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The effect of changing crosshead speed on the shear bond strength of orthodontic bonding adhesive

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Objective: To examine the influence of different crosshead speeds on the in vitro shear bond strength and adhesive remnant index scores for the same orthodontic adhesive.
Materials and methods: One hundred human molars were randomly allocated to four groups. Brackets (.022 inch Victory series, 3M, Monrovia, CA, USA) were bonded with Ortho Solo primer (Ormco, Glendora, CA, USA) and Enlight (Ormco, Glendora, CA, USA) adhesive paste to their buccal surfaces. The brackets were debonded with a universal testing machine (Instron, Canton, MA, USA) with each group subjected to a different crosshead speed of 0.5 mm/min, 1.0 mm/min, 2.0 mm/min and 5.0 mm/minute. Shear bond strength (SBS) was measured and enamel surfaces were examined to determine the adhesive remnant index (ARI) score.
Results: No significant differences were found between the mean SBS or ARI score for any of the groups.
Conclusions: Studies using different crosshead speeds when testing identical adhesives may be used to compare the SBS of other orthodontic adhesives, provided the testing protocols are similar.
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Introduction

Due to a lack of standardisation in the testing procedures, a comparison of shear bond strength (SBS) of orthodontic adhesives can be extremely difficult, if not impossible. Many published studies compare the results and conclusions between apparently similar studies. In a review article, Rueggeberg[1] noted that 'with adhesion research being performed in a non-standardised manner, it becomes impossible for results to be compared between different research groups'. Fox et al.[2] also noted key findings and highlighted the lack of consistency in controlling parameters between studies.

A considerable number of confounding factors for SBS testing exist. Tooth factors include: the source of the teeth (human or animal), the type of tooth (incisor, premolar, molar, permanent, deciduous), the convexity of the buccal surface of the tooth, the age of the tooth, and the fluoride/calcium/phosphate content of the enamel. Storage factors include: the type and temperature of the storage media, the length of storage time and the time elapsed after bracket bonding before debonding. Tooth preparation factors include: the mounting material and mounting technique for the teeth, whether enamel surfaces have been ground before testing, the strength and enamel contact time of etchant and conditioner, and whether exothermic setting reactions are controlled during tooth mounting. Other miscellaneous factors include: the design of the bracket bases, the force with which brackets are placed onto the teeth, and the differences in curing-light source (if required). The reporting and measurement of surface area of bracket bases is apparently also an area of conjecture, evidenced by Bishara et al.,[3,4] using identical brackets in two different papers but listing a surface area of 10.3 mm^2

in one paper[3] and 11.9 mm^2 in another.[4] The larger value represents an increase of 15.5% from the smaller value for what was reportedly the same bracket. This could be expected to influence the reported SBSs for the tested adhesives and possibly alter conclusions drawn from test results.

An additional problem arises when the type of machine employed to detach bonded brackets from the enamel surface during SBS testing, is considered. Many studies[5-11] have used the Instron Universal Testing machine, while the Zwick machine is also commonly used.[12-16] The brand of testing machine may be influential as it is possible that two supposedly identical and accurately calibrated machines could produce different test results. One significant problem is the method by which different machines debond brackets. Reported SBS studies generally use a steel rod with a flattened end,[3,4,13,14] a sharpened crosshead blade,[8,9,11,12,16-18] or a wire lasso[6,19-22] to debond brackets. Furthermore, it is difficult to determine how brackets were debonded in some studies.[5,7,23-25] Depending on the direction of force and its application, forces may range from shear-peel stresses to tensile stresses.[2] Therefore, while many studies claim to test shear bond strength, Fox et al.[2] noted that pure testing requires the force to be applied directly to the bracket-adhesive interface. This is reported to be difficult to achieve and the likelihood of torsional forces being delivered is high.[26]

Machine crosshead speed provides an additional confounding variable. Most studies use crosshead speeds which range from 0.1 mm/min[9] up to 5 mm/minute.[14] When testing composite resin discs bonded to a flattened dentine surface, Hara et al.[27] found a significant difference in SBS between a crosshead speed of 0.5 and 0.75 mm/min when compared to speeds of 1.0 and 5.0 mm/minute.

A degree of discretion must therefore be applied when comparing results of different studies employing different methodologies. The aim of the present paper is to therefore determine whether the crosshead speed of a testing machine significantly affects the shear bond strength of orthodontic brackets bonded with the same adhesive.

The null hypothesis is that there is no difference in the shear bond strength or adhesive resin index between groups tested with different speeds of a crosshead blade.

Materials and methods

To meet the inclusion criteria of the study, teeth were selected only if they had intact, unrestored enamel on their buccal surface, were free of visible cracks, and had no signs of dental caries or white spot lesions. One hundred and seven freshly extracted permanent human molar teeth were collected from several clinics and placed in 10% formalin. After three to six weeks, teeth were stored in distilled water until testing. Upon examination, seven teeth were excluded due to the presence of missed caries or restorations on the buccal surface, leaving a total of one hundred molars. The teeth were vertically mounted in self-curing acrylic resin (Castapress, Vertex-Dental B.V, Zeist, Netherlands), so that the direction of force application could be directed parallel to the long axis of each tooth. During polymerisation of the acrylic, the teeth and mounting jig were kept under chilled water to minimise the effect of the exothermic setting reaction. To avoid desiccation of the enamel surface, the teeth were returned to distilled water and maintained at room temperature until shear bond strength testing was performed several days later.

Stainless steel 0.022 inch slot upper central incisor brackets with a bracket base surface area of 10.71 mm^2 (Victory series, 3M, Monrovia, CA, USA) were used in this study. Teeth were randomly allocated to one of four groups. Each group was assigned a set crosshead speed to be applied for bracket debonding. Crosshead speeds were as follows: Group 1 = 0.5 mm/min (24 teeth), Group 2 = 1.0 mm/min (25 teeth), Group 3 = 2.0 mm/min (26 teeth), and Group 4 = 5.0 mm/min (25 teeth).

Bonding

The teeth were handled and prepared by the same operator (KS). A bracket was placed on the most convex region of each tooth and aligned mesio-distally and occluso-gingivally with reference to the tooth's long axis. Firm pressure was applied for several seconds to fully seat the bracket, after which excess adhesive was removed with a hand instrument.

Tooth preparation

Even though evidence exists that pumicing has no effect on shear bond strength,[5] visible debris was removed with a pumice slurry and a silicone cup in a slow-speed handpiece operating at 3000-4000 rpm for 3 to 5 seconds. The buccal enamel on each tooth was conditioned with 37% phosphoric acid for 20 seconds. The etchant was removed by washing with air and water spray for 5 seconds. The teeth were dried with oil- and moisture-free air until the surface appeared frosty. The etched surfaces were subsequently coated with Ortho Solo (Ormco, Glendora, CA, USA). Enlight adhesive paste (Ormco, Glendora, CA, USA) was applied to the bracket base and the bracket applied to the tooth with pressure similar to that used for clinical bracket bonding. The adhesive was cured with a Cool Beam curing light (Ormco, Glendora, CA, USA) for 20 seconds (10 seconds from each proximal side). Following curing, the teeth were returned to storage in distilled water at room temperature until required for debonding.

Debonding procedure

The Shear Bond Strength (SBS) of each group was recorded 24 hours after bracket bonding. The brackets were debonded with a sharp, chisel-shaped rod attached to a universal testing machine (Instron, Canton, MA, USA). The acrylic blocks were positioned in the machine so that the shearing blade was as close as possible to the bracket base and parallel to the long axis of the tooth. A computer, electronically connected to the Instron machine, recorded the result of each test.

Evaluation of the residual adhesive

After SBS testing, the teeth were examined under 4x and 10x magnification. The buccal surface of each tooth was assessed using a modified adhesive remnant index (ARI) as described by Bishara et al.[28] The single evaluator (KS) was blinded to the grouping of teeth being evaluated. Scoring was as follows:

1 = 100% of the adhesive remained on the tooth,
2 = 90-100% of the adhesive remained on the tooth,
3 = 10-90% of the adhesive remained on the tooth,
4 = 0-10% of the adhesive remained on the tooth,
5 = none of the adhesive remained on the tooth.

During microscopic investigation, enamel 'tear-outs' (identified as the loss of enamel from the tooth surface that can occur during the debonding process) were noted on several teeth.

Statistical analysis

Data were analysed using SAS 9.2 statistical software (SAS Institute, Cary, NC, USA). Descriptive statistics, including the mean, standard deviation and minimum and maximum values were calculated for each group. Normal probability plots were used to confirm the assumption of normality. A one-way ANOVA compared the differences in SBS between groups. The Kruskal-Wallis test was used to compare the bond failure mode (ARI) scores between the four groups and a Wilcoxon signed-rank test was used to test each pair of groups for significance. For ARI scores, the operator (KS) was blinded to the identity of the crosshead speed being examined and teeth were measured in random order. Significance for all statistical tests was set at $p < 0.05$.

Results

Shear Bond Strength

SBS testing failed for two teeth (one tooth from Group 1 and one tooth from Group 3) for which a reading of less than two Newtons was recorded. These results were excluded from the study, leaving a total of 98 teeth (23 teeth in Group 1, and 25 teeth in each of Groups 2, 3, and 4).

Descriptive statistics, including the mean, standard deviation, minimum and maximum values for the crosshead speeds are presented in Table I. The mean shear bond strengths were as follows: the 0.5 mm/min group was 10.22 ± 4.13 MPa; the 1.0 mm/min group was 8.18 ± 3.88 MPa; the 2.0 mm/min group was 9.73 ± 4.10 MPa; and the 5.0 mm/min group was 8.53 ± 3.99 MPa. The results for mean SBS are also given in Newtons (N) in Table I. The one-way ANOVA revealed no significant differences in SBS between any of the groups. Table II compares the mean SBS of each group for significance ($p < 0.05$). No correlation was apparent between the group possessing the greatest mean, lowest minimum or highest maximum SBS.

Adhesive Resin Index

The ARI scores for the four test groups are shown in Table III and a Kruskal-Wallis test indicated that no significant difference existed ($p = 0.37$) between the groups tested. The Wilcoxon signed-rank test was used to compare ARI scores between groups. These results are presented in Table IV which indicates that no significant differences existed between groups. Two teeth from each of the 0.5 mm/min, 2.0 mm/min, and 5.0 mm/min groups suffered enamel 'tear-outs' during the testing procedure. These teeth were excluded from the ARI statistical comparisons.

Table I. Descriptive statistics for SBS using variable crosshead speed.

Crosshead speed	N	Mean (SD) (N)	Mean (SD) (MPa)	Minimum (MPa)	Maximum (MPa)
0.5 mm/min	23	109.46 (44.18)	10.22 (4.13)	2.10	16.19
1.0 mm/min	25	87.63 (41.53)	8.18 (3.88)	2.66	17.69
2.0 mm/min	25	104.26 (43.87)	9.73 (4.10)	3.05	18.11
5.0 mm/min	25	91.33 (42.77)	8.53 (3.99)	3.13	16.22

Table II. Comparison of mean SBS, Standard Error (SE), and significance between means. To compare, select crosshead speed from first column, then match with crosshead speed adhesive in top row.

Crosshead speed		0.5mm/min	1.0mm/min	2.0mm/min	5.0mm/min
0.5mm/min	Difference		2.04	0.49	1.69
	SE		1.55	1.55	1.55
	p value	-	0.30	0.98	0.47
1.0mm/min	Difference	-2.04		-1.55	-0.35
	SE	1.55		1.52	1.52
	p value	0.30	-	0.52	0.99
2.0mm/min	Difference	-0.49	1.55		1.21
	SE	1.55	1.52		1.52
	p value	0.98	0.52	-	0.71
5.0mm/min	Difference	-1.69	0.35	-1.21	
	SE	1.55	1.52	1.52	
	p value	0.47	0.99	0.71	-

Table III. Frequency distribution of ARI* results of the groups and findings of the statistical analyses.

Group	N	ARI					Enamel tearout
		1	2	3	4	5	
0.5 mm	23	0	6	15	0	0	2
1.0 mm	25	2	8	15	0	0	0
2.0 mm	25	3	9	11	0	0	2
5.0 mm	25	2	9	14	0	0	2

Kruskal-Wallis test: $\chi^2 = 3.18$; $p = 0.37$

*ARI indicates Adhesive Resin Index. 1 = all adhesive remained on the tooth, 2 = 90-100% of the adhesive remained on the tooth, 3 = 10-90% of the adhesive remained on the tooth, 4 = less than 10% of the adhesive remained on the tooth, 5 = no adhesive remained on the tooth.

Table IV. Comparison of ARI scores for significance. Results are for Wilcoxon signed-rank test with *p* values shown.

Crosshead speed	1.0 mm/min	2.0 mm/min	5.0 mm/min
0.5mm/min	0.34	0.074	0.37
1.0mm/min	-	0.38	0.97
2.0mm/min	-	-	0.38

Discussion

Stanford[29] noted that standardisation of test protocols would allow practitioners to 'navigate through the wealth of scientific information' that is generated from bond strength studies. One common testing variable is the crosshead speed of the testing machine. The speed of either flattened rods, sharpened chisels or pulling loops used for SBS testing in previous studies include: 0.1 mm/minute,[8] 0.5 mm/minute,[17,18,30] 1.0 mm/minute,[10,12,16,19-21,23-25,31] 1.5 mm/minute,[32] 2.0 mm/minute,[22,33,34] 3.0 mm/minute,[26] and 5.0 mm/minute.[3,4,6,13,28,35-37] With such a varied range, it was decided to determine if there was a significant difference in SBS between different crosshead speeds. The findings of the present study indicated that varying the crosshead speed of the testing machine between 0.5 mm/min and 5.0 mm/min did not produce statistically significant differences in SBS for the tested adhesive (Enlight). The null hypothesis was therefore accepted. This is in contrast with Bishara et al.[15] who found that the mean SBS recorded at 5.0 mm/min became significantly greater (p = 0.014) when the crosshead speed was reduced to 0.5 mm/minute. The Bishara study[15] and the current study used the same type of brackets, although Bishara et al. used Transbond XT (3M Unitek) adhesive. Because all brackets were bonded with the same adhesive within each study, it was considered that there would be no effect on outcome related to inter-group statistical significance of SBS. In the current study, the group with the highest mean SBS also recorded the overall lowest minimum SBS for any single sample in the study. There appeared to be no correlation between groups which contained the highest mean SBS, lowest minimum SBS and highest maximum SBS of a single sample.

There are several possible explanations for the difference in outcomes between the two studies, the most obvious being a difference in the type of tooth examined. Both studies used a relatively broad inclusion criteria with the possibility of six tooth groups (upper or lower, first, second or third molar). Hobson et al.[38] found that there was a significant difference (p < 0.001) when upper and lower molar SBS values were compared for the same adhesive. Ozturk et al.[39] recorded that adhesive used on lower molars displayed a significantly higher SBS compared with the same adhesive on upper molars. However, Ozturk et al. used composite buttons and a debonding technique that was a true shear test rather than a combination of shear-peel, tensile and torque testing that is usually associated with SBS testing of orthodontic brackets.[26,39] Therefore, even though permanent molars were used, it is possible that there was considerable heterogeneity in the sample. Since there are known and significant differences in bond strengths between different tooth types, bond strength studies would ideally take this into account by using only one tooth type in test groups.[38] Unfortunately, collecting a specific tooth from either the upper or lower arch is often logistically difficult, especially if teeth are collected from multiple sources. Additionally, sample sizes of individual tooth types would likely be small unless sample collection times extended over longer periods. This is undesirable if information on emerging materials is required within a short time-frame.

An additional problem with the use of molars is the possible wide age variation of the samples. Unrestored, non-carious molars are not often indicated for extraction in most orthodontic treatment plans. Therefore, collected molars that fulfilled the inclusion criteria were likely to come from the young (eg third molars) or the relatively old (eg periodontally unsound teeth). The discrepancy in age range between two studies using molar teeth may have an impact, as age affects the fluoride content of enamel and therefore bond strength.[40]

Bishara et al.[15] stored test teeth in 0.1% (wt/vol) thymol and the current study stored teeth in 10% formalin for approximately three weeks before transferring to distilled water. Few studies have examined the effect of storage media on enamel SBS when testing orthodontic brackets. Jaffer et al.[21] tested the SBS of teeth stored in six different media before brackets were debonded. When teeth stored in 10% formalin were rinsed with water before bracket placement, the mean SBS was statistically greater than for others of the tested storage media (no medium, filtered water, 1% chloramine T, 10% chloramine T, isotonic saline solution, and 70% ethanol). Due to their dessicating effect, it was recommended that dry storage and ethanol should be avoided as storage media. The authors also suggested that formalin should be avoided but were unsure of why samples stored in the fixative had higher average shear bond strengths. However, a storage media study on dentine SBS by Lee et al.[42] concluded that storage in 10% formalin might be the best option for use in in vitro SBS studies.

In vitro SBS testing should aim to be clinically relevant and desirably, use non-ground, human teeth. Grinding teeth to provide a flat surface that is consistent between specimens makes a direct comparison of adhesives easier. However, teeth, and usually bracket bases, rarely have flattened surfaces. The use of flattened brackets results in conditions that poorly relate to clinical circumstances.[2] Circumstances in which the curvature of the teeth and brackets do not coincide produce a non-uniform thickness of adhesive. Increased adhesive thickness is associated with lower bond strength.[22] However, unless custom-made bracket bases are used, an uneven adhesive thickness beneath brackets is a clinical reality and should not be artificially corrected for in vitro studies if clinical relevance is the goal. Grinding also alters the fluoride content of enamel in deeper zones as the outermost layer has a higher fluoride content.[41] In agreement with Fox,[2] Eliades and Brantley[43] noted that grinding not only fails to simulate clinical conditions, but introduces variable enamel conditions that preclude comparison of results arising from different studies.

The standardisation of in vitro testing is required to allow comparison between similar shear bond strength studies. One controllable factor, the crosshead speed of the testing machine, was investigated in the present study and speeds between 0.5 mm/min and 5.0 mm/min were found to have no statistically significant influence on mean SBS. This contrasts with a previous paper[15] and indicates that more testing is required. However, in vitro testing will never be a substitute for in vivo testing. Clinical-based trials, in tandem with in vitro testing, are required to evaluate the clinical suitability of new adhesives.

Conclusions

Under the conditions of the present study, no significant differences were found in mean SBS of an orthodontic adhesive tested with a crosshead speed between 0.5 mm/min and 5.0 mm/minute. In addition, there were no significant differences in ARI scores. From these findings, studies using similar methodology (other than crosshead speed) for SBS testing may be compared even if different crosshead speeds are used.

As much as possible, homogeneous tooth types should be used in SBS testing and in vitro testing should attempt to simulate clinical situations.

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References

1. Rueggeberg FA. Substrate for adhesion testing to tooth structure - review of the literature. Dent Mater 1991;7:2-10.
2. Fox NA, McCabe JF, Buckley JG. A Critique of Bond Strength Testing in Orthodontics. Br J Orthod 1994;21:33-43.
3. Bishara SE, Ostby AW, Ajlouni R, Laffoon JF, Warren JJ. Early shear bond strength of a one-step self-adhesive on orthodontic brackets. Angle Orthod 2006;76:689-93.
4. Bishara SE, Ajlouni R, Laffoon JF, Warren JJ. Comparison of shear bond strength of two self-etch primer/adhesive systems. Angle Orthod 2006;76:123-6.
5. Lindauer SJ, Browning H, Shroff B, Marshall F, Anderson RH, Moon PC. Effect of pumice prophylaxis on the bond strength of orthodontic brackets. Am J Orthod Dentofacial Orthop 1997;111:599-605.
6. Sunna S, Rock WP. An ex vivo investigation into the bond strength of orthodontic brackets and adhesive systems. Br J Orthod 1999;26:47-50.
7. Sfondrini MF, Cacciafesta V, Pistorio A, Sfondrini G. Effects of conventional and high-intensity light-curing on enamel shear bond strength of composite resin and resin-modified glass-ionomer. Am J Orthod Dentofacial Orthop 2001;119:30-5.
8. Linn BJ, Berzins DW, Dhuru VB, Bradley TG. A comparison of bond strength between direct- and indirect-bonding methods. Angle Orthod 2006;76:289-94.
9. Northrup RG, Berzins DW, Bradley TG, Schuckit W. Shear bond strength comparison between two orthodontic adhesives and self-ligating and conventional brackets. Angle Orthod 2007;77:701-6.
10. Sethusa MP, Seedat AK, du Preez IC, Hlongwa P. Shear bond strength comparison of RelyX Unicem with six other orthodontic resin adhesive systems. SADJ 2009;64:72-5.
11. Al-Saleh M, El-Mowafy O. Bond strength of orthodontic brackets with new self-adhesive resin cements. Am J Orthod Dentofacial Orthop 2010;137:528-33.
12. Faltermeier A, Behr M, Mussig D. A comparative evaluation of bracket bonding with 1-, 2-, and 3-component adhesive systems. Am J Orthod Dentofacial Orthop 2007;132:144 e1-5.

13. Bishara SE, Vonwald L, Laffoon JF, Jakobsen JR. Effect of altering the type of enamel conditioner on the shear bond strength of a resin-reinforced glass ionomer adhesive. Am J Orthod Dentofacial Orthop 2000;118:288-94.
14. Bishara SE, Soliman M, Laffoon JF, Warren J. Shear bond strength of a new high fluoride release glass ionomer adhesive. Angle Orthod 2008;78:125-8.
15. Bishara SE, Soliman M, Laffoon J, Warren JJ. Effect of changing a test parameter on the shear bond strength of orthodontic brackets. Angle Orthod 2005;75:832-5.
16. Holzmeier M, Schaubmayr M, Dasch W, Hirschfelder U. A new generation of self-etching adhesives: comparison with traditional acid etch technique. J Orofac Orthop 2008;69:78-93.
17. Polat O, Karaman AI, Buyukyilmaz T. In vitro evaluation of shear bond strengths and in vivo analysis of bond survival of indirect-bonding resins. Angle Orthod 2004;74:405-9.
18. Vilar RV, Souza NF, Cal-Neto JP, Galvao M, Sampaio-Filho H, Mendes Ade M. Shear bond strength of brackets bonded with two light-curing orthodontic adhesives. J Adhes Dent 2009;11:259-62.
19. Al Shamsi A, Cunningham JL, Lamey PJ, Lynch E. Shear bond strength and residual adhesive after orthodontic bracket debonding. Angle Orthod 2006;76:694-9.
20. Oesterle LJ, Shellhart WC. Effect of aging on the shear bond strength of orthodontic brackets. Am J Orthod Dentofacial Orthop 2008;133:716-20.
21. Jaffer S, Oesterle LJ, Newman SM. Storage media effect on bond strength of orthodontic brackets. Am J Orthod Dentofacial Orthop 2009;136:83-6.
22. Evans LB, Powers JM. Factors affecting in vitro bond strength of no-mix orthodontic cements. Am J Orthod 1985;87:508-12.
23. Kecik D, Cehreli SB, Sar C, Unver B. Effect of acidulated phosphate fluoride and casein phosphopeptide-amorphous calcium phosphate application on shear bond strength of orthodontic brackets. Angle Orthod 2008;78:129-33.
24. Toledano M, Osorio R, Osorio E, Romeo A, de la Higuera B, Garcia-Godoy F. Bond strength of orthodontic brackets using different light and self-curing cements. Angle Orthod 2003;73:56-63.
25. Turk T, Elekdag-Turk S, Isci D. Effects of self-etching primer on shear bond strength of orthodontic brackets at different debond times. Angle Orthod 2007;77:108-12.
26. Katona TR, Long RW. Effect of loading mode on bond strength of orthodontic brackets bonded with 2 systems. Am J Orthod Dentofacial Orthop 2006;129:60-4.
27. Hara AT, Pimenta LA, Rodrigues AL, Jr. Influence of cross-head speed on resin-dentin shear bond strength. Dent Mater 2001;17:165-9.
28. Bishara SE, Gordan VV, VonWald L, Jakobsen JR. Shear bond strength of composite, glass ionomer, and acidic primer adhesive systems. Am J Orthod Dentofacial Orthop 1999;115:24-8.
29. Stanford SK, Wozniak WT, Fan PL. The need for standardization of test protocols. Semin Orthod 1997;3:206-9.
30. House K, Ireland AJ, Sherriff M. An in-vitro investigation into the use of a single component self-etching primer adhesive system for orthodontic bonding: a pilot study. J Orthod 2006;33:116-24.
31. Vicente A, Bravo LA, Romero M, Ortiz AJ, Canteras M. A comparison of the shear bond strength of a resin cement and two orthodontic resin adhesive systems. Angle Orthod 2004;75:109-13.
32. Urabe H, Rossouw PE, Titley KC, Yamin C. Combinations of etchants, composite resins, and bracket systems: an important choice in orthodontic bonding procedures. Angle Orthod 1999;69:267-75.
33. Yamada R, Hayakawa T, Kasai K. Effect of using self-etching primer for bonding orthodontic brackets. Angle Orthod 2002;72:558-64.
34. Montasser MA, Drummond JL, Evans CA. Rebonding of orthodontic brackets. Part I, a laboratory and clinical study. Angle Orthod 2008;78:531-6.
35. Ajlouni R, Bishara SE, Oonsombat C, Denehy GE. Evaluation of modifying the bonding protocol of a new acid-etch primer on the shear bond strength of orthodontic brackets. Angle Orthod 2004;74:410-13.
36. Bishara SE, Laffoon JF, VonWald L, Warren J. Effect of time on the shear bond strength of cyanoacrylate and composite orthodontic adhesives. Am J Orthod Dentofacial Orthop 2002;121:297-300.
37. Bishara SE, Laffoon JF, Vonwald L, Warren JJ. The effect of repeated bonding on the shear bond strength of different orthodontic adhesives. Am J Orthod Dentofacial Orthop 2002;121:521-5.
38. Hobson RS, McCabe JF, Hogg SD. Bond strength to surface enamel for different tooth types. Dent Mater 2001;17:184-9.
39. Ozturk B, Malkoc S, Koyuturk AE, Catalbas B, Ozer F. Influence of different tooth types on the bond strength of two orthodontic adhesive systems. Eur J Orthod 2008;30:407-12.
40. Weatherell JA, Robinson C, Hallsworth AS. Changes in the fluoride concentration of the labial enamel surface with age. Caries Res 1972;6:312-24.
41. Nanci A. Ten Cate's Oral Histology. Development, Structure and Function. Mosby; 2003. pp.145-91.
42. Lee JJ, Nettey-Marbell A, Cook A, Jr., Pimenta LA, Leonard R, Ritter AV. Using extracted teeth for research: the effect of storage medium and sterilization on dentin bond strengths. J Am Dent Assoc 2007;138:1599-603.
43. Eliades T, Brantley WA. The inappropriateness of conventional orthodontic bond strength assessment protocols. Eur J Orthod 2000;22:13-23.