Fracture resistance of teeth restored with different resin-based restorative systems

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Abstract: The aim of the present study was to evaluate the fracture resistance of teeth restored with resin composite. Forty-eight maxillary premolar teeth were chosen and randomly divided to six groups: G1 (control): sound teeth; G2: MOD preparation, unrestored; G3: MOD + Adper Single Bond 2/P60; G4: MOD + Adper Easy One/P60; G5: MOD + P90 restorative system; G6: MOD + Adper Easy One/P90 Bond/P90. Specimens were subjected to compressive axial loading (0.5 mm/min). Flexural strength and the modulus of elasticity were also tested (n = 7). The only statistical equivalence with sound teeth was noted for G3 ($p < 0.05$). Flexural strength and the modulus of elasticity varied among the composites tested (n = 10). The reestablishment of the resistance to fracture in premolars subjected to Class II MOD preparations is restorative-system-dependent. The silorane restorative system is not able to recover the resistance to fracture.

Descriptors: Compressive Strength; Dentin-Bonding Agents; Dental Restoration, Permanent.

Introduction

Recent studies have focused on several concerns related to weakening of the teeth following MOD preparations and the effect of restorations in strengthening the remnant tissue.[1,2] It has been claimed that the strength of a tooth decreases in proportion to the amount of tooth tissue removed, particularly in relation to the width of the occlusal section of the preparation.[1] In spite of the problems related to the application of direct composites in posterior teeth, it has been demonstrated that the development of bonding and restorative systems has contributed to the longevity of restored teeth.[3] However, the clinical consequences of polymerization shrinkage represent the main reason for replacing resin-composite restorations, which explains why polymerization shrinkage is regarded as the main limitation of current resin composites.[4]

Recently, in an attempt to reduce shrinkage stress, a new type of resin composite, known as low-shrinkage composites, was launched on the market. These composites included Filtek P90, which contains cationic ring-opening monomers.[5] This monomer system was obtained from the reaction of oxirane and siloxane molecules,[5] which combine a low rate of polymerization shrinkage due to the ring-opening oxirane with an increased hydrophobicity due to the presence of the siloxane. It has been

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found[6] that the cuspal deflection caused by the polymerization shrinkage was significantly lower when teeth were restored with an experimental silorane material when compared to a methacrylate-based composite.

The purpose of this *in vitro* study was to compare the fracture resistance of restored teeth using silorane-based composite restorations. The flexural strength and the modulus of elasticity of both composites were also tested. The results were compared to those of a methacrylate-based composite with the same indication (posterior composites). The research hypothesis was that no difference in the fracture resistance of restored teeth would be observed when both restorative systems were compared.

Methodology

Compressive loading test

Forty-eight extracted sound maxillary premolar teeth were selected and used in accordance with a protocol approved by the Research Ethics Committee, Anhanguera-Uniban University. Teeth were stored in saline solution containing 0.1 % thymol at 4°C. The teeth were selected based on the average crown dimensions. The teeth were subsequently embedded in epoxy resin, with the resin rising up only to 1.0 mm below the CEJ. Specimens were then divided at random into six experimental groups, which are summarized in Figure 1. Groups 2 through 6 were submitted to Class II MOD preparations performed with a tungsten carbide bur (#245, Brasseler, Savannah, USA). The preparations were ½ of the intercuspal width and 2.0 mm deep pulpally, and the proximal boxes were prepared at a width of ½ the total faciolingual dimensions, with an axial wall that was 2.0-mm wide and 1.5-mm deep (Figure 2). The characteristics of the restorative materials selected (3M ESPE, St. Paul, USA) are described in Table 1.

The composites were applied onto the preparations using an incremental technique.[7] The restoration was progressively built up with photoactivation following each increment (1200 mW/cm² for 40 s) using an LED light (Bluephase, Ivoclar-Vivadent, Schaan, Liechtenstein). All specimens were subjected to compressive axial loading (0.5 mm/min.) in a testing machine (Instron model 3342, Instron Corp., Canton, USA) using a steel bar (8 mm in diameter) which was placed centrally to the occlusal surface and applied in parallel to the long axis of the tooth and to the slopes of the cusps (rather than the restoration). The mode of fracture of each specimen follows the classification by Burke *et al.*[8] (Figure 3).

Flexural strength (FS)

The performed FS testing differed slightly from

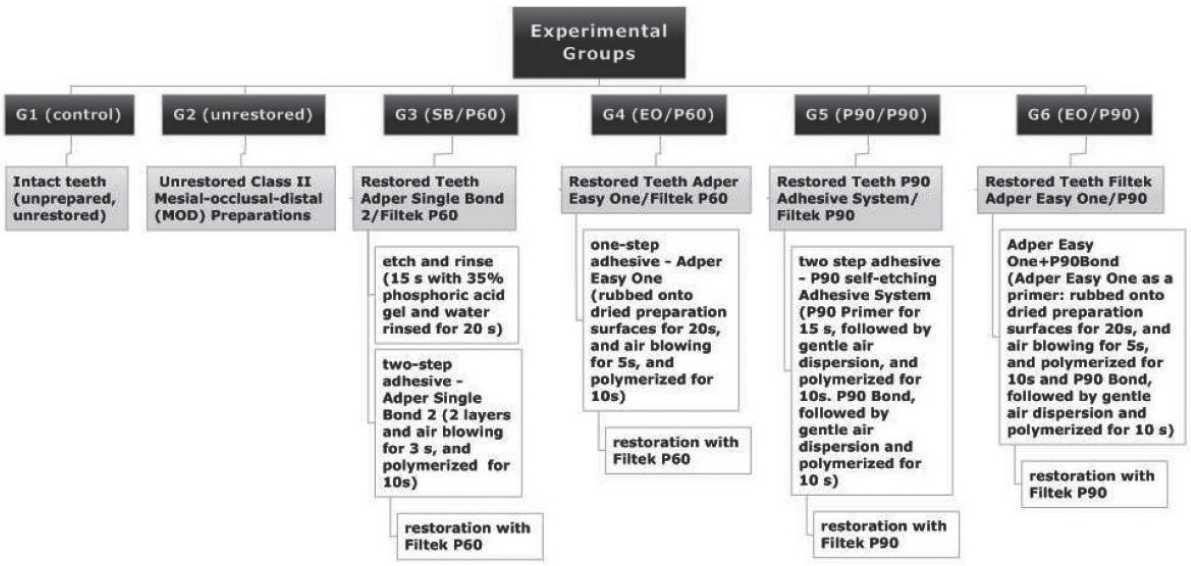

Figure 1 - Experimental groups of the present study.

that described in ISO 4049. The composites were applied to a Teflon mold (8 × 2 × 2 mm) that was positioned over a polyester strip (n = 10). After filling the mold to excess, the material surface was covered with a Mylar strip and a glass slide was compressed to extrude excess material. The specimens were photoactivated as previously described. The specimen dimensions were measured using digital calipers (Digimatic Caliper CD, Mitutoyo, Japan). The specimens were then stored in distilled water at 37°C for 24 h. The three-point bending test was carried out in a universal testing machine (model 3342, Instron Corp., Canton, USA) at 0.5 mm/min with a 5-mm span between supports. FS was calculated as follows:

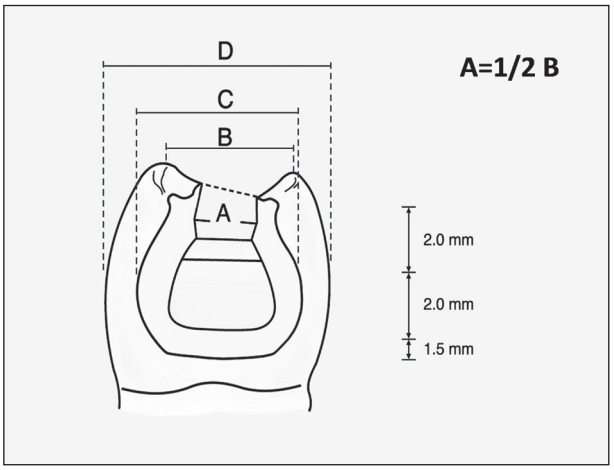

Figure 2 - Preparation design and dimensions.

$$\sigma = \frac{3F \times L}{2b \times h^2}$$

The modulus of elasticity (E) was calculated using the following equation:

$$E = \frac{L^3}{4b \times h^3} \times \frac{F}{Y}$$

where F is the maximum strength in N, L is the distance between the rests, b is the width of the

Figure 3 - Classification of fracture modes.

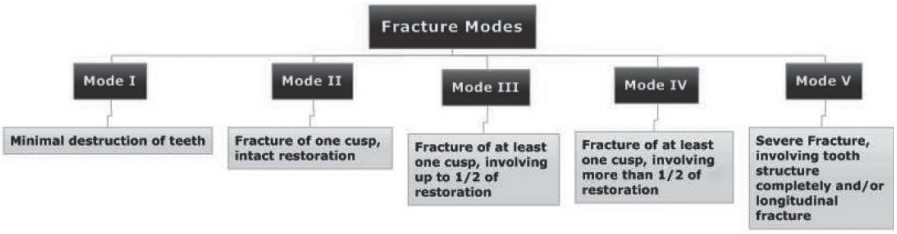

Table 1 - Materials used in the study.

Materials	Composition	Lot #
Filtek P90	3,4-epoxycyclohexylethylcyclopolymethylsiloxane; bis-3,4-poxycyclohexy lethylphenylmethylsilane; Silanized quartz; yttrium fluoride; 76wt%	9ER
Filtek P60	Bis-GMA; Bis-EMA; UDMA; TEGDMA; Silica nanofiller; 83wt%	9PG
Adper Single Bond 2	Etch-and-rinse, conventional adhesive system; Bis-GMA; polyalkenoic acid co-polymer; dimethacrylates; HEMA; photoinitiators; ethanol; water; nanofiller particles	9WF
P90 System Adhesive	Two-bottle self-etch adhesive system; **Primer:** phosphorylated methacrylates, Vitrebond copolymer, Bis-GMA, HEMA, water, ethanol, silane-treated silica filler, initiators, stabilizers; **Bond:** hydrophobic dimethacrylate, phosphorylated methacrylates, TEGDMA, silane-treated silica filler, initiators, stabilizers	9BL (P) 9BH (B)
Adper Easy One	One-step, self-etching adhesive system;Bis-GMA; polyalkenoic acid co-polymer; dimethacrylates; phosphorylated methacrylates; HEMA; photoinitiators; ethanol; water; nanofiller particles	9WF

Bis-GMA: bisphenol-glycidyl-methacrylate; Bis-EMA: bisphenol-a-ethoxy dimethacrylate; UDMA: urethane-dimethacrylate; TEGDMA: triethyleneglycol dimethacrylate; HEMA: hydroxyethyl methacrylate.

specimen, and h is the height of the specimen and F/Y is the slope of the linear part of the stress-strain curve.

Statistical analysis of FS and E was performed with ANOVA and Tukey tests (5 %).

Results

The mean loads (kN) necessary to induce fracture in the groups are presented in Table 2. G1 presented the highest mean, whereas G2 presented the lowest. No significant difference in fracture resistance was noted when the SB/P60 was compared to the control group. The mean fracture resistance of G3 was 0.78 kN. The remaining groups exhibited similar significantly lower mean values (Table 2) when compared to that of the control group.

The mode of fracture of each specimen is shown in Table 3. A higher number of samples in the groups restored with SB/P60 (G3) showed mode IV and V patterns of fracture, with detachment occurring in at least part of the restoration and fracturing occurring at the interface. The teeth were almost completely destroyed in some samples (higher values). The patterns in the other groups were characteristic of modes I and II.

The results for both FS and E are listed in Table 4. In general, the methacrylate-based composite P60 exhibited higher mean FS and E ($p < 0.05$).

Table 2 - Fracture resistance and recovery for all groups.

Experimental Group	Fracture resistance kN (s.d.)	Recovery (in %)
G 1	0.94 (0.18) a	100
G 2	0.46 (0.13) b,c	49
G 3	0.78 (0.12) a,d	83
G 4	0.52 (0.14) b,c	55
G 5	0.52 (0.13) b,c	55
G 6	0.56 (0.09) b,c	59

Different lower letters a/b (comparison with G1), and c/d (comparison with G2): significant ($p < 0.05$).

Table 3 - Mode of fracture of restored specimens.

Specimen	G 3	G 4	G 5	G 6
1	V	II	III	III
2	IV	III	II	IV
3	IV	IV	I	II
4	III	I	II	III
5	IV	II	IV	II
6	II	IV	II	II
7	IV	II	II	I
8	V	II	II	II

Table 4 - Comparative mechanical properties of restorative materials.

Restorative material	Flexural strength (MPa)	Elastic modulus (GPa)
P60	249 |	16.6 |
P90	200 |	14.4 |
Enamel	20[1]	40.8[1]
Dentin	75[1]	13.6[1]

Vertical bars in the same column: significant ($p < 0.05$).

Discussion

In a well-bonded restoration with mechanically resistant tooth tissue, the weakest link is the tooth/composite interface. In this case, fracture by microleakage and subsequent secondary decay could be associated with higher risks.[9,10] To protect the tooth structure from these risks, newer restorative systems were developed. Although an underperformed bonding approach has been claimed to influence the interfacial quality more than the differences in the resin composite formulations,[11] different restorative systems (adhesive/resin composite) were compared when evaluating the resistance to fracture in premolars. In the present study, the only restorative system that restored the resistance to fracture of teeth to levels similar to that of the intact group was SB/P60 ($p < 0.05$). The silorane system was not able to restore fracture resistance in relation to the control group, presenting a significantly lower mean ($p > 0.05$). The same was noted for G6, in which the P90 primer was replaced by the EO adhesive ($p > 0.05$). Moreover, there was no significant increase in the fracture resistance when compared with the prepared, unrestored group (G2). Thus, the

research hypothesis, that there would be no difference in the fracture resistance when comparing both restorative systems, was not accepted.

The sound teeth presented higher resistance to fracture because of the rigidity and the integrity of the tooth structure, even considering that the tension was applied in such a way as to favor separation of the cusps. It would be expected that, irrespective of the restorative system used, all of the restored groups should present higher resistance to fracture when compared to the prepared, unrestored group because the "emptiness" of the preparation was replaced by rigid restorative materials. In the restored teeth, it would be expected that the composite rigidity (elastic modulus) would restore the resistance to fracture as well as guide the mode of fracture that was evaluated. Both resin composites are indicated for restoring posterior teeth. The silorane composite is filled with a combination of fine quartz particles and radiopaque yttrium fluoride and is classified as a microhybrid resin composite (concentration of 76% by weight). The filler in P60 is zirconia/silica at a concentration of 83% by weight and is classified as a hybrid composite. Previous studies noted that variables such as size, shape, distribution, and content per volume/weight of the filler particles in the matrix influence the mechanical strength, hardness, and elastic modulus of resin composites.[12-14] In the present study, the flexural strength test allowed the authors to conclude that fracture resistance was not related to the modulus and, moreover, was not dependent on the resin matrix type.

This difference is related to the adhesive layer present when SB is applied.[15] The morphology of the one-step, self-etching adhesive EO is quite different. This material exhibits a tenuous hybrid layer, which is generally accompanied by a tenuous adhesive layer.[16] The adhesive layer in the SB seemed to have acted as a stress-absorbent structure. It has been claimed that a limited magnitude of stress transfer to the preparation walls occurs with the use of a substantially thicker adhesive layer, which is able to partially absorb dental composite deformations.[17] Additionally, it is important to mention that the gradient concentration of nanofillers in the SB adhesive seems to create a layer in which the stress generated due to both the polymerization shrinkage and to the loading test is more evenly distributed.[18] According to the manufacturer's information, SB and EO have a similar composition, with the exception of methacrylated phosphoric esters in the latter. This modification in the adhesive composition reduced the pH (from 4.3 to 3.5) and eliminated the need to apply the aggressive, low-pH phosphoric acid gel (pH 0.6), which increased the ability of the adhesive to effectively etch and permeate the smear layer. Thus, it would be expected that EO/P60 and P90/P90 presented similar means in comparison to G1. Nevertheless, only the SB/P60 combination was able to restore the resistance to fracture.

The magnitude of tooth deformation depends on several factors such as the preparation design, the magnitude of and the type of load application mode, the mechanical properties of the substrate and of the restorative material, and the compliance of the substrate. Efforts have been made to investigate these factors and understand the way in which the magnitude of the stress generated at the interface is affected.[17,19] Stress values have been correlated with elastic modulus;[20] however, the modulus and shrinkage rate have shown weak relationships with polymerization stress.[21] The modulus of P90 was similar to that of the dentin tissue (Table 4). It has also been suggested that mechanical loadings should be limited during the first hours after the restoration procedure due to subsequent polymerization.

However, it seems that the resistance to fracture was more dependent on the ability of the P90 adhesive to resist the loading test. According to the manufacturer, the P90 primer (pH 2.7) allows for mild etching and demineralization of the tooth structure and strong and durable bonding. The P90 primer has also been claimed to bond chemically to the hydroxyapatite crystals, as confirmed in a recent study.[22] This dedicated adhesive system is designed to link the hydrophilic dentin and hydrophobic silorane. P90 primer and bonding material are sold in separate bottles and are photoactivated as separate layers, unlike any other two-step, self-etching adhesive system, in which the primer and bond are photoactivated together and mixed on the dentin surface before curing. A previous study supported

the hypothesis that optimal stability of silorane adhesive can be achieved; however, concerns regarding the quality and long-term stability of the hybrid layer created by applying the P90 adhesive have been reported.[23] In another study,[24] an intermediate zone of approximately 1 μm between the silorane primer and the bond was detected. This zone has been claimed to be the weakest link in the failure mechanism of silorane restorations. In group 6, the P90 primer was replaced by EO. In this case, the bridge between the hydrophilic dentin and the P90 bond was made using a two-step, self-etching adhesive system. In spite of the possible chemical incompatibility between the adhesive and P90 bond, this scenario could occur in daily practice if the dentist runs out of P90 primer. The results showed a slight, but not significant, increase in the resistance to fracture in this group. In addition, the fractographic analysis was similar to that noted in groups 4 and 5.

Initial overcutting followed by continual "replacement therapy"[25] with additional tooth reduction at each replacement leads to deterioration and ultimately to fracture.[26] Clinically, the chewing forces are of a relatively large magnitude, which leads to variation in the time, speed and direction of application.[27] This study proved that SB/P60 was the most effective combination. The same was not observed when the silorane was applied. Investigations are necessary to evaluate the fracture resistance for longer periods because the adhesive bond might fail in the clinical situation, especially when multi-layered adhesives are used.

Conclusions

Within the limitations of the present study, the following conclusions can be drawn:

- Reestablishment of the resistance to fracture of premolars subjected to Class II MOD preparations is restorative-system-dependent.
- The silorane restorative system does not recover the resistance to fracture.

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References

1. Dalpino PH, Francischone CE, Ishikiriama A, Franco EB. Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly restored with ceramic materials. Am J Dent. 2002 Dec;15(6):389-94.
2. Massa F, Dias C, Blos CE. Resistance to fracture of mandibular premolars restored using post-and-core systems. Quintessence Int. 2010 Jan;41(1):49-57.
3. Liu Y, Tjaderhane L, Breschi L, Mazzoni A, Li N, Mao J, *et al*. Limitations in bonding to dentin and experimental strategies to prevent bond degradation. J Dent Res. 2011 Aug;90(8):953-68.
4. Peutzfeldt A, Asmussen E. Determinants of *in vitro* gap formation of resin composites. J Dent. 2004 Feb;32(2):109-15.
5. Weinmann W, Thalacker C, Guggenberger R. Siloranes in dental composites. Dent Mater. 2005 Jan;21(1):68-74.
6. Palin WM, Fleming GJ, Nathwani H, Burke FJ, Randall RC. *In vitro* cuspal deflection and microleakage of maxillary premolars restored with novel low-shrink dental composites. Dent Mater. 2005 Apr;21(4):324-35.
7. Wieczkowski G Jr, Joynt RB, Klockowski R, Davis EL. Effects of incremental *versus* bulk fill technique on resistance to cuspal fracture of teeth restored with posterior composites. J Prosthet Dent. 1988 Sep;60(3):283-7.
8. Burke FJ, Wilson NH, Watts DC. Fracture resistance of teeth restored with indirect composite resins: the effect of alternative luting procedures. Quintessence Int. 1994 Apr;25(4):269-75.
9. Versluis A, Douglas WH, Cross M, Sakaguchi RL. Does an incremental filling technique reduce polymerization shrinkage stresses? J Dent Res. 1996 Mar;75(3):871-8.
10. Ensaff H, O'Doherty DM, Jacobsen PH. The influence of the restoration-tooth interface in light cured composite restorations: a finite element analysis. Biomaterials. 2001 Dec;22(23):3097-103.
11. D'Alpino PHP, Bechtold J, Santos PJ, Di Hipólito V, Silikas N, Alonso RCB, *et al*. Methacrylate- and silorane-based composite restorations: hardness, depth of cure and interfacial gap formation as a function of the energy dose. Dent Mater. 2011 Nov;27(11):1162-9.
12. Peris AR, Mitsui FH, Amaral CM, Ambrosano GM, Pimenta LA. The effect of composite type on microhardness when using quartz-tungsten-halogen (QTH) or LED lights. Oper Dent. 2005 Sep-Oct;30(5):649-54.
13. Oberholzer TG, Grobler SR, Pameijer CH, Hudson AP. The effects of light intensity and method of exposure on the hardness of four light-cured dental restorative materials. Int Dent J. 2003 Aug;53(4):211-5.

14. Manhart J, Kunzelmann KH, Chen HY, Hickel R. Mechanical properties and wear behavior of light-cured packable composite resins. Dent Mater. 2000 Jan;16(1):33-40.
15. Botelho Amaral FL, Martao Florio F, Bovi Ambrosano GM, Basting RT. Morphology and microtensile bond strength of adhesive systems to *in situ*-formed caries-affected dentin after the use of a papain-based chemomechanical gel method. Am J Dent. 2011 Feb;24(1):13-9.
16. Belli R, Sartori N, Peruchi LD, Guimaraes JC, Vieira LC, Baratieri LN, *et al*. Effect of multiple coats of ultra-mild all-in-one adhesives on bond strength to dentin covered with two different smear layer thicknesses. J Adhes Dent. 2010 Nov 8. doi: 10.3290/j.jad.a19814.
17. Ausiello P, Apicella A, Davidson CL. Effect of adhesive layer properties on stress distribution in composite restorations--a 3D finite element analysis. Dent Mater. 2002 Jun;18(4):295-303.
18. Miyazaki M, Ando S, Hinoura K, Onose H, Moore BK. Influence of filler addition to bonding agents on shear bond strength to bovine dentin. Dent Mater. 1995 Jul;11(4):234-8.
19. Asmussen E, Peutzfeldt A. Class I and Class II restorations of resin composite: an FE analysis of the influence of modulus of elasticity on stresses generated by occlusal loading. Dent Mater. 2008 May;24(5):600-5.
20. Cadenaro M, Codan B, Navarra CO, Marchesi G, Turco G, Di Lenarda R, *et al*. Contraction stress, elastic modulus, and degree of conversion of three flowable composites. Eur J Oral Sci. 2011 Jun;119(3):241-5.
21. Boaro LC, Goncalves F, Guimaraes TC, Ferracane JL, Versluis A, Braga RR. Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. Dent Mater. 2010 Dec;26(12):1144-50.
22. Mine A, De Munck J, Van Ende A, Cardoso MV, Kuboki T, Yoshida Y, *et al*. TEM characterization of a silorane composite bonded to enamel/dentin. Dent Mater. 2010 Jun;26(6):524-32.
23. Navarra CO, Cadenaro M, Armstrong SR, Jessop J, Antoniolli F, Sergo V, *et al*. Degree of conversion of Filtek Silorane Adhesive System and Clearfil SE Bond within the hybrid and adhesive layer: an *in situ* Raman analysis. Dent Mater. 2009 Sep;25(9):1178-85.
24. Santini A, Miletic V. Comparison of the hybrid layer formed by Silorane adhesive, one-step self-etch and etch and rinse systems using confocal micro-Raman spectroscopy and SEM. J Dent. 2008 Sep;36(9):683-91.
25. Gelb MN, Barouch E, Simonsen RJ. Resistance to cusp fracture in class II prepared and restored premolars. J Prosthet Dent. 1986 Feb;55(2):184-5.
26. Fennis WM, Kuijs RH, Kreulen CM, Verdonschot N, Creugers NH. Fatigue resistance of teeth restored with cuspal-coverage composite restorations. Int J Prosthodont. 2004 May-Jun;17(3):313-7.
27. Ausiello P, De Gee AJ, Rengo S, Davidson CL. Fracture resistance of endodontically-treated premolars adhesively restored. Am J Dent. 1997 Oct;10(5):237-41.