Dental Traumatology

Dental Traumatology 2012; **28**: 153–157; doi: 10.1111/j.1600-9657.2011.01063.x

Shear bond strength of restorations applied to un-complicated crown fractures: an *in vitro* study

Tijen Pamir[1], Ece Eden[2], Shenay Sebahtin Ahmed[3]

Departments of [1]Restorative Dentistry, [2]Pediatric Dentistry, Ege University, School of Dentistry, İzmir; [3]Private Dentist, İzmir, Turkey

Abstract – *Background*: Study was designed to evaluate shear bond strengths of different restorative techniques of uncomplicated enamel-dentin fractures in permanent incisors. *Material and Methods*: Forty human mandibular incisors were divided into four groups. One-third of their anatomical crowns from the incisal edges were cut off in three groups, representing an uncomplicated enamel-dentin fracture. Intact teeth in group 1 were used as control. In group 2, edge fragments were reattached by flowable composite (Filltek Flowable Supreme XT). In group 3, teeth were restored with universal resin composite (Filtek Z 250). In group 4, pre-impregnated glass fiber sheet (everStickNet) was positioned onto fractured surface, and then restorations were completed with resin composite. Three-step etch-and-rinse adhesive system (Adper Scotchbond Multi Purpose) was used in all test groups. Shear bond strengths of all samples were determined in universal testing machine, and data were analyzed with Kruskal–Wallis followed by Mann–Whitney U tests. Failure types were observed by light microscope. *Results*: Shear bond strength of sound teeth was significantly higher than those of restored teeth ($P < 0.05$). Mean shear bond strengths of the reattached teeth were lower than the other two restoration types; however, differences were not statistically significant ($P > 0.05$). *Conclusions*: Load-bearing capacity of restored teeth was not as high as sound teeth in the uncomplicated crown fracture. However, shear bond strength of different types of restorations seems close to each other.

Corresponding to: Tijen Pamir, Ege University, School of Dentistry, Department of Restorative Dentistry, Bornova, 35100 İzmir, Turkey
Tel.: +90 232 388 0328
Fax: +90 232 388 0325
E-mail: tijenpamir@gmail.com

Accepted 17 August, 2011

Crown fractures in the permanent dentition account for about 75% of dental injuries following trauma (1). More frequently, trauma to teeth causes 'uncomplicated crown fracture' involving enamel and dentin without pulp exposure. Even if it is called as 'uncomplicated', they may pose many problems during treatment and prognosis may differ because of the patient age, the amount of enamel available for bonding, wideness and wetness of dentin tubules in young permanent teeth and possibility of bacterial contamination of dentine and pulp. Furthermore, esthetic appearance of the definite restoration may cause a problem as well (2). Therefore, treatment options for restorations in such fractures may extend from reattachment of the original tooth fragment and composite adhesive resin restorations with or without pin to laminate veneers and full-coverage crowns (3–5).

Reattachment of the fracture fragment can be performed using various adhesive systems with or without flowable materials (3). This treatment method offers a conservative approach in conjunction with natural appearance. However, the most important drawback of this type of restorations seems their tendency to refracture or debonding in the danger of new trauma because studies showed that teeth that have been fractured once are always subject to further fracture (6, 7). Alternative treatment options to restore uncomplicated crown fracture are ceramic veneers or crowns. Although ceramic full-coverage crowns and laminate veneers provide a satisfactory results with their good esthetic properties and color stabilities, these treatment approaches are very destructive methods in the restoration of fractured anterior teeth. However, the intention of the dentists should be to retrieve the function and esthetics of the patient while healthy tooth structure is being preserved with a minimally invasive and reversible treatment approaches. Furthermore, some practitioners are concerned about longevity of lamina veneers because of the brittleness of the conventional ceramic materials (8). On the other hand, resin restorations provide relatively low cost, less brittleness and reliable bonding properties when compared to ceramics. Resin composite materials although presents the elastic behavior under repeated compressive and tensile stresses, their acceptance especially in the high-stress-bearing areas seemed to be limited by their low mechanical properties (9, 10). Attempts should be made to improve the load-bearing capacity of this type of restoration by using different materials and techniques. Fiber-reinforced composites (FRCs) can serve this purpose, and their use has gained popularity in current dental applications including dental splints, complete or partial dentures, direct and indirect composite restorations etc. (11–13). In this context, glass fibers, being thin and flexible materials, should be packed into the resin composite, and this reinforcement technique might prevent the early failure of the restorations in the treatment of uncomplicated crown fracture. In this study therefore, it was hypothesized that the incorporation of glass fibers would improve the fracture resistance of incisal restorations of the anterior teeth. In line with the hypothesis, the purpose of this *in vitro* study was to compare the shear bond strengths of the restorations that were placed with reattachment, conventional resin composite or FRCs techniques with that of the healthy incisors.

Materials and methods

Forty extracted non-restored human mandibular incisors free of visible caries were selected for this study. After calculus and soft tissue removal by curettes, teeth were placed into the 0.01% thymol solution until use. To represent uncomplicated enamel-dentin fracture, incisal edges of thirty teeth were horizontally cut at one-third of their anatomical crowns using a thin (0.2 mm) single-sided diamond cutting wheel (Meisinger Gmbh, Neuss, Germany) in a laboratory handpiece under water cooling. Areas of fractured surfaces were measured using a software program (Leica Application Suite; Leica Microsystems Ltd., Heerbrugg, Switzerland) connected to a light microscope (Leica S8APO; Leica Microsystems Ltd) integrated with a digital camera (Leica DFC 280; Leica Microsystems Ltd) (Fig. 1a,b). Thirty teeth with fractured incisal edges were equally distributed into three experimental groups, each consisting of 10 teeth. Remaining 10 teeth were intact, which formed the control group I.

Group I: intact teeth

Ten teeth in this group were remained intact and used as control.

Group II: incisal edge reattachment

In this group, the fractured surface and the incisal portion of the tooth were etched with 35% phosphoric acid gel (Scotchbond Etch; 3M ESPE, St Paul, MN, USA). Subsequently, the gel was thoroughly rinsed, and excess water was removed with air flow gently for 2 s, leaving the surface moist, according to the instruction of the manufacturer. The primer (Adper Scotchbond Multi Purpose; 3M ESPE) was applied to enamel and dentin of both fragments, and then the solvent was made to evaporate using a gentle air flow for 5 s. The adhesive (Adper Scotchbond Multi Purpose; 3M ESPE) was applied to the fractured surfaces of the incisal portion and remaining tooth and light-cured with Optilux 501 (Kerr, CA, USA) for 10 s having output light intensity of 850 mW cm^{-2}, which was checked by the built-in radiometer of the unit. After application of the adhesive system, flowable resin composite (Filtek Supreme XT; 3M ESPE, Seefeld, Germany) was expressed onto a dispensing pad and applied to both surfaces with a brush. Incisal portion was mounted to its respective tooth using hand pressure, and the excess material was removed with a microbrush. Specimen was then light-cured for 20 s from vestibule and 20 s from lingual directions, totally 40 s. Finishing and polishing procedure was completed with Sof-Lex discs (3M ESPE).

Group III: incisal edge restoration with resin composite

Fracture lines of teeth were roughed using a fine diamond bur under water cooling. Three-step seven adhesive system (Adper Scotchbond Multi Purpose, 3M ESPE) was used as mentioned in group II. In this group, however, incisal portions of the teeth were restored with a universal resin composite (Filtek Z 250; 3M ESPE, Germany). This material was placed incrementally and light-cured for 40 s. Following the adjustment of crown length, Sof-Lex disks (3M ESPE Dental Products, St. Paul, MN, USA) were used for finishing and polishing process.

Group IV: incisal edge restoration with fiber-reinforced resin composite

Lingual surface preparation in approximately depth of 0.5 mm was made using a diamond bur under water cooling in this group. Same adhesive system was applied to the fractured surfaces of the teeth as described previously. Following adhesive application, pre-impregnated glass fiber sheet (everStick Net; Stick Tech, Turku, Finland) was positioned from the palatal cavity to the incisal edge of each tooth with the assistance of flowable resin composite (Filtek Supreme XT, 3M ESPE, Germany). After light-curing of fiber sheet and flowable resin composite for 20 s, universal resin composite (Filtek Z 250; 3M ESPE, Germany) was incrementally built up and polymerized.

After the completion of restorative procedure, all teeth in the experimental and control groups were

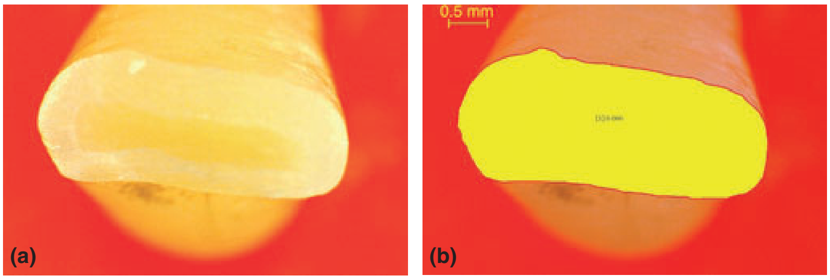

Fig. 1. (a) The microscopic images of a tooth after its incisal edge were cut off. (b) The measurement of fracture area with Leica Application Suite program in the same tooth.

embedded in self-cure acrylic resin at the cemento-enamel junction. Acrylic blocks containing the teeth were tightly fixed to the universal testing machine (Shimadzu Autograph, AGS-J 5 kN; Shimadzu Corporation, Tokyo, Japan). Load was applied to the incisal edges perpendicularly with a crosshead speed of 0.5 mm s^{-1}. Shear bond strengths were obtained in megapascal (MPa) based on the areas, measured by the light microscope stated earlier, of the fractured surfaces of each sample. The statistical analysis was performed with SPSS (Statistical Package for the Social Sciences) 11.0 (SPSS Inc., Chicago, IL, USA) program. Bond strengths among the groups were compared with Kruskal–Wallis followed by Mann–Whitney tests at a significance level of 0.05.

Following the shear test, samples were examined under a light microscope, and the types of bond failure were recorded according to the following criteria:

1. Adhesive failures occured at the tooth/resin interface were characterized having less than 25% resin composite remaining at the interfacial bond area.
2. Cohesive failures occurred within the resin restoration were characterized having greater than or equal to 75% resin remaining at the interfacial bond area.
3. Adhesive/cohesive mixed failures were characterized having 25% to 75% composite resin at the interfacial bond area.

Results

The mean shear bond strengths and standard deviations for the experimental groups and the control were presented in Table 1. Kruskal–Wallis test indicates the significant differences among the groups ($P < 0.05$). Table 2 exhibits the result of pairwise comparisons. Shear bond strengths of the intact teeth were significantly different from those of the restored teeth ($P < 0.05$). Mean shear bond strength of the reattached teeth was lower than that of the restored with resin composite and fiber-reinforced resin composite. However, differences among the test groups were not statistically significant ($P < 0.05$).

Table 1. Mean shear bond strength of the control and test groups

Groups	Mean ± SD (MPa)
I. Control	39.99 ± 16.03
II. Reattachment	13.49 ± 5.28
III. Resin composite restoration	20.24 ± 9.64
IV. Fiber-reinforced resin composite (FRC)	20.54 ± 13.18

MPa, megapascal.

Table 2. Pairwise comparisons of the study groups

	Group II	Group III	Group IV
Group I	0.001*	0.005*	0.008*
Group II		0.089	0.199
Group III	0.089		0.762

*Significant ($P < 0.05$).

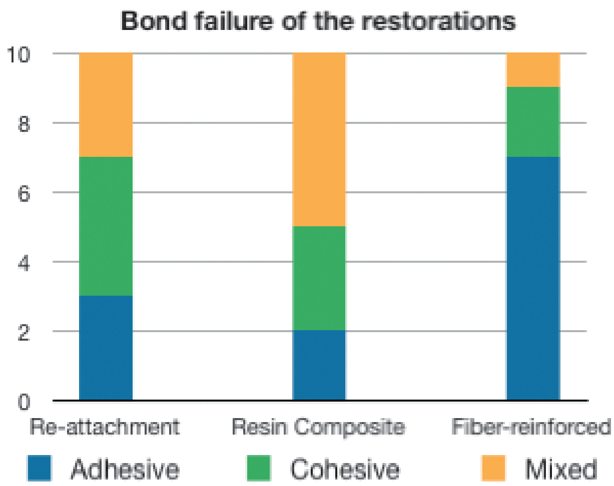

Chart 1. The mode of failure analysis of the test groups.

Chart 1 shows the results of the mode of failure analysis. Mode of failures observed for the experimental groups seems different from each other.

Discussion

This *in vitro* study compared the load-bearing capacity of the uncomplicated fractured incisors restored with different treatment techniques. Even though diverse shear bond strengths were obtained in three experimental groups of this study, significance among them was not determined. Although tooth fractures mainly arise in maxillary incisors, mandibular incisor teeth were used, because they are extracted in large numbers because of periodontal reasons.

Uncomplicated crown fractures should never be left untreated (1). When the excellent adhesive materials that are now available are considered, reattachment of a fractured fragment seems to be feasible. Many authors have listed the advantages of this technique in order, such as simple and safe clinical procedure with perfect tooth color, contour, translucence and surface texture (14, 15). However, the success of this type of restoration was formerly debatable by the reason of narrow enamel surfaces of the adhesive joint and the possibility of debonding because of the low mechanical strength of the reattached teeth (1, 2, 6, 16, 17). To eliminate these problems, some researchers have proposed different reattachment techniques such as bevel or chamfer preparations, internal dentinal groove and overcontouring (3, 16–19). However, these techniques are more invasive and require additional preparation when compared to simple reattachment. In circumferential chamfer for instance, preparation of 2 mm in length and one-half the thickness of enamel in depth is needed to achieve this type of restoration. In the groups of this study, as it was preferred the least quantity of enamel preparation as far as possible, simple reattachment procedure with an intermediated material was used for bonding of the fractured teeth fragments. Conventional etch-and-rinse adhesive systems have generally been recommended for the reattachment procedure (5, 16, 20, 21). Furthermore, the importance of using intermediated material as addition to adhesive system was emphasized (20), and hence, several materials were added to the designs of the reattachment studies (18, 19). Therefore, Scotchbond Multi Purpose was selected as conventional etch-and-rinse adhesive and flowable material Filtek Supreme XT as intermediated material in the reattachment group of this study.

In this *in vitro* study, the lowest mechanical strength of the reattachment group was observed; nevertheless, the differences among the test groups were not statistically significant except for the control. Sengun et al. (22) stated that fracture strength of the fragments reattached with Scotchbond Multi Purpose was not different from that of the intact teeth. The findings of the present study pointed out that any restoration types and materials did reach the load-bearing capacity of the intact teeth (18, 19, 23).

Attention was paid to conserve the enamel at the fracture line in all groups of the present study. In group III, for example, only fracture lines were roughed with fine diamond burs before the incisal edges were restored with the resin composite. However, the success of resin restoration at the incisal area is questionable (2, 24, 25) despite the improvement in material and adhesive technology. Therefore, some researchers proposed aggressive enamel preparation as it was performed in chamfer or stair-step chamfer techniques to increase mechanical strength of restored teeth (2, 26–28). On the other hand, authors recommend minimal tooth preparation for the treatment of crown fracture (5). Within the conservative approach, Garoushi et al. (23) did not find any significant difference between the restoration of incisal edge using resin composite and reattachment technique in spite of the load-bearing capacity. This finding is in accordance with that of the reattachment and resin composite groups of our study. On the contrary, there is a study (22) pointing out less fracture strength for the resin restorations when compared to reattachment.

Although elastic behavior and bonding characteristics of resin composite have well documented, its mechanical properties seem to be limited, in especially high-stress-bearing areas (10, 29). The reinforcing efficiency and esthetic properties of glass fibers have been detailed with many studies in the literature (9, 11–13, 30). To increase load-bearing capacity of resin composite, glass fibers as tooth colored framework might placed into the restorations. In this study, therefore, bidirectional mesh fiber everStick NET was used to reinforce the resin composite in the restoration of fractured teeth. When the orientation of fibers is in two or three directions, the dynamics of adhesive interface can change and interfacial bond failures are diminished (31). Therefore, bidirectional FRCs have been used to mimic the biomechanics of tooth structure and to transfer stress to a wider surface area (32).

The mobility of teeth during function causes repeated compressive and tensile stress at the bonding interface. The use of a material with low modulus of elasticity at tooth–composite interface can reduce the formation of debonding stress. Therefore, fiber mesh was placed with the assistance of flowable resin composite.

Bidirectional fiber mesh used in this study is silanated E-glass fiber impregnated with bis-GMA and PMMA. The pre-impregnated FRC allows formation of semi-interpenetrating polymer network (semi-IPN) after polymerization; hence, good adhesion between the adhesive resin and FRC can be obtained (31–33). However, there is conflicting evidence in the literature with related to the bond strength of fiber-reinforced resin composite to enamel and dentin (13, 30, 32). In this study, it was hypothesized that shear bond strength of resin composite would increase through the fiber reinforcement in the restoration of fractured teeth. Although fiber-reinforced resin restorations exhibited relatively high bond strength, any statistically significant difference was not determined among the restoration types applied to the test groups of this study. On the contrary, Garoushi et al. (23, 34) stated that FRCs provided higher load-bearing capacity than those made with resin composite without fiber reinforcement in the fractured teeth.

In this study, failure mode of FRC group was mainly adhesive being different from that of the reattachment and resin composite groups (Chart 1). We think that the majority of adhesive failures in this group might have resulted from the perpendicular placement of fiber meshes to the bonding surface. In a previous study (35) in fact, dominant adhesive failure mode was observed when fibers were oriented perpendicularly to the bonding surface.

To form a standardization in sectioning the teeth, a thin diamond cutting wheel in a laboratory handpiece under water cooling was used as mentioned in the previous studies (3, 23). The fact that the surface characteristics of naturally fractured teeth were different from those of the sectioned ones was ignored. Besides, excessive enamel preparation was not applied to any group of this study. If additional enamel preparation was applied to all three types of restorations to increase the bonding surfaces of adhesive joint, higher bond strengths might have been obtained and significant differences might have been observed. The importance of additional enamel preparation for the restorations should also be examined hereafter.

Conclusion

Within the limitation of this study, it was concluded that load-bearing capacity of intact teeth was the highest and different from than that of all restorations examined in this study. Besides, none of the restoration types was exhibited superior bond strength than the others. Therefore, the hypothesis that fiber reinforcement would increase the fracture resistance of incisal resin restorations was rejected.

Conflict of interest

We declare that we have no proprietary, financial, professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript.

References

1. Andreasen JO, Andreasen FM. Textbook and colour atlas of traumatic injuries to the teeth, 3rd edn. Copenhagen: Munksgaard Publishers; 1993.
2. Toumba KJ. Restoration of fractured teeth. In: Curzon MEJ, editor. Handbook of dental trauma, Chapter 12. Oxford: Wright Publishing; 1999. p. 131–8.
3. Chazine M, Sedda M, Ounsi HF, Paragliola R, Ferari M, Grandini S. Evaluation of the fracture resistance of reattached incisal fragments using different materials and techniques. Dent Traumatol 2011;27:15–8.
4. Brambilla GP, Cavalle E. Fractured incisors: a judicious restorative approach-Part 2. Int Dent J 2007;57:100–8.
5. Oliveira GM, Ritter AV. Composite resin restorations of permanent incisors with crown fractures. Pediatr Dent 2009;31: 102–9.
6. Andreasen FM, Noren JG, Andreasen JO, Engethardtsen S. Long-term survival of fragment bonding in the treatment of fractured crowns: a multicenter clinical study. Quintessence Int 1995;26:669–81.
7. Munksgaard EC, Hojtved L, Jorgensen EHW, Andreasen JO, Andreasen FM. Enamel-dentin crown fractures bonded with various bonding agents. Endodont Dent Traumatol 1991;7:73–7.
8. Koutayas SO, Vagkopoulou T, Pelekanos S, Koidis P, Strub JR. Zirconia in dentistry: part 2. Evidence-based clinical breakthrough. Eur J Esthet Dent 2009;4:348–80.
9. Ahistrand WM, Finger WJ. Direct and indirect fiber-reinforced fixed partial dentures: case reports. Quintessence Int 2002;33: 359–65.
10. Bayne SC, Thompson JY. Mechanical property analysis of two admixed PRIMM-modified commercial dental composites. Trans Acad Dent Mater 1996;9:238.
11. Brown D. Fiber-reinforced materials. Dent Update 2000;27: 442–8.
12. Butterworth C, Ellakwa AE, Shortall A. Fibre-reinforced composites in restorative dentistry. Dent Update 2003;30:300–6.
13. Turkaslan S, Tezvergil-Mutluay A, Bağış B, Shinya A, Vallittu P, Lasila LV. Effect of intermediate fiber layer on the fracture load and failure mode of maxillary incisors restored with laminate veneers. Dent Mater J 2008;27:61–8.
14. Maia EA, Baratieri LN, de Andrada MA, Monteiro S Jr, Araujo EM Jr. Tooth fragment reattachment: fundamentals of the technique and two case reports. Quintessence Int 2003;34: 99–107.
15. Rappelli G, Massaccesi C, Putignano A. Clinical procedures for the immediate reattachment of a tooth fragment. Dent Traumatol 2002;18:281–4.
16. Reis A, Francci C, Loguercio AD, Carrilho MR, Rodriques Filho LE. Reattachment of anterior fractured teeth: fracture strength using different techniques. Oper Dent 2001;26:287–94.
17. Demarco FF, Fay RM, Pinzon LM, Powers JM. Fracture resistance of re-attached coronal fragments- influence of different adhesive materials and bevel preparation. Dent Traumatol 2004;20:157–63.
18. Brusci-Alonso RC, Alonso RCB, Correr GM, Alves MC, Lewgoy HR, Sinhoreti MAC et al. Reattachment of anterior fractured teeth: effect of materials and techniques on impact. Dent Traumatol 2010;26:315–22.
19. Bhargava M, Pandit IK, Srivastava N, Gugnani N, Gupta M. An evaluation of various materials and tooth preparation designs used for reattachment of fractured incisors. Dent Traumatol 2010;26:409–12.
20. Reis A, Kraul A, Francci C, de Assis TG, Crivelli DD, Oda M et al. Reattachment of anterior fractured teeth: fracture strength using different materials. Oper Dent 2001;27:621–7.
21. Farik B, Munksgaard EC, Andreasen JO. Impact strength of teeth restored by fragment bonding. Endod Dent Traumatol 2000;16:151–3.
22. Sengun A, Ozer F, Unlu N, Ozturk B. Shear bond strengths of tooth fragments reattached or restored. J Oral Rehabil 2003;30:82–6.
23. Garoushi SK, Ballo AM, Lassila LVJ, Vallittu PK. Fracture resistance of fragmented incisal edges restored with fiber-reinforced composite. J Adhes Dent 2006;8:91–5.
24. Robertson A, Robertson S, Noren JG. A retrospective evaluation of traumatized permanent teeth. Int J Paediatr Dent 1997;7:217–26.
25. Smales RJ. Effects of enamel bonding, type of restoration, patient age, and operator on the longevity of an anterior composite resin. Am J Dent 1991;4:130–3.
26. Donly KJ, Browning R. Class IV preparation design for microfilled and macrofilled composite resin. Pediatr Dent 1992;14:34–6.
27. Gandhi K, Nandlal B. Effect of enamel preparations on fracture resistance of composite resin buildup of fractures involving dentine in anterior bovine teeth: an in vitro study. J Indian Soc Pedod Prev Dent 2006;24:69–75.
28. Eid H, White GE. Class IV preparations for fractured anterior teeth restored with composite resin restorations. J Clin Pediatr Dent 2003;27:201–11.
29. Anusavice KJ. Phillips' science of dental materials, 10th edn. Philadelphia: WB Saunders; 1996.
30. Tezvergil A, Lassila LVJ, Vallittu PK. Strength of adhesive-bonded fiber-reinforced composites to enamel and dentin substrates. J Adhes Dent 2003;5:301–11.
31. Tezvergil A, Lassila LVJ, Vallittu PK. The shear bond strength of bidirectional and random-oriented fiber-reinforced composite to tooth structure. J Dent 2005;33:509–16.
32. Cekic-Nagas I, Ergun G, Tezvergil A, Vallittu PK, Lassila LVJ. Effect of fiber-reinforced composite at the interface on bonding of resin core system to dentin. Dent Mater J 2008;27: 736–43.
33. Lastumaki TM, Lassila LVJ, Vallittu PK. The semi-interpenetrating polymer network matrix of fiber-reinforced composite and its effect on the surface adhesive properties. J Mater Sci Mater Med 2003;14:803–9.
34. Garoushi S, Vallittu PK, Lassila LVJ. Direct restoration of severely damaged incisors using short fiber-reinforced composite resin. J Dent 2007;35:731–6.
35. Lassila LVJ, Tezvergil A, Dyer SR, Vallittu PK. The bond strength of particulate filler composite to differently oriented fiber-reinforced composite substrate. J Prosthodont 2007;16:10–7.