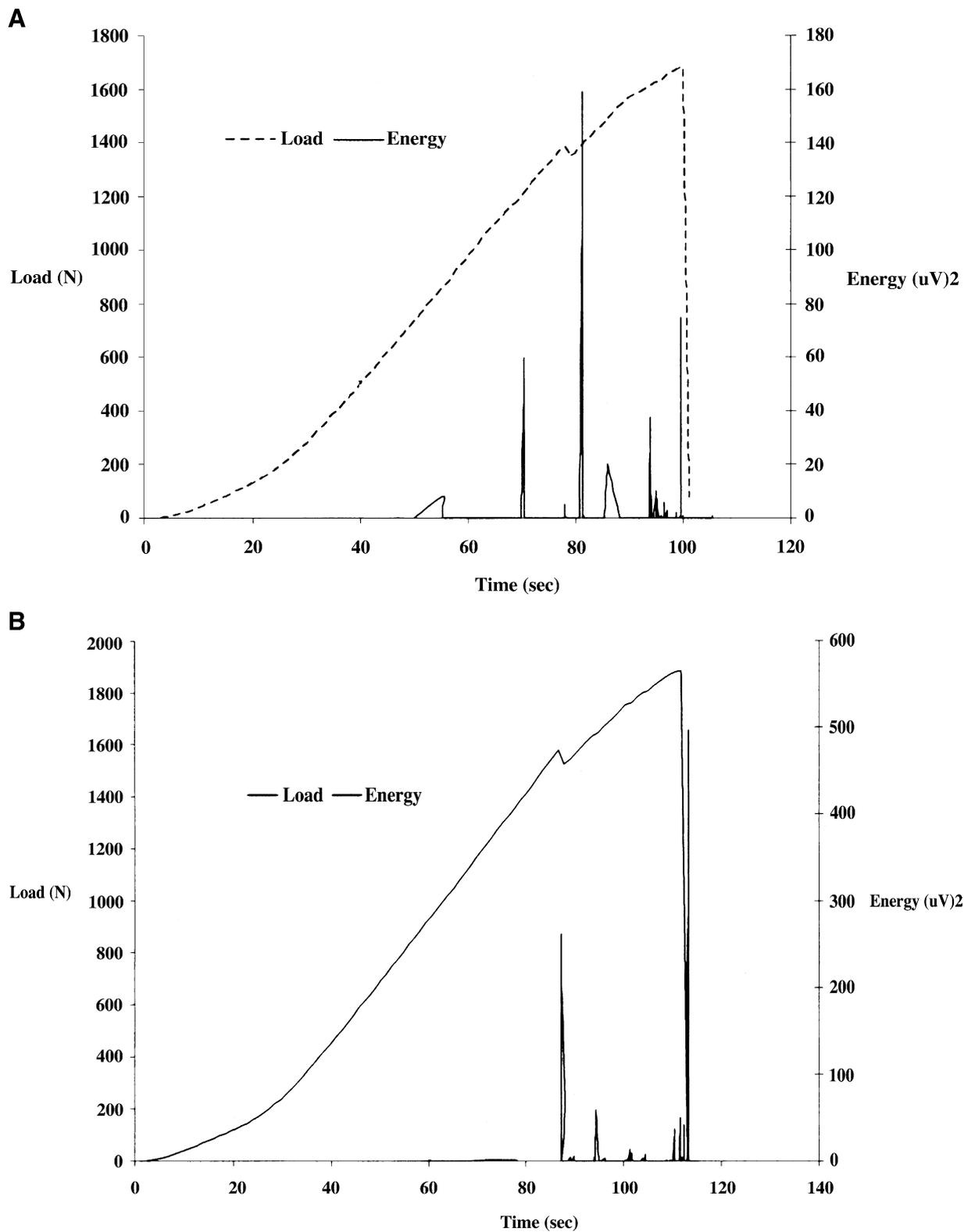


Fig. 2. A, Acoustic emission rates showing some initial failures at lower energy levels between 50 and 75 (μV)² that corresponded to 400 N and 700 N before final failure in group prepared with conventional burs. **B,** Acoustic emission rates showing peaks at energy levels at 250 (μV)² that corresponded to 1100 N before final failure in group prepared with small ultrasonic tips. **C,** Acoustic emission rates showing peaks at energy levels of 100-150 (μV)² that corresponded to 500-800 N before final failure in group prepared with large ultrasonic tips.

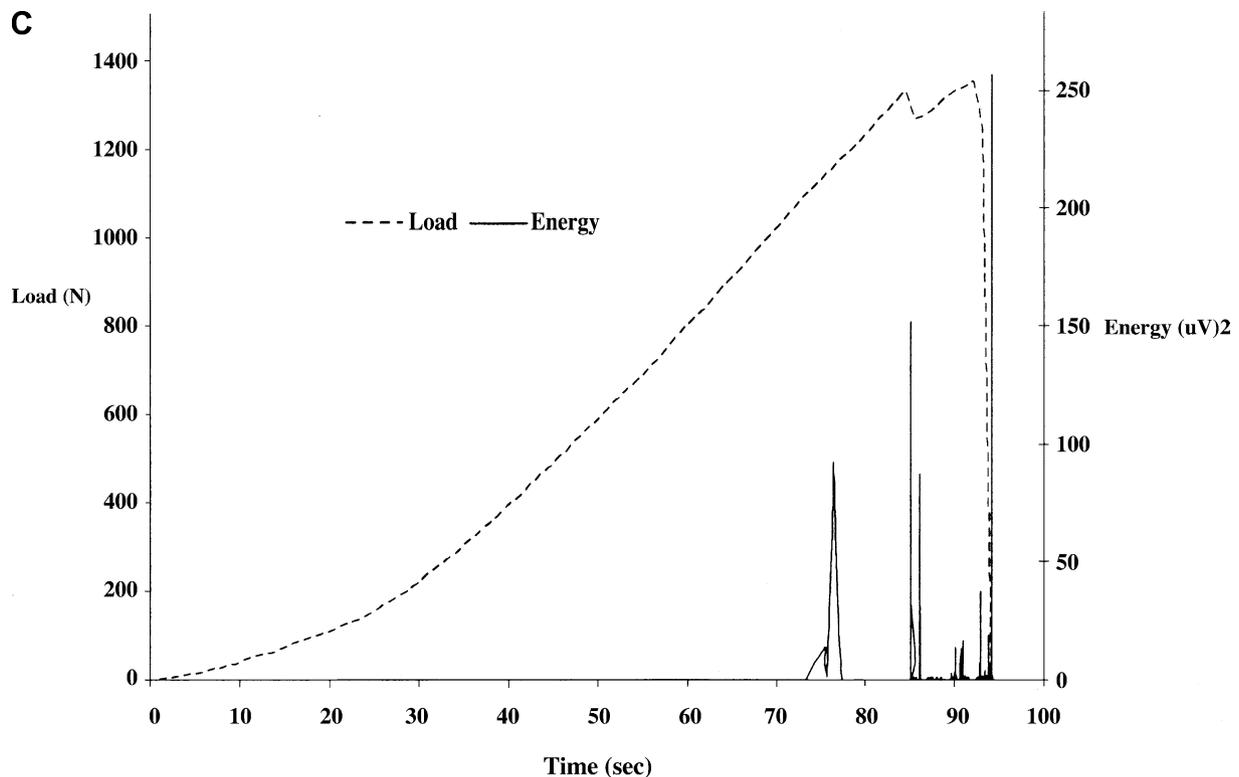


Fig. 2.—Cont'd.

group (842 ± 267 N, 1161 ± 428 N) and those prepared with either the small size (1088 ± 381 N, 1320 ± 380 N) or large size (1070 ± 280 N, 1557 ± 321 N) ultrasonic tip combinations. The AE tests revealed that some initial failures occurred at lower energy levels between 50 to 75 $(\mu V)^2$, which corresponded to 400 N to 700 N before final failure in the FRC FPDs in the restorations for which boxes were prepared using conventional inlay burs (Fig. 2, A). The energy level required for fracture was 250 $(\mu V)^2$, corresponding to 1100 N in the restorations for which boxes were prepared using small ultrasonic tips (Fig. 2, B), and 100 to 150 $(\mu V)^2$ at 500 N to 800 N when large ultrasonic tips were used (Fig. 2, C).

Table IV displays the number of fracture types of FRC FPDs per group relative to the different types of preparation. Three types of failure were observed: (1) delamination of the veneering resin (VD) (18/21) either at the lingual and buccal surface with a crack path in the mesiodistal direction, (2) catastrophic failure (CF) (1/22), in which fracture was at the connector area with some fiber exposure, or (3) a combination of both (VD+CF) (2/21). Delamination of the veneering resin was the predominant failure. The only CF, including the fracture at the connector area, was noted for the group in which boxes were prepared with the traditional burs. The 2 specimens with combined failure were prepared using large ultrasonic burs (Fig. 3). No fracture

within the fiber itself occurred. The Fisher exact test demonstrated no significant difference between the failure types ($P=.3$).

DISCUSSION

Minimal or no tooth preparation of the abutment teeth is desirable for the replacement of missing teeth with FRC FPDs. However, depending on the clinical situation, especially in posterior applications, sufficient space is required for the fiber frame and the resin composite materials. When space is insufficient, wear of the composite may result in early failure of the restoration or in fiber exposure that may lead to plaque accumulation. In this study, ultrasonic tips were used in an attempt to standardize substructure geometry. The dimensions of the box preparation demonstrated a wide range (1.8 to 5.2 mm) in the BL direction with the use of conventional inlay burs when compared to the dimensions of the boxes prepared under controlled circumstances using the ultrasonic tips (Table I). However, although there was a trend toward higher strength values in the boxes prepared with the large ultrasonic burs, no significant difference was found at initial and final failure compared to the group prepared using conventional inlay burs. There were no failures at the connector area with the use of either small or large tips; however, with such a small sample size, it is difficult

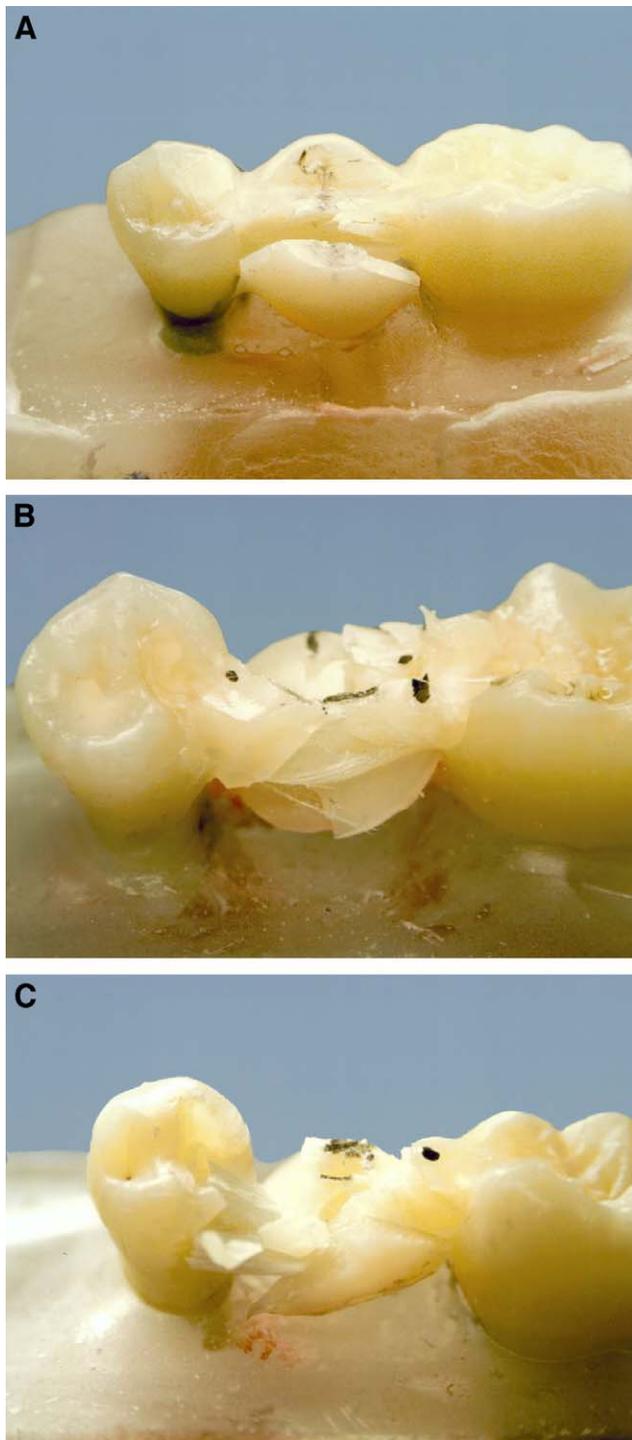


Fig. 3. **A**, Typical view of veneering-resin delamination on lingual surface. Note that broken piece did not detach completely from fiber-reinforced framework. **B**, Typical view of catastrophic failure that included all sites of pontic. **C**, Only catastrophic failure noted, including fracture at connector area experienced in group in which boxes were prepared with conventional inlay burs.

Table IV. Number of fracture types per group ($n = 7$) in relation to different types of preparation

	VD	CF	VD + CF
Conventional inlay burs	6/7	1/7	–
SONICSYS approx tips (small)	7/7	–	–
SONICSYS approx tips (large)	5/7	–	2/7
Total	18/21	1/21	2/21

VD, Veneering-composite delamination; CF, catastrophic failure; VD + CF, combination of both.

to state that a more standardized approach in preparations resulted in additional strength of the restorations. The single catastrophic fracture that was experienced in the group prepared with conventional inlay burs may have been due to a flaw in the specimen rather than the method of preparation.

The results of the present study exhibited mean values for the initial failure ranging between 842 N to 1070 N and values for final failure between 1161 N and 1557 N, which exceed the highest reported masticatory force values of 1000 N¹⁰; therefore, these restorations may be strong enough for clinical applications. Direct comparison with previous studies is difficult due to differences in design, but the fracture-strength values of the present study were higher than those reported by Behr et al,²⁵ who found final fracture-strength values of 696 N and 722 N for 3-unit indirect FRC FPDs for which glass fibers were used (Vectris; Ivoclar Vivadent) as the fiber framework in box-shaped and tube-shaped preparations. The fiber system used in the present study is based on impregnation of the reinforced fibers with polymer-monomer gel, which is different from the monomer resin impregnation of the Vectris system, which includes light-polymerized resins (BisGMA, TEGDMA, and inorganic particulate fillers).⁹ The E-glass fiber chosen in the present study allows for fabrication of direct restorations that can be polymerized using a hand-held polymerization light unit. The Vectris system, however, requires light polymerization of the fiber in a light polymerization oven unit and was designed to be used for indirect restorations.⁴

The failure mode observed in the present study was primarily in the form of veneering-resin delamination. This finding is in accordance with Cho et al,¹⁴ who reported cracking and chipping of the veneering resin as a 2-phase failure pattern that was followed by adhesive failure between the veneering resin and the fiber framework. For most specimens, the displaced fragment was not completely detached from the fiber framework. In the present study, the fracture analysis supported this statement, as fractures were either within the composite or between the resin composite and the fiber framework.

Resin composites with different elastic moduli could affect the initial and final failures. The flexure strength of fiber-reinforced restorations might be improved with the use of new polymer formulations with high filler-particle distribution (Estenia, Sinfony, Gradia, Sculpture) that are now commercially available; however, these materials are not suitable for chairside use.⁵

The changes in energy levels revealed small failures occurring between 300 N to 500 N and continuing until final failure occurred. While no fractures were observed at the connector area, the failure analysis demonstrated that the weakest parts of the restoration were in the cohesive strength of the veneering composite and the bond between the fiber composite framework. The direction of the failures was primarily in the MD direction, indicating that unidirectional fibers change the path of the crack.

Clinically, when using FRC for FPDs, an important parameter may be the initial failure point. Some studies have determined the fracture forces of FPDs by determining the initial failure from the force deflection curve.^{11,13} A more precise method for determining the initial failure point is based on determining the initiation of AE signals.¹⁷ When comparing the relationship between the stress for the first AE activity observed at initial failure and the strength needed for the final failure, AE started at a lower stress level in specimens for which the boxes were prepared using conventional inlay burs and large ultrasonic tips. However, more energy was required for final failure in the specimens for which boxes were prepared using small ultrasonic tips, indicating that the large amount of resin composite surrounding the fiber at the connector area may decrease the strength. Most likely, in a restoration with small box dimensions, the transmittance of the force was more even in the FRC restoration. Therefore, even though no significant difference was found for either the initial or final fracture strengths between the 2 sizes of ultrasonic burs, the use of small tips may be advised.

A correlation exists between a low-amplitude AE signal and polymer matrix cracking and also between a high-amplitude AE signal and fiber breaking.^{12,16,17} However, those studies did not involve resin composite surrounding the fiber as in the present study. Clinically, if the load (for example, from the opposing teeth) remains at a certain level, more AE signals may not be emitted, and crack propagation may not continue. However, other factors such as thermal cycling, water storage, or flaws in the composite weaken the fiber-polymer interface. In this study, exposing the specimens to 6000 thermal cycles can be considered a worst-case scenario when compared to water storage only.²⁸

A limitation of this study is the small sample size. As a result of the findings of this study, a power analysis of data indicated that 40 specimens per group

were needed to obtain a power of 80% in detecting differences between group mean values. Clinically, factors such as span length, pointed cusps, cusp height, anatomical variables of the antagonist teeth, shock absorbance characteristics of the periodontal ligament, and direction of the masticatory forces may cause slight deviations in force transfer, resulting in different tension areas in FRC FPDs that require further investigation.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The box dimensions prepared with conventional burs varied significantly ($P=.0146$ and $P=.0086$ for the premolars and molars, respectively) compared to those prepared under controlled conditions using ultrasonic tips.
2. Standardized box dimensions had no significant effect on fracture strength at either initial or final failure of the FRC FPDs.
3. According to the AE tests, a higher energy level was required for the final failure of the FRC FPDs with boxes finished using small ultrasonic tips.
4. The predominant failure type after the fracture test was delamination of the veneering resin.

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