Comparison of shear bond strength of three bonding agents with metal and ceramic brackets

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Abstract: Shear bond strengths of a light-cured composite resin, a light-cured glass ionomer cement, and a light-cured compomer used with metal and ceramic brackets were compared, and ARI scores were evaluated. Ceramic brackets showed statistically higher shear bond strengths than metal brackets when bonded with all test materials ($p<0.001$). When used with metal brackets, the light-cured glass ionomer cement (LCGIC) and compomer materials demonstrated statistically lower shear bond strengths than the light-cured composite ($p<0.01$ and $p<0.001$, respectively). When used with ceramic brackets, LCGIC was found to have significantly lower shear bond strength than the composite material ($p<0.001$). Despite its relatively low shear bond strength, LCGIC demonstrated optimal bonding values (8.39±3.24 MPa) with ceramic brackets. Bond failures within the LCGIC groups occurred at the adhesive-tooth interface, whereas in the compomer and composite groups, failures were detected at the adhesive-bracket interface. In the metal bracket group, clinically acceptable shear bond strength was obtained only with the composite resin (7.06±1.65 MPa). Compomer and LCGIC demonstrated values well below the accepted standard for metal brackets (4.32±1.75 MPa and 4.45±1.06, respectively), while in the ceramic bracket group, values for composite and compomer were above the desired level (14.40±5.88 MPa and 12.31±6.09, respectively). LCGIC showed reasonably good bond strength with ceramic brackets, suggesting that this material may be considered suitable for use with ceramic brackets in clinical situations where moisture cannot be controlled.

Key Words: Ceramic and metal brackets, Shear bond strength, Glass ionomer cement

Since the introduction of the acid etching technique by Buonocore,[1] direct bonding of brackets has become widely accepted by orthodontists throughout the world. But this technique has also introduced potential disadvantages, such as enamel decalcification[2,3,4] and subsequent risk of dental caries. In addition, the orthodontist must keep the bonding surface dry throughout the procedure[5] because contamination by water or saliva reduces bond strength dramatically.

Glass ionomer cement (GIC), introduced to dentistry by Wilson and Kent,[6] was popularized in orthodontics by White.[7] GIC contains a powder similar to that of silicate cement and a polyacrylic liquid similar to polycarboxylate cement. It adheres chemically to enamel, dentin, nonprecious metals, and plastics.[7,8] When bonding to dental hard tissues, GIC works by molecular interactions between the calcium ions in the enamel and carboxylic groups in the cement.[9] Because of this unique property, GICs do not require acid-etching of the tooth surface to create micromechanical retention. Additionally, they are not susceptible to moisture contamination.[10] Another advantage of GICs is that they release fluoride for periods of at least 12 months,[8] and they have the ability to absorb fluoride topically from fluoride-containing materials, such as toothpastes, allowing them to act as rechargeable fluoride reservoirs.[11-14] Fluoride is known to be an important factor in preventing decalcification and white spot lesions around bonded orthodontic appliances.[5,12,15] Glass ionomer cements are marketed in both chemically cured and light-cured systems. Compton et al.[16] demonstrated that light-cured GICs produce higher

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bond strengths than chemically cured products.

Compomers have been introduced with claims that they combine the advantages of glass ionomer cements and light-curing composite materials within a unique chemical formulation. In fact, they are a single-component composite resin formed by combining a composite resin and a glass ionomer cement. They set initially with photopolymerization, and then gradually through diffusion of water into the set material.[17,18] When set, compomers do not exhibit the typical properties of true GICs, such as chemical bonding to tooth structures or fluoride rechargeability.[19]

Contemporary orthodontic treatment provides a service to many adults, and the need for esthetic appliances, such as ceramic brackets, has been proven. However, ceramic brackets pose several clinical complications, including increased friction and greater chance of enamel damage during debonding.[20] Ceramic brackets adhere chemically to enamel, producing very high bond strengths. With the recent concern about difficulties debonding ceramic brackets,[21] a logical question would be whether there is a resin/bracket combination that will aid in bracket removal and yet maintain adequate bond strength.[22]

Since Kula et al.[23] demonstrated that fluoride ions had no negative effect on ceramic brackets, GICs and compomers could be tested for their bond strengths with ceramic brackets. The bond strength of ceramic brackets to enamel using GICs and compomers has not been investigated previously.

The aim of this study was to compare the shear bond strengths of three different light-cured bonding agents: a GIC, a compomer, and a conventional composite resin, using both ceramic and metal brackets.

Materials and methods

Seventy bovine mandibular incisors were collected. Selection criteria included noncarious and intact tooth surfaces. The teeth were cleansed of soft tissue, and the greater portion of the roots were removed. The clean teeth were stored in distilled water at room temperature before being randomly assigned to one of seven test groups. The facial surface of each incisor was cleaned with a mixture of water and pumice using a rubber polishing cup, rinsed with oil-free water, and air-dried. The teeth were then embedded in self-curing acrylic leaving the crowns exposed, and the specimens were immersed in water until testing. In each specimen, the facial surface of the acrylic base was trimmed so that it was parallel to the facial surface of the tooth and to the plunger of the testing instrument.

Maxillary central metal brackets (Roth Omniarch, GAC International, Central Islip, NY) and maxillary central ceramic brackets (Allure IV, GAC International, Central Islip, NY) were used. Allure IV ceramic brackets were chosen to test whether fluoride-releasing agents would compromise the bonding characteristics of this brand; the manufacturer warns that fluoride may compromise bonding by neutralizing the silane coupling agent on the base of the bracket.

The bonding agents used were a light-cured glass ionomer cement (Fuji Ortho LC, GC Corp, Tokyo, Japan), a compomer (Compoglass, Vivadent Dental GmbH, Ellwangen, Germany), and a light-cured composite resin (Transilluminate, Ortho Organizers Inc, San Marcos, Calif), all of which contain fluoride. In order to further test whether any differences would be recorded between the fluoride-releasing composite and a nonfluoridated composite, a light-cured composite resin that does not contain fluoride (Transbond, 3M Unitek Dental Products, Monrovia, Calif) was also tested with ceramic brackets. The other agents were tested with both ceramic and metal brackets.

Seven groups were evaluated in the present study (Table 2). In the light-cured fluoride-releasing composite resin groups (groups 2 and 5), 20 teeth were acid-etched with 37% phosphoric acid for 30 seconds, rinsed with oil-free air-water spray for 30 seconds, and dried with an air syringe. A light-cured adhesive primer was applied to the acid-etched surfaces and light-cured for 10 seconds, according to the manufacturer's instructions. A thin layer of composite (Transilluminate) was applied to the bases of 10 ceramic and 10 metal brackets, which were then pressed onto the facial surfaces of the teeth using cotton forceps. Excess material was removed with an explorer. The specimens were then light-cured from the occlusal, gingival, mesial, and distal aspects for 10 seconds each, for a total cure time of 40 seconds.

The specimens in group 7 were prepared as described above, and Transbond was used to bond 10 ceramic brackets.

Groups 3 and 6 were bonded with light-cured compomer (Compoglass). These 20 teeth were acid-etched as described previously, and a thin layer of compomer was applied to the bases of 10 metal and 10 ceramic brackets, which were then pressed on to the teeth and light-cured as described above.

Groups 1 and 4 constituted the light-cured glass ionomer group. According to the manufacturer's instructions, no acid-etching was performed, and the enamel surfaces were dampened with distilled water using a brush. A Fuji Ortho LC capsule was placed in a capsule mixer and mixed for 10 seconds at 4000 RPM, then applied to 10 metal and 10 ceramic brackets. Light-curing was done as described above.

A Visilux 2 (3M Unitek, Monrovia, Calif) light-curing unit was used for all the specimens tested. The adequacy of the unit irradiance was confirmed with a curing meter prior to photopolymerization.

The teeth were stored in distilled water for 24 hours at room temperature prior to shear bond testing on a Lloyd universal testing machine (Figure 1). The specimens were held with the lower jaw of the instrument so that the bracket base was positioned parallel to the direction of force. A knife-edged shearing blade was used with the direction of force parallel to the labial surface and the bracket interface. The crosshead speed was 1 mm/minute. The shearing blade struck flush against the edge of the bracket base without touching the enamel. The force required to dislodge the bracket was recorded in Newtons and converted to MPa using the following equation:

$$\text{Shear force (MPa)} = \frac{\text{F(debonding force:N)}}{d.l\ (mm^2)}$$

where d = width of bracket base, and l = height of bracket base.

The metal brackets used in this study had an adhesive base area of 14.19 mm^2 and the ceramic brackets measured 12.95 mm^2. The adhesive remnant index (ARI) was used to evaluate the amount of residual adhesive after debonding. Developed by Årtun and Bergland,[24] the ARI is a 4-point scale where 0 indicates no adhesive left on the tooth, 1 indicates less than half the adhesive remains on the tooth, 2 indicates more than half the adhesive remains on the tooth, and 3 indicates all of the adhesive remains on the tooth, including a distinct impression of the bracket mesh.

The nonparametric Mann Whitney *U*-test was used to determine the statistical significance of differences between groups. ARI scores were distributed by percentage for the groups.

Table 1
Shear bond strength values of the tested bonding agents with metal and ceramic brackets in MPa

	Fuji Ortho LC Mean	Fuji Ortho LC SD	Compoglass Mean	Compoglass SD	Transilluminate Mean	Transilluminate SD	Transbond Mean	Transbond SD
Metal bracket (Omni Arch, GAC)	4.45	1.06	4.32	1.75	7.06	1.65	-	
Ceramic bracket (Allure IV, GAC)	8.39	3.24	12.31	6.09	14.40	5.88	20.17	8.67

Results

Mean shear bond strengths and standard deviations for the groups are shown in Table 1. Statistical comparisons and ARI percentages are shown in Tables 2 and 3, respectively.

Group 5 (light-cured composite resin with metal brackets) had a mean shear bond strength value of 7.06±1.65 MPa. Group 2 (light-cured composite resin with ceramic brackets) had a mean value of 14.40±5.88 MPa, the highest of all test groups. Groups 3 and 6 (Compoglass) had mean bond strengths of 12.31±6.09 and 4.32±1.75 MPa for ceramic and metal brackets, respectively. Groups 1 and 4 (LCGIC) had mean bond strengths of 8.39±3.24 MPa and 4.45±1.06 MPa for ceramic and metal brackets, respectively. Group 7 (nonfluoride light-cured composite resin with ceramic brackets) had a mean value of 20.17±8.67 MPa. Metal and ceramic brackets showed significantly different values, depending on the bonding agent used ($p<0.001$).

LCGIC and Compoglass had statistically lower shear bond strengths compared with the composite resins when bonded with metal brackets ($p<0.001$ and $p<0.01$, respectively). However, when ceramic brackets were used, composite resin showed significantly higher values than LCGIC ($p<0.001$).

Bond failure with the LCGIC occurred at the adhesive/tooth interface, in contrast to the Compoglass

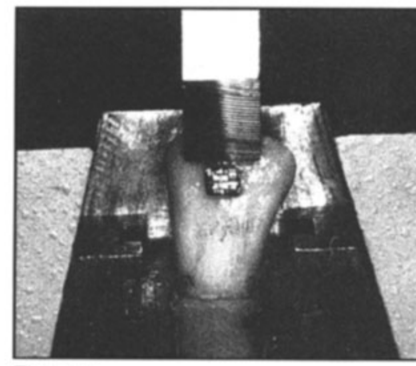

Figure 1
Specimen placed in the Lloyd universal testing machine

and composite, where failure occurred at the adhesive/bracket interface. All the LCGIC-metal brackets had an ARI score of 0, as did 50% of the LCGIC-ceramic brackets.

Discussion

Mandibular bovine teeth were used as specimens in this study because previous studies have indicated that bovine enamel and human enamel are similar in their physical properties and adhesive bond strength.[25,26]

The shear bond strength of glass ionomer cement has been reported to be 35% to 39% that of composite resin.[16] The maximum bond strength recommended for successful clinical bonding is estimated to be 7 MPa.[27] Shear stresses exerted on attachments during orthodontic treatment range from 1 to 3 MPa,[10] although higher stresses can occur during mastication. Studies have shown that metal brackets bonded with composite resins show average bond strengths ranging from 2

Table 2
Statistical comparison of the groups tested

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Group 1 Ceramic bracket-Fuji Ortho LC		**		***		***	****
Group 2 Ceramic bracket-Transilluminate				****	***	****	
Group 3 Ceramic bracket-Compoglass				***		***	*
Group4 Metal bracket-Fuji Ortho LC					***		****
Group 5 Metal bracket-Transilluminate						**	****
Group 6 Metal bracket-Compoglass							****
Group 7 Ceramic bracket-Transbond							

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.0001$

to 13 MPa; these values are in accordance with our findings. Metal brackets bonded with LCGIC showed very different values, ranging from 0.8 MPa to 20.1 MPa, depending on whether enamel etching was performed.[5,10,13,16,28,29] However, as glass ionomer cements bond chemically to enamel and do not rely on a mechanical bond, the manufacturer does not recommend acid-etching or any other pretreatment except pumicing. Wiltshire[30] achieved a shear bond strength of 4.4 MPa using GIC with metal brackets without etching, similar to our findings. Messersmith et al.[31] reported a bond strength value of 24.47 newtons with Fuji Ortho LC without etching. In the present study, the mean value to dislodge the metal brackets bonded with Fuji Ortho LC was 46.0 N. Because of the probable difference in bracket base area, a direct comparison cannot be made with the findings of the study by Messersmith et al.[31] However, higher values seem to have been obtained in the present study. Other studies in which brackets were bonded to acid-etched enamel have also reported higher values.[13,16,28,29] Our observations confirm the findings of studies that conclude that the bond strength of composite resin is significantly higher than that of glass ionomer cement.[9,28-32] The results for metal brackets indicate that neither Compoglass nor light-cured GIC can replace composite resin, as their bond strength values are less than the optimum clinical value of 7 MPa. Thus, we are in agreement with Miguel et al.,[33] who concluded in an in vivo study that GIC had a low clinical performance. Our findings do not support the view that GICs can be used efficiently instead of composite resins.[5,7,14,34,35] However, no previously published reports have compared the bonding characteristics of GICs and compomers used with ceramic brackets; therefore, the findings of the present study are of clinical interest.

Table 3
ARI Scores of the tested groups in percentage

	0 No adhesive on tooth	1 >½ adhesive on tooth	2 <½ adhesive on tooth	3 all adhesive on tooth
Group 1 Ceramic bracket-Fuji Ortho LC	50%	30%	20%	
Group 2 Ceramic bracket-Transilluminate			60%	40%
Group 3 Ceramic bracket-Compoglass	30%	20%	10%	40%
Group 4 Metal bracket-Fuji Ortho LC	100%			
Group 5 Metal Bracket-Transilluminate				100%
Group 6 Metal bracket-Compoglass		10%		90%
Group 7 Ceramic bracket- Transbond	80%	20%		

Significantly higher shear bond strength values were obtained with ceramic brackets and composite resins, in agreement with previous studies.[20,21,36-38] Shear bond strengths of the two composite resins used were not significantly different, although one of the composites contained fluoride. The manufacturer of Allure IV brackets recommends that they not be used with fluoride-releasing agents because fluoride can neutralize the silane coupling agent on the base of the bracket and lead to higher rates of bond failure. Ashcraft et al.[13] reported that the initial burst of fluoride from the fluoride-releasing agents occurred over the first 24 hours, and decreased gradually after the first day. Our shear bond strength test was performed after 24 hours, and the fluoride ions did not significantly affect bond strength in this time period. Shear bond strengths of fluoride-releasing composite (Transilluminate) and nonfluoride composite (Transbond) did not show any significant difference when the two groups were compared. This is in agreement with Kula et al.,[23] who concluded that there were no negative effects of topical fluoride application on ceramic brackets. The effect of fluoride-release over the long-term should be further investigated, using ceramic brackets that have a silane coupling agent on the base. Additionally, manufacturers should address the fact that most of the bonding agents marketed today contain fluoride.

The high bond strengths reported with ceramic brackets may not be an advantage. The work of Retief[39] on bond failure indicated that enamel fractures can occur with bond strengths as low as 13.5 MPa. This is comparable to the mean strength of 14.5 MPa previously reported by Bowen and Rodriguez.[40] The amount of enamel loss due to acid-etching was estimated to be 50 to 60 μm.[41] Diedrich[2] estimated that up to 150 to 160 μm of enamel loss can occur after debonding. This represents 10% of the original enamel surface.[28] The main disadvantage of ceramic brackets is the high bond strength, which can result in enamel fractures during debonding. Gwinnet[42] found a bond strength of 18.3 MPa for ceramic brackets, similar to our mean values of 14.40±5.88 and 20.17±8.67 MPa obtained with light-cured composites. Joseph and Rossouw[37] assumed that with the high bond strength obtained with rigid ceramic brackets, the safety margin of stresses that could be withstood by the cohesive strength of enamel was reduced; this assumption has been supported by several studies.[20,38,43,44] In clinical use, the bond between the ceramic bracket and the adhesive must be strong enough to withstand orthodontic and chewing forces while still allowing the removal of the bracket without injury to the tooth.[45] The bond strength values obtained with LCGIC and ceramic brackets seem to meet both these conditions. In the present study, the shear bond strength of LCGIC with ceramic brackets was 8.39±3.24, which is higher than the optimum clinical value 7 MPa but lower than 13.5 MPa. Compoglass showed similar high values of shear bond strength with the ceramic brackets, in contrast to metal brackets. Because of this property, Compoglass may not be an appropriate choice of adhesive for bonding ceramic brackets. Although not recommended for use with metal brackets, LCGIC may be an ideal bonding agent for use with ceramic brackets due to its lower bond strength, thereby reducing the disadvantage of ceramic brackets.

Fuji Ortho LC is a capsulated agent that has a disadvantage of limited application time. Following activation of the capsules, only three or four brackets can be bonded before setting occurs; an excessive amount of mixed cement is left in the capsule. Capsules that contain less cement may be more appropriate.

Conclusions

1. Fuji Ortho LC may be appropriate only with metal brackets in cases of insufficient saliva isolation, where bonding with composite resin will fail. However, Fuji Ortho LC may be the most appropriate bonding agent with ceramic brackets, since optimal bonding values were obtained with this combination.
2. Compoglass is a relatively new material, but it offers no advantages over other agents. It demonstrated lower-than-desired bond strength with metal brackets, and higher-than-desired values with ceramic brackets.
3. Clinically desired shear bond strengths with metal brackets were obtained using light-cured composite agents.

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References

1. Buonocore MG. A simple method of increasing the adhesion of acrylic filling material to enamel surfaces. L Dent Res 1955;34:849-53.
2. Diedrich P. Enamel alterations from bracket bonding and debonding: A study with the scanning electron microscope. Am J Orthod 1981;79:500-22.
3. Brannström M, Malmgren O, Nordevall KJ. Etching of young permanent teeth with an acid gel. Am J Orthod 1982;82:379-83.
4. Ogaard B, Rolla G, Arends J. Orthodontic appliances and enamel demineralization. Part 1. Lesion development. Am J Orthod Dentofac Orthop 1988;94:68-73.
5. Silverman E, Cohen M, Demke R, Silverman M. A new light-cured glass ionomer cement that bonds brackets to teeth without etching in the presence of saliva. Am J Orthod Dentofac Orthop 1995;108:231-36
6. Wilson AD, Kent BE. A new translucent cement for dentistry. Brit Dent J 1972;132:133-5.
7. White LW. Glass ionomer cement. J Clin Orthod 1986;20:387-91.
8. Maijer R, Smith DC. A comparison between zincphosphate and glass ionomer cement in orthodontics. Am J Orthod Dentofac Orthop 1988;93:273-79.
9. Voss A, Hickel R, Mölkner S. In vivo bonding of orthodontic brackets with glass ionomer cement. Angle Orthod 1993;2:149-53.
10. Klockowski R, Davis E, Joynt R, Wieczkowski G. Bond strength and durability of glass ionomer cement used as bonding agents in the placement of orthodontic brackets. Am J Orthod Dentofac Orthop 1989;96:60-4.
11. McCourt JW, Cooley RL, Huddleston AM. Fluoride release from fluoride containing liners, bases. Quint Int 1990;21:41-5.
12. Hatibovic-Kofman S, Koch G. Fluoride release from glass ionomer cements, in vivo and in vitro. Swed Dent J 1991; 15:253-8.
13. Ashcraft D, Staley R, Jakobsen J. Fluoride release and shear bond strengths of three light-cured glass ionomer cements. Am J Orthod Dentofac Orthop 1997;111:260-5.
14. Fricker JP. A 12 month clinical evaluation of a light activated glass polyalkenoute (ionomer) cement for the direct bonding of orthodontic brackets. Am J Orthod Dentofac Orthop 1994;105:502-5.
15. Hallgren A, Oliveby A, Twetman S. Caries associated microflora in plaque from orthodontic appliances retained with glass ionomer cement. Scand J Dent Res 1992;100:140-3.
16. Compton AM, Meyers CE, Hondrum SO, Lorton L. Comparison of shear bond strength of a light-cured glass ionomer and a chemically cured glass ionomer for use as an orthodontic bonding agent. Am J Orthod Dentofac Orthop 1992;101:138-44.
17. Fritz UB, Finger WJ, Uno S. Resin modified glass ionomer cements. Bonding to enamel and dentin. Dent Mat 1996;12:161-66.
18. Rock WP, Abdullah MSB. Shear bond strengths produced by composite and compomer light-cured orthodontic adhesives. J Dent 1997;25:243-49.
19. Peutzfeldt A. Compomers and glass ionomers. Bond strength to dentin and mechanical properties. Am J Dent 1996;9:259-63.
20. Redd TB, Shivapuja PK. Debonding ceramic brackets: Effects on enamel. J Clin Orthod 1991;25:475-81.
21. Ostertag AJ, Dhuru V, Ferguson DJ, Meyer R. Shear, torsional and tensile bond strengths of ceramic brackets using three adhesive filler concentrations. Am J Orthod Dentofac Orthop 1991;100:251-8.
22. Ghafari J. Problems associated with ceramic brackets suggest limiting use to selected teeth. Angle Orthod 1992; 62:145-52.
23. Kula K, Josell S, Kula T. Effect of topical fluorides on ceramic brackets. Am J Orthod Dentofac Orthop 1994; 106:513-17.
24. Årtun J, Bergland S. Clinical trials with crystal growth, conditioning as an alternative to acid etch enamel pretreatment. Am J Orthod 1984;85:333-40.
25. Nakamichi I, Iwaku M, Fusayama T. Bovine teeth as possible substitutes in the adhesion test. J Dent Res 1983; 62:1076-81.
26. Smith H, Casko J, Leinfelder K, Utley JD. Comparison of orthodontic bracket bond strengths: human vs. bovine enamel. J Dent Res 1976;55:153-67.
27. Lopez JI. Retentive shear bond strengths of various bonding attachment bases. Am J Orthod 1980;77:669-78.
28. Komori A, Ishikawa H. Evaluation of a resin reinforced glass ionomer cement for use as an orthodontic bonding agent. Angle Orthod 1997;67:189-96.
29. McCarthy MF, Hondrum SO, Meade FG. Mechanical and bond strength properties of light-cured and chemically cured glass ionomer cements. Am J Orthod Dentofac Orthop 1994; 105:135-41.
30. Wiltshire WA. Shear bond strengths of glass ionomer for direct bonding in orthodontics. Am J Orthod Dentofac Orthop 994;106:127-30.
31. Messersmith ML, Devine SM, Zionic AE. Effects of tooth surface preparation on the shear bond strength of resin modified glass ionomer cements. J Clin Orthod 1997;31:503-9.
32. Fajen VB, Duncanson MG, Nanda RS, Currier GF, Angolkar PV. An in vitro evaluation of bond strength of three glass ionomer cements. Am J Orthod Dentofac Orthop 1990;97:316-22.
33. Miguel JAM, Almeida MA, Chevitarese O. Clinical comparison between a glass ionomer cement and a composite for direct bonding of orthodontic brackets. Am J Orthod Dentofac Orthop 1995;107:484-7.
34. Cook PA. Direct bonding with glass ionomer cements. J Clin Orthod 1990; 24;509-11.
35. Silverman E, Cohen M, Demke R, Silverman M. A new self curing hybrid glass ionomer. J Clin Orthod 1997; 31:315-8.
36. Bishara SE, Olsen M, Von Wald L. Comparisons of shear bond strength of precoated and uncoated brackets. Am J Orthod Dentofac Orthop 1997;112:617-21.
37. Joseph VP, Rossouw E. The shear bond strengths of stainless steel and ceramic brackets used with chemically and light activated composite resins. Am J Orthod Dentofac Orthop 1990;97:121-5.
38. Viazis AD, Cavanaugh G, Bevis RR. Bond strength of ceramic brackets under shear stress: An in vitro report. Am J Orthod Dentofac Orthop 1990; 98:214-21.
39. Retief DH. Failure at the dental adhesive-etched enamel interface. J Oral Rehabil 1974;1:265-84.
40. Bower RL, Rodriguez MS. Tensile strength and modulus of elasticity of tooth structure and several restorative materials. J Am Dent Assoc 1962;64:378.
41. Brown CRL, Way DC. Enamel loss during orthodontic bonding and subsequent loss during removal of filled and unfilled adhesives. Am J Orthod Dentofac Orthop 1978;74:663-71.
42. Gwinnet AJ. A comparison of shear bond strengths of metal and ceramic brackets. Am J Orthod Dentofac Orthop 1988;93:346-8.
43. Eliades T, Viazis AD, Eliades G. Bonding of ceramic brackets to enamel: Morphologic and structural considerations. Am J Orthod Dentofac Orthop 1991;99:369-75.
44. Karamouzos A, Athanasiou A, Papadopoulos MA. Clinical characteristics and properties of ceramic brackets: A comprehensive review. Am J Orthod Dentofac Orthop 1997;112:34-40.
45. Merrill S, Oesterle L, Hermesch C. Ceramic bracket bonding. A comparison of shear, tensile, and torsional bond strengths of ceramic brackets. Am J Orthod Dentofac Orthop 1994;106:290-7.