Shear/peel bond strength of repositioned ceramic brackets

Peter G. Gaffey, BDS, MSc, Dip Ortho; Paul W. Major, DDS, MSc, MRCD (C); Kenneth Glover, BSc, DDS, MSc, MRCD (C); Michael Grace, PhD; James R. Koehler, BSc, DDS

A simple method to reposition bonded brackets has eluded operators since the advent of bonded attachments. Andrews[1] said the clinician must position the brackets correctly on the teeth to assure a functional end result. Inaccurately located brackets should be repositioned during treatment to take full advantage of the archwire slot values and sliding mechanics.[2]

Regan et al.[3] investigated the bond strength of rebonded stainless steel brackets and treated the bases at chairside. A significant decrease in bond strength was noted for all rebonded metal brackets. This decrease ranged from 41.4% for conventional foil mesh base brackets (A-Company, San Diego, Calif) to 64.4% for Microlok brackets (GAC International, Inc, Comnak, NY).

In 1990, Lew and Djeng[4] reported a chairside method of recycling ceramic brackets. The brackets were heated to remove residual bonding resin, silanated, then rebonded. Lew et al.[5] later investigated the shear bond strength of recycled ceramic brackets following debonding with the Transcend debonding instrument and found that bond strength was reduced approximately 40%.

Damage to enamel following debonding of

Abstract

Improper orthodontic bracket position may necessitate bracket removal and rebonding to establish correct bracket position. This procedure is necessary to use efficient orthodontic mechanics. The purpose of the study was to investigate (1) the amount of bonding resin remaining on single crystal bracket bases following electrothermal debonding, and (2) the bond strength of rebonded single crystal ceramic brackets under different treatment conditions. The bases of debonded, single crystal ceramic brackets (n=100) were inspected for resin, classified with an adaptation of the adhesive remnant index (ARI), and evenly assigned to four experimental groups (n=25). Groups were (1) silane coupling agent, (2) heat plus silane coupling agent, (3) hydrofluoric acid plus silane coupling agent, and (4) heat plus hydrofluoric acid plus silane coupling agent. An additional group of brackets not previously bonded was used as the control (n=25). The brackets were bonded to 125 fresh bovine teeth. A force was applied 1 mm from the bracket–resin interface by a testing machine. The force measured in this experiment was shear/peel and the ratio of shear to peel was 0.53. The ARI index showed 79% of the brackets had no resin on their bases. The shear/peel bond strength was significantly greater for the control group than all other groups ($P<0.01$). Treatment of electrothermally debonded ceramic brackets with silane or heat plus silane resulted in bond strength greater than 9 MPa. The use of hydrofluoric acid significantly reduced the bond strength below 2 MPa.

Key Words

Shear/peel bond strength • Ceramic bracket • Electrothermal debonding • Bovine teeth • Silane coupling agent • Bracket repositioning

Submitted: July 1994 **Revised and accepted:** November 1994 Angle Orthod 1995;65(5)351-358.

Table 1	
ARI Score	Percent
0	79
1	16
2	5
3	0

Table 2
Discriptive statistics of study

	Mean, MPa	Std.Dev, MPa	Minimum, MPa	Maximum, MPa	Coef.Var %.
No Tx	16.9	4.0	7.9	26.6	23.4
Silane	12.7	3.3	6.4	20.6	25.7
Heat + Silane	9.1	3.7	1.8	16.6	40.9
HF + Silane	1.6	2.0	0	8.5	129.1
Heat + HF + Silane	0.7	1.0	0	4.2	142.9

Figure 1
Free-body diagram of bracket during bond strength testing.

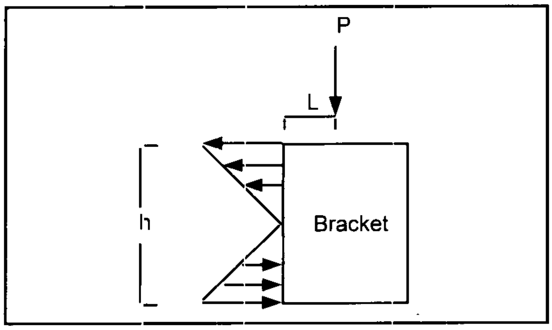

Figure 1

ceramic brackets[6-22] has challenged the ingenuity of orthodontic manufacturers. In the mid 1980s, A-Company introduced a new concept in bracket removal, the Electro Thermal Debonder (ETD).[23] This unit transfers heat through the bracket, allowing bond failure at the bracket-adhesive interface as the heat deforms the adhesive.[11] The ETD has a debonding tip machined to fit the vertical slot of A-Company brackets. The force required to remove the bracket is low, and the bracket base is relatively free from resin upon debonding.[24] Studies have not demonstrated any pathologic pulpal reaction to the ETD process.[18,25]

The objectives of this study were (1) to investigate the potential value of the ETD to leave debonded ceramic brackets in a physical state capable of being rebonded (adhesive remnant study), and (2) to evaluate the shear/peel bond strength of brackets that have been repositioned with a variety of base treatments (bond strength study).

Materials and method

Starfire™ (A-Company, San Diego, Calif) single crystalline aluminum oxide brackets were used in this study. The brackets were maxillary central incisor brackets with the standard edgewise 0.022 x 0.028-inch slot.

A total of 237 mandibular bovine incisors were stored in distilled water at room temperature following extraction. A flat enamel surface was obtained by wet-sanding the labial surface with progressively finer silicon carbide abrasive paper (final grit 400).[29,30] The teeth were mounted in PVC rings, and the rings were filled with acrylic resin (Fastcure, Kerr Manufacturing Co, Romulus, Mich). The surfaces of these complexes each received one more polish with 600-grit silicon carbide paper to remove any acrylic flash material. Prepared teeth were cleansed of fine debris in an ultrasonic cleaning unit and stored in distilled water at room temperature until bonding.

All teeth were subjected to a 30-second etch with 37% orthophosphoric acid, washed for 20 seconds, then dried with warm air. Bonding material was applied in accordance with the manufacturer's instructions. Reliance™ (Reliance Orthodontic Products, Inc, Itasca, Ill) light-cured adhesive, with an average filler particle size of 0.04 mm and filler weight of 52%, was used. To control the adhesive thickness and maintain uniform bracket placement, a bonding jig with a ~20N load was used.[29] Excess composite was carefully removed from the bracket-tooth interface, and the adhesive was light-cured with one 20-second exposure. Specimens were then stored in distilled water at room temperature for 3 days until debonding.

Adhesive remnant study

One hundred twelve ceramic brackets bonded to bovine teeth were thermally debonded using the electrothermal debonder. The ETD unit was used in accordance with the manufacturer's instructions. During debonding, 12 brackets fractured and were discarded, leaving 100 brackets for the experiment. Bracket bases were visually inspected for resin under a stereoscopic microscope with magnification of x20. An adaptation of the adhesive remnant index (ARI)[31] system was used to evaluate the amount of adhesive remaining on the bracket base following debonding.

The classification system is listed below:

Score 0 = No adhesive on bracket base.

Score 1 = Adhesive covering less than half of bracket base.

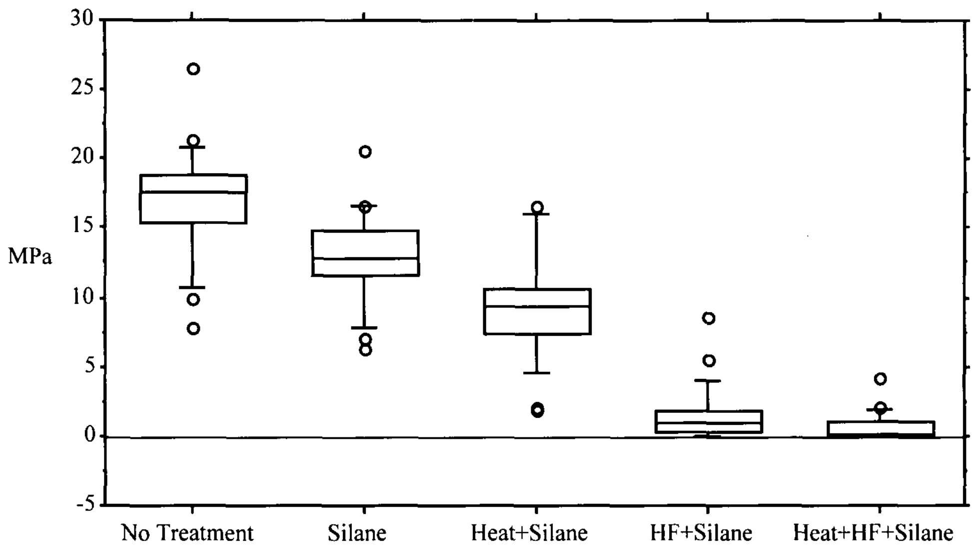

Figure 2
Boxplots of shear/peel bond strengths. A boxplot displays a summary of statistics. It plots the median (horizontal line in the box) while the lower and upper boundaries of the box represent the 25th and 50th percentiles of the respective group. The box and whisker plot represent smallest and largest observable values that are not outliers. The boxplot includes two categories of values with outlying values.

Figure 2

Score 2 = Adhesive covering more than half of bracket base.

Score 3 = Adhesive covering all of bracket base.

Bond strength study

Up to three treatment procedures were used on the debonded bracket bases.

1. Silane coupling agent: Scotchprime™ (Ceramic Primer No 2721, 3M Dental Products St Paul, Minn) was applied as per manufacturer's directions.

2. Heat: Protocol as described by Lew and Djeng.[4] Brackets heated until cherry red to burn off residual composite resin. Bracket base then rinsed with 100% alcohol and left to dry.

3. Hydrofluoric acid: Brackets were treated with 3% hydrofluoric acid (PorceLock[a], Porcelain Etching Solution No. 2061, DenMat) for 5 minutes then rinsed under cold water to remove all traces of acid.

A control group and four experimental groups were used. These groups are listed below.

1. Control, brackets not previously bonded (n=25).
2. Silane coupling agent (n=25).
3. Heat and silane coupling agent (n=25).
4. Hydrofluoric acid plus silane coupling agent (n=25).
5. Heat plus hydrofluoric acid plus silane coupling agent (n=25).

The 125 prepared teeth were randomly assigned to five groups. Debonded brackets (from the ARI study) were evenly distributed into groups 2 - 5. Brackets were bonded to the bovine teeth as per bonding protocol. Following bonding, specimens were independently coded, then stored at room temperature for 3 days.

Bond strength was measured with an Instron testing machine (T.T.K. Instron Corp, Canton, Mass). A cross-head speed of 0.02 inch per minute was used. Testing was carried out in random order with each bonded unit placed in a holding jig and an increasing force applied 1 mm from the resin/base interface until bond failure. Figure 1 shows a free-body diagram of a bracket being tested (viewed from the mesial aspect) where P = debonding force, d = width of bracket, h = height of bracket, and L = distance from bracket resin interface to point of force application. In this study h= 3.2 mm, L= 1.0 mm, and d= 3.9 mm.

Shear/peel bond strength was measured in this study as it is one of the major forces acting on orthodontic brackets during function. The shear/peel ratio was analyzed into its components by the formulas shown below:

$$\text{Shear force} = \frac{P}{hd}$$

$$\text{Peel force} = \frac{6PL}{h^2d}$$

The ratio is 0.53 and is calculated with two assumptions:

1. The shear force is uniformly distributed.
2. The stresses for peel are linearly distributed from top to bottom of the bracket.

Figure 3
Scanning Electron Micrograph (X25) of a bracket showing residue after heat treatment to remove resin.

Figure 3

Load at failure was recorded (N) and the bond failure was calculated as stress per unit area (MPa). The mean and standard deviation were calculated for each group. A one-way analysis of variance followed a Scheffe test to determine significant differences between bracket bond strengths due to different treatments.

Results

During debonding, 12 brackets (11%) fractured at the tie wings and were discarded from the experiment.

Results of the ARI study (listed in Table 1) show 79% of bracket bases had a score of 0, 16% scored 1, and 5% scored 2.

Descriptive statistics of the shear/peel bond strengths for each base treatment are shown in Table 2; boxplots of bond strengths are shown in Figure 2. A boxplot displays a summary of statistics, instead of plotting actual values. It plots the median, the 25th percentile, the 75th percentile, and values that are far removed from the rest. The lower boundary of the box is the 25th percentile and the upper boundary is the 75th percentile.

A Scheffe's test of multiple comparisons calculated from a one-way analysis of variance showed a significant difference ($P<0.01$) among all pairs of groups, with the exception of experimental groups 4 (hydrofluoric acid plus silane) and 5 (heat plus hydrofluoric acid plus silane).

Discussion

Bovine teeth were chosen as a substitute for human teeth due to their greater availability and larger size.[26,27] Histochemical and comparative anatomical studies suggest that all mammalian teeth are essentially similar.[28] Nakamichi et al.[27] reported no significant differences in adhesion to enamel between human and bovine teeth, although values were slightly lower with bovine teeth.

Part 1 of this study investigated the bonding surface of brackets following thermal debonding. Seventy-nine percent of debonded brackets were resin free, 16% had less than half the bracket base covered by resin, and 5% had more than half the bracket base covered with resin. These results agree with those of Bishara and Trulove.[11]

A number of brackets fractured during debonding. These fractures occurred predominantly at the tie wing. However, debonding was accomplished during the same procedure by reversing torque direction, thus applying force to the unbroken tie wings. This site of fracture agrees with that of conventionally debonded Starfire brackets.[11] However, when Bishara and Trulove used the ETD to debond 20 ceramic brackets, they reported no bracket fractures. Possible reasons for these fractures are: (1) insufficient heat delivered to bracket at time of debonding, (2) application of force too early in the debonding procedure, and (3) a surface crack on the bracket resulting in crack propagation and fracture of the bracket.[13]

Part 2 of this study evaluated the bond strength of thermally debonded, rebonded ceramic brackets. Reynolds[33] suggests bond strength of 60 to 80 kg/cm^2 (5.9 to 7.8 MPa) would meet most orthodontic needs. Studies published by Lew et al.[5] compared shear bond strengths between new and recycled ceramic brackets. They debonded polycrystalline brackets using the Unitek debonding tool. This debonding process places a torquing force on the ceramic bracket that could potentially damage the underlying tooth structure. Damage to enamel can occur at bond strengths as low as 14 MPa.[34] Although Lew et al.[5] did not detail any bracket damage during debonding, the physical effect of this debonding technique could leave the bracket with surface imperfections. Swartz[32] discussed the ability of high-strength ceramics to fail easily from surface cracks or imperfections. These surface anomalies allow stress concentration that may result in bracket failure.

Treatment of debonded brackets with a silane coupling agent yielded the highest bond strength

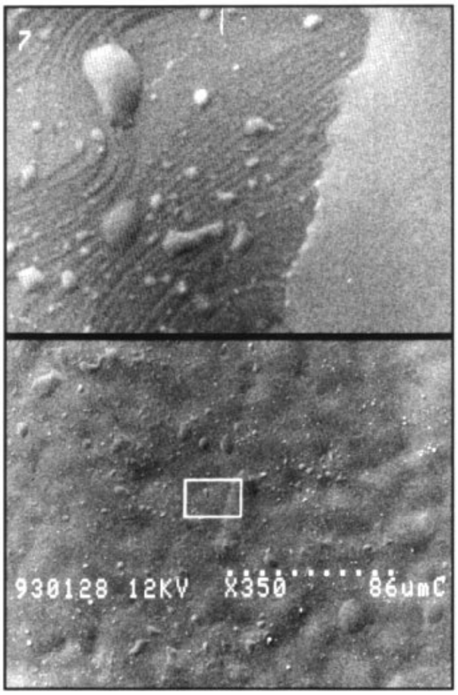

Figure 4

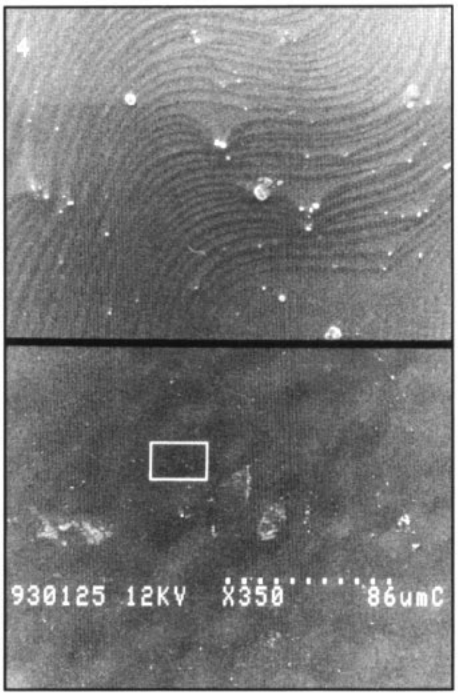

Figure 5

Figure 4
Scanning electron micrograph (X350) of untreated bracket base.

Figure 5
Scanning electron micrograph (X350) of bracket base after a 3-minute etch with 3% hydrofluoric acid.

of all experimental groups. This bracket treatment was the quickest and simplest of all bracket treatments. Bond strength of this group was 12.7 ± 3.3MPa and was a reduction of 25% relative to the nontreatment group. This reduction in bond strength might be attributable to: (1) silane coupling agent used, and (2) difference in the method of silane coupling agent application. The bond strength of the silane-treated, rebonded bracket was below the level resulting in enamel damage cited by Retief,[34] but above the minimum bond strength stated by Reynolds.[33]

Resin remaining on the bracket base following electrothermal debonding can be removed by heat.[4] Bond strength of the heat and silane group was 8.8 ± 3.5 MPa, which is clinically acceptable.[33] A reduction in bond strength of this group in comparison to the silane treatment alone group was noted. An electron micrograph (Figure 3) shows residue remaining on a bracket following heating to remove resin prior to washing with alcohol. Any residue not removed during this process could lead to a reduction in bond strength. The bond strength for group 3 was lower than found by Lew.[4] Such differences could be due to: differences in ceramic materials, methods of retention, types of bonding resin, and characteristics of teeth.

A silane coupling agent was used in this study, as it chemically mediates adhesion between the ceramic base and adhesive resin. A silica layer is placed on the bracket base by the manufacturer to facilitate silanation. The use of hydrofluoric acid as a base preparation resulted in radical reduction in bond strength. Electron micrographs illustrate the change in the bracket surface following treatment with hydrofluoric acid (Figures 4 and 5). The silica layer is removed from the brackets by the acid, resulting in unacceptable bond strengths.

Brackets debonded during treatment can be rebonded if (a) there is no visible sign of damage to the bracket, and (b) the bracket is cleaned and resilanated prior to rebonding.

The bond strengths observed in this study may be higher than those witnessed clinically. This is because in-vitro studies of bonding are ideal, with moisture contamination, bonding pressure, temperature, and other oral variables eliminated or controlled.[33] Clinical studies that investigate long-term in-vivo bond strength of repositioned ceramic brackets are required for the orthodontic practitioner. Bond strengths obtained from this study would be different if brackets had been rebonded to the original bovine teeth.[29]

Conclusions

This study was carried out to determine the amount of resin remaining on bracket bases following electrothermal debonding and to determine bond strength of electrothermally debonded, rebonded ceramic brackets under different treatment conditions.

From the study the following observations were made:

1. After electrothermal debonding, 79% of

brackets were resin free, 16% had less than half their base covered by resin while 5% had more than half their base covered by resin.

2. Bond strength of single crystal ceramic brackets (nontreatment group) was 16.9 MPa.

3. Rebonding electrothermally debonded ceramic brackets treated with a silane coupling agent resulted in a clinically acceptable bond strength of 12.7 MPa.

4. Rebonding electrothermally debonded ceramic brackets treated with heat and a silane coupling agent resulted in a clinically acceptable bond strength of 9.1MPa.

5. Rebonding electrothermally debonded ceramic brackets treated with hydrofluoric acid resulted in a bond strength that was below 2 MPa.

Acknowledgments

This study was supported by the McIntyre Research Fund.

Special thanks to A-Company Pty Ltd and the Department of Mechanical Engineering at the University of Alberta for advice and technical support.

Author address

Dr. Paul Major
Division of Orthodontics
Faculty of Dentistry
Edmonton, Alberta
Canada
TG6 2N8

P.G. Gaffey is a postgraduate student in the Division of Orthodontics, University of Alberta, Edmonton, Alberta, Canada.

P.W. Major is associate professor and chairman, Division of Orthodontics, University of Alberta, Edmonton, Alberta, Canada.

K. Glover is professor and chairman, Department of Stomotology, University of Alberta, Edmonton, Alberta, Canada.

M. Grace is adjunct professor, Department of Stomotology, University of Alberta, Edmonton, Alberta, Canada.

J.R. Koehler is a research student, University of Alberta, Edmonton, Alberta, Canada.

References

1. Andrews L. Andrews six keys to normal occlusion. Am J Orthod 1972;62:296-309.
2. McLaughlin R, Bennett J. Finishing and detailing with a preadjusted appliance system. J Clin Orthod 1991;25:251-264.
3. Regan D, LeMasney B, Van Noort R. The tensile bond strength of new and rebonded stainless steel orthodontic brackets. Europ J Orthod 1993;15: 125-35.
4. Lew K, Djeng S. Recycling ceramic brackets. J Clin Orthod 1990;14:44-7.
5. Lew K, Chew C, Lee K. A comparison of shear bond strengths between new and recycled ceramic brackets. Europ J Orthod 1991;13:306-10.
6. Redd T, Shivapuja PK. Debonding ceramic brackets: Effects of enamel. J Clin Orthod 1991; 25:475-81.
7. Jeiroudi M. Enamel fracture caused by ceramic brackets. Am J Orthod Dentofac Orthop 1991;99:97-9.
8. Brouns E, Schopf P, Kocjancic B. Electro thermal debonding of ceramic brackets: an in vitro study. Europ J Orthod 1993;15:115-23.
9. Dischinger T. Debonding ceramic brackets. J Clin Orthod 1990;24:321-2.
10. Birnie D. Ceramic brackets. Br J Orthod 1990; 17:71-5.
11. Bishara S, Trulove T. Comparisons of different debonding techniques for ceramic brackets: An in vitro study. Part I. Background and methods. Am J Orthod Dentofac Orthop 1990;98:145-53.
12. Bishara S, Fehr D. Comparisons of the effectiveness of pliers with narrow and wide blades in debonding ceramic brackets. Am J Orthod Dentofac Orthop 1993;103:253-7.
13. Britton J, McInnes P, Weinberg R, Ledoux W, Retief D. Shear bond strength of ceramic orthodontic brackets to enamel. Am J Orthod Dentofac Orthop 1990;98:348-53.
14. Carter R. Clinical management of ceramic brackets. J Clin Orthod 1989;23:807-9.
15. Douglass J. Enamel wear caused by ceramic brackets. Am J Orthod Dentofac Orthop 1989;95:96-8.
16. Fox N, McCabe J. An easily removable ceramic bracket? Br J Orthod 1992;19:305-9.
17. Harris A, Joseph V, Rossouw P. Shear peel bond strengths of esthetic orthodontic brackets. Am J Orthod Dentofac Orthop 1992;102:215-9.
18. Jost-Brinkmann P-G, Stein H, Miethke R-R, Nakata M. Histologic investigation of the human pulp after thermodebonding of metal and ceramic brackets. Am J Orthod Dentofac Orthop 1992; 102:410-7.
19. Ostertag A, Virendra B, Ferguson D, 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.
20. Rueggeberg F, Lockwood P. Thermal debracketing of single crystal sapphire brackets. Angle Orthod 1992;62:45-50.
21. Storm E. Debonding ceramic brackets. J Clin Orthod 1990;14:91-94.
22. Sylvester E. Thermal debonding of ceramic brackets. J Clin Orthod 1991;:748.
23. Sheridan J, Brawley G, Hastings J. Electro thermal debracketing. Part I. An in vitro study. Am J Orthod Dentofac Orthop 1986;89:21-27.
24. Bishara S, Trulove T. Comparisons of different debonding techniques for ceramic brackets: An in vitro study. Part II. Findings and clinical implications. Am J Orthod Dentofac Orthop 1990; 98:263-73.
25. Sheridan J, Brawley G, Hastings J. Electro thermal debracketing. Part II. An in vivo study. Am J Orthod Dentofac Orthop 1986;89:141-145.
26. Maskeroni A, Meyers C, Lorton L. Ceramic bracket bonding: A comparison of bond strength with polyacrylic acid and phosphoric acid enamel conditioning. Am J Orthod Dentofac Orthop 1990;97:168-75.
27. Nakamichi I, Iwaku M, Fusayama T. Bovine teeth as possible substitutes in the adhesion test. J Dent Res 1983;62:1076-81.
28. Leicester H. Biochemistry of the teeth. St Louis: Mosby, 1949:13-15.
29. Shiau J-Y, Rasmussen S, Phelps A, Enlow D, Wolf G. Bond strength of aged composites found in brackets placed by an indirect technique. Angle Orthod 1993;63:213-220.
30. O'Brien K, Watts D, Read M. Residual debris and bond strength - Is there a relationship? Am J Orthod Dentofac Orthop 1988;94:222-30.
31. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod 1984;85:333-40.
32. Swartz M. Ceramic brackets. J Clin Orthod 1988;12:82-8.
33. Reynolds I. A review of direct orthodontic bonding. Br J Orthod 1975;2:171-8.
34. Retief D, Harris B, Bradley E, Denys F. Pyruvic acid as an etching agent in clinical dentistry. J Biomed Mater Res 1985;19:335-48.
35. Nikolai RJ. Bioengineering analysis of orthodontic mechanics. (First ed.) Philadelphia: Lea and Febiger, 1985