A better understanding of orthodontic bracket bonding

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CHAPTER 2

A systematic review of the in vitro shear bond strength of Transbond XT

2.1 Abstract

The purpose of this chapter is to review current literature on Transbond XT (3M Unitek), one of the most frequent used light curing bonding agent for bracket bonding, on the *in vitro* shear bond strength.

After application of the in- and exclusion criteria to the systematically searched articles 61 publications remained. The shear bond strength, bond strength in relation to time and the influence of possible external variables on the bond strength, like storage medium of the enamel, speed of the tensilometer during testing, and type of enamel are evaluated.

The average bond strength reported varied between 9.3 - 15.4 MPa. The material is fully cured after 24 hours and the type of enamel, crosshead speed and storage medium of the enamel do not seem to have any importance on the bond strength.

2.2 Introduction

Nowadays, Transbond XT of 3M Unitek is one of the most used light curing resin composites for bracket bonding. The bonding to enamel is achieved by etching the enamel with 35% phosphoric acid followed intermediate layer of Transbond XT primer to which the Transbond XT is applied. Transbond XT is composed of 14% volume Bis-GMA, 9% volume Bis-EMA, and 77% volume filler particles.(1) Because of its clinical effectiveness Transbond XT is often used as reference material in laboratory research. As this thesis aims to investigate the usability of glass ionomer cements for bracket bonding, Transbond XT could possibly function as the bench-mark or golden standard. For that reason a literature review was carried out on Transbond XT to reveal the important properties of the material and the variables influencing the bracket bonding cement.

The aim of this chapter is to review the current literature on the shear bond strength value and on the adhesive remnant index (ARI score) for stainless steel brackets bonded with Transbond XT to enamel. Furthermore the influence of different substrates, storage time, bracket base surface size and crosshead speed on the shear bond strength was evaluated. Because of the non-uniformity of some confounding variables, like bracket design, storage medium of the specimens, specimen preparation, and the way of performing the test, these were not incorporated in this review.

2.3 Material and method

Literature published from January 1996 to July 2008 was reviewed for bonding stainless steel brackets with Transbond XT. The Medline / Pubmed database (www.pubmed.com) was systematically searched using the term “orthodontic shear bond strength testing” and “Transbond XT” giving 384 and 128 hits, respectively. The following inclusion and exclusion criteria were applied. The inclusion criteria were (i) only *in vitro* shear test studies (ii) brackets of stainless steel (iii) specimen consisted of a bracket-cement-enamel system (iv) a minimum sample sizes of 8 specimens (v) a bond strength reported in MPa and (vii) storage time or debonding at ½ -1 h, 24 h, 48 h, or 72 h. The exclusion criteria were (i) bonding of brackets by an indirect technique (ii) debonding after rebonding the brackets (iii) pre-coated brackets and (iv) the use of self etching primers or moisture intensive primers. Repeated reported values in different articles from the same author(s) were also omitted. From the selected articles the average bond strength, the debonding time, the bonding surface area, the crosshead speed, the type of enamel type (bovine or human), and the adhesive remnant indexes were collected.

Independent t-test, one way-ANOVA, and regression analysis were used for statistical analysis. The comparison between the groups was analyzed with the Tukey test. A P-value < 0.05 was considered significant. The software used was SPSS 14.0 (SPSS inc., Chicago, USA).

2.4 Results

Out of the hit articles 61 fulfilled the inclusion and exclusion criteria. The selected articles are listed in Table 2.1 and resulted in 77 specimen groups at different storage times and substrates.

Table 2.1 List of studies selected from the literature (1996 – July 2008)

	First Author	Journal	Reference
1	Ajlouni, R.	Angle Orthod 2004; 74: 410-3.	(2)
2	Amra, I.	Am J Orthod Dentofacial Orthop 2007; 131: 160 e11-5.	(3)
3	Arhun, N.	Am J Orthod Dentofacial Orthop 2006; 129: 547-50.	(4)
4	Arici, S.	Angle Orthod 2005; 75: 254-9.	(5)
5	Arnold, R.W.	Am J Orthod Dentofacial Orthop 2002; 122: 274-6.	(6)
6	Bishara, S.E.	Am J Orthod Dentofacial Orthop 1997; 112: 617-21.	(1)
7	Bishara, S.E.	Am J Orthod Dentofacial Orthop 1998; 114: 447-51.	(7)
8	Bishara, S.E.	Am J Orthod Dentofacial Orthop 2002; 121: 521-525.	(8)
9	Bishara, S.E.	Angle Orthod 2002; 72: 464-7.	(9)
10	Bishara, S.E.	Am J Orthod Dentofacial Orthop 2004; 125: 348-50.	(10)
11	Bishara, S.E.	Angle Orthod 2004; 74: 400-4.	(11)
12	Bishara, S.E.	Angle Orthod 2006; 76: 689-93.	(12)
13	Bulut, H.	Am J Orthod Dentofacial Orthop 2007; 132: 77-83.	(13)
14	Buyukyilmaz, T.	Angle Orthod 2003; 73: 64-70.	(14)
15	Cacciafesta, V.	Eur J Orthod 2002; 24: 689-97.	(15)
16	Cacciafesta, V.	Am J Orthod Dentofacial Orthop 2003; 123: 633-40.	(16)
17	Cacciafesta, V.	Am J Orthod Dentofacial Orthop 2005; 128: 99-102.	(17)
18	Cal-Neto, J.P.	Angle Orthod 2006; 76: 466-9.	(18)
19	Chamda, R.A.	Am J Orthod Dentofacial Orthop 1996; 110: 378-82.	(19)
20	Coups-Smith, K.S.	Angle Orthod 2003; 73: 436-44.	(20)
21	Damon, P.L.	Angle Orthod 1997; 67: 169-72.	(21)
22	D'Attilio, M.	Angle Orthod 2005; 75: 410-5.	(22)
23	Dorminey, J.C.	Am J Orthod Dentofacial Orthop 2003; 124: 410-3.	(23)
24	Dunn, W.J.	Am J Orthod Dentofacial Orthop 2007; 131: 243-7.	(24)
25	Elvebak, B.S.	Angle Orthod 2006; 76: 837-44.	(25)
26	Evans, L.J.	Am J Orthod Dentofacial Orthop 2002; 121: 510-5.	(26)
27	Faltermeier, A.	Am J Orthod Dentofacial Orthop 2007; 132: 144 e1-5.	(27)
28	Gronberg, K.	Angle Orthod 2006; 76: 682-8.	(28)
29	Hajrassie, M.K.	Am J Orthod Dentofacial Orthop 2007; 131: 384-90.	(29)
30	Kim, M.J.	Angle Orthod 2005; 75: 678-84.	(30)
31	Klocke, A.	Am J Orthod Dentofacial Orthop 2002; 122: 643-8.	(31)
32	Klocke, A.	Angle Orthod 2003; 73: 176-80.	(32)
33	Klocke, A.	Angle Orthod 2004; 74: 245-50.	(33)

34	Korbmacher, H.M.	Angle Orthod 2006; 76: 845-50.	(34)
35	Korbmacher, H.	Eur J Orthod 2006; 28: 457-61.	(35)
36	Kula, K.S.	Orthod Craniofac Res 2003; 6: 96-100.	(36)
37	Mavropoulos, A.	Eur J Orthod 2005; 27: 408-12.	(37)
38	Montasser, M.A.	Angle Orthod 2008; 78: 531-6.	(38)
39	Nemeth, B.R.	Am J Orthod Dentofacial Orthop 2006; 129: 396-401.	(39)
40	Oesterle, L.J.	Am J Orthod Dentofacial Orthop 1998; 114: 514-9.	(40)
41	Owens, S.E.	Angle Orthod 2000; 70: 352-6.	(41)
42	Oztoprak, M.O.	Am J Orthod Dentofacial Orthop 2007; 131: 238-42.	(42)
43	Pithon, M.M.	Angle Orthod 2006; 76: 700-4.	(43)
44	Polat, O.	Angle Orthod 2004; 74: 405-9.	(44)
45	Rajagopal, R.	Angle Orthod 2004; 74: 264-8.	(45)
46	Sayinsu, K.	Am J Orthod Dentofacial Orthop 2007; 131: 391-4.	(46)
47	Sfondrini, M.F.	Am J Orthod Dentofacial Orthop 2001; 119: 30-5.	(47)
48	Sfondrini, M.F.	J Orthod 2002; 29: 45-50.	(48)
49	Signorelli, M.D.	Am J Orthod Dentofacial Orthop 2006; 129: 277-82.	(49)
50	Staudt, C.B.	J Dent 2006; 34: 498-502.	(50)
51	Su, J.	Am J Orthod Dentofacial Orthop 2004; 125: 51-5.	(51)
52	Sunna, S.	Br J Orthod 1999; 26: 47-50.	(52)
53	Tecco, S.	Angle Orthod 2005; 75: 672-7.	(53)
54	Turk, T.	Angle Orthod 2007; 77: 108-12.	(54)
55	Usumez, S.	Angle Orthod 2004; 74: 259-63.	(55)
56	Valente, R.M.	Am J Orthod Dentofacial Orthop 2002; 121: 516-20.	(56)
57	Vicente, A.	Angle Orthod 2005; 75: 109-13.	(57)
58	Vicente, A.	Am J Orthod Dentofacial Orthop 2006; 129: 390-5.	(58)
59	Vicente, A.	Angle Orthod 2007; 77: 524-7.	(59)
60	Webster, M.J.	Am J Orthod Dentofacial Orthop 2001; 119: 54-8.	(60)
61	Zeppieri, I.L.	Am J Orthod Dentofacial Orthop 2003; 124: 414-9.	(61)

The distribution of the articles between the human and bovine enamel used as substrate was 59 and 18, respectively. Table 2.2 shows the descriptive statistics of the shear bond strengths of human and bovine enamel at 24 hours. The distributions at the other storage times were to small to be representative and therefore omitted from the analysis. An independent t-test showed that the shear bond strength to bovine enamel are slightly higher compared to the shear bond strength to human enamel, but the difference was not significant ($P = 0.087$).

Table 2.2 Descriptive statistics of the shear bond strengths of bracket bonded with Transbond XT to human and bovine enamel at 24 hours.

Substrate	n	Shear Bond Strength (MPa)	Minimum	Maximum
Human	28	13.5 (4.4)	7.2	22.3
Bovine	12	16.1 (3.9)	11.3	24.1

The selected articles provided shear bond strength at four different times, ½ -1 h, 24 h, 48 h, and 72h, which are graphically depicted in Figure 2.1 and summarized in Table 2.3. One-way ANOVA (F = 5.9; P = 0.001) showed that only the first group, debonding between ½ and 1 h differs significantly from the 24 h, 48 h, and 72 h.

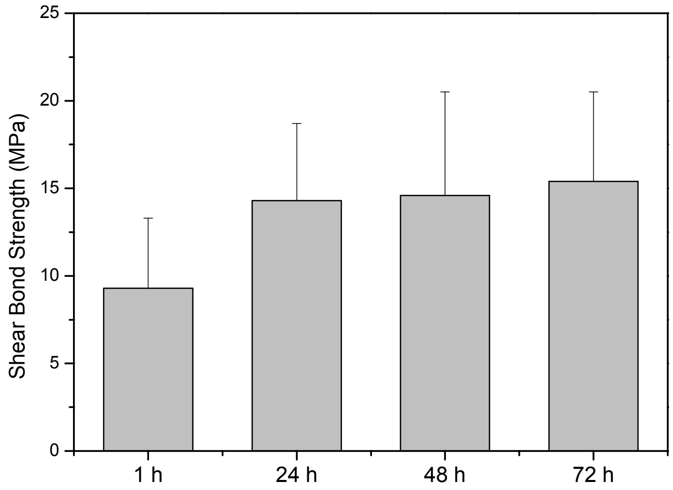

Figure 2.1 Shear bond strength (MPa) plotted against the debonding time. One-way ANOVA (F = 5.9; P = 0.001) showed significant difference between ½ -1 h and 24 h, 48 h, and 72 h.

Figure 2.2 and 2.3 show the plots between the shear bond strength of 24 h, 48 h, and 72 h and the bracket surface area and the crosshead speed, respectively. No correlations were found which implies that the size of the bonding area does not influence the shear test results and the crosshead speed between 0.5 and 5 mm/min also does not influence the measured shear bond strength significantly.

Table 2.3 Descriptive statistics of the shear bond strengths of bracket bonded with Transbond XT debonded at different times.

Time	n	Shear bond strength (MPa)	Minimum	Maximum
1 h	18	9.3 (4.0)*	4.6	17.0
24 h	40	14.3 (4.4)	7.2	24.1
48 h	11	14.6 (5.9)	6.4	26.9
72 h	8	15.4 (5.1)	10.8	23.5

* significant different based on one-way ANOVA (F = 5.9; P = 0.001).

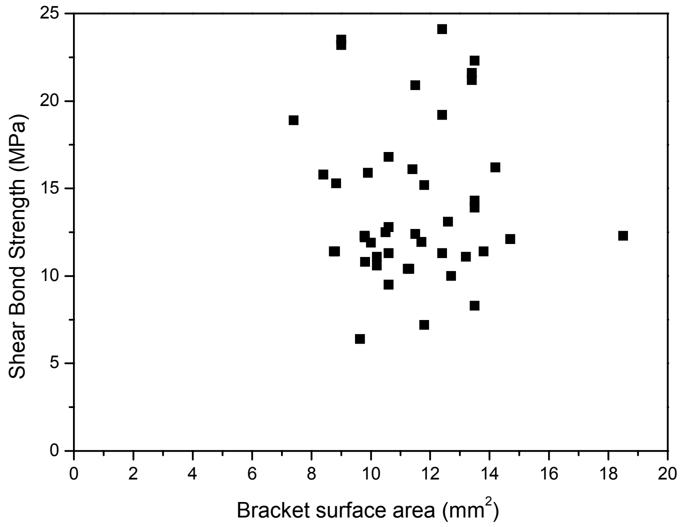

Figure 2.2 Shear bond strength (MPa) plotted against the bracket surface area (mm^2). Linear regression showed that there was no correlation between the two variables ($r^2 = 0.0$).

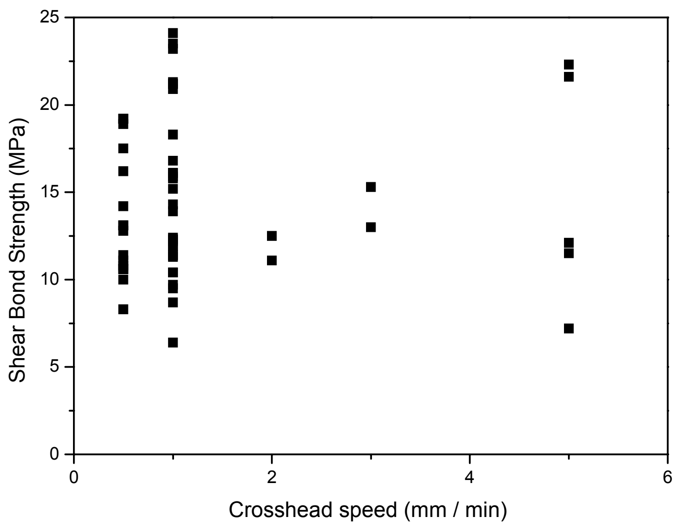

Figure 2.3 Shear bond strength (MPa) plotted against the crosshead speed (mm/min). Linear regression showed that there was no correlation between the two variables ($r^2 = 0.0$).

Of the 61 articles selected 48 used an adhesive remnant index (ARI score). In 30 of the 48 articles the index described by Årtun was used.(62) Although, the ARI score of Årtun is commonly used, the first description of the 'location of system failure' was to our knowledge by Bishara in 1975.(63) In 18 papers a modified 5-point index was used. This modified index showed up for the first time in articles from the research group of Bishara.(64) A score 1 indicates that all composite remained on the tooth, a score 2 > 90% remained on the tooth, a score 3 < 90% but more then 10%, a score 4 < 10% and a score 5 indicates that no adhesive was left on the tooth. The average score reported for the 4-point and 5-point scale were 1.8 (0.5) and 2.6 (0.8), respectively. This means that ca. 50% of the cement remains on the tooth, which implies that most fractures after shear testing are partly cohesive.

2.5 Discussion

Most of the bonding studies are carried out with human enamel from the third molar or the premolar, which are extracted for surgical or orthodontic reasons. As alternative substrates researchers have sought for substitutes like ivory, or enamel from canine, monkey-, porcine-, or bovine teeth. Bovine teeth are mostly used, because these teeth are easy to standardize and they are very similar to human teeth. Moreover, the age of the teeth can easily be controlled. The type of enamel, human or bovine, seems not to have a large influence on the shear bond strength. Nakamichi *et al.*, Oesterle *et al.*, and Reis *et al.* found shear bond strength results to bovine enamel slightly lower compared to human enamel.(40, 65, 66) In this review the bovine enamel gives in general slightly higher results compared to human enamel. The same was found for shear bond strength of different adhesive systems to primary enamel of bovine and humans.(67) In none of these articles significant differences between human or bovine enamel was found.

Figure 2.1 shows that the shear bond strength increases with time. The average initial shear bond strength is 9.3 (4.0) MPa and increases till 15.4 (5.1) MPa after 72 hours. The reason for the increase of the bond strength is most probably due to the ongoing post polymerization within the resin. From a clinical point of view it is therefore advisable not to load the brackets immediately to a maximum. Transbond XT is generally accepted as a clinically good functioning material for bracket bonding. *In vitro* measured shear bond strength of ca. 14 MPa might therefore be considered as sufficient for clinical use.

Based on the reviewed literature there was no correlation between the shear bond strength and the bracket surface area. In general in bond strength testing the geometry of the specimens plays a crucial role. There are differences observed between ‘micro’ and ‘macro’ tests and the investigated geometry can lead to specific local stresses.(68) In bracket testing most of the brackets are of similar dimensions: rectangular with a bonding area of 8 – 12 mm^2. Based on this literature review there is no significant relationship between the bond strength and the bracket surface area, but theoretical in specific situation one can expect these effects. Also the crosshead speed did not have any influence on the measured fracture force. An explanation for this finding is most probably the fact that although the variation of speed is very limited and the visco-elastic properties of the bracket, cement, and enamel do not change in the time intervals.

Only 75% of the articles reported an ARI score. This is remarkable because it provides important information about the weakest link of the bracket-cement-enamel system. Both the 4- and 5-point ARI score showed that ca. 50% of the Transbond XT remains on the tooth, which implies that most fractures after shear testing are partly cohesive. Compared to the use of the original ARI score, the “new” 5-point scale does not provide additional information. The reason for modifying the original index and the basis on what is unclear.(64) For unclear reasons the authors refer to a paper of Oliver (69) as the source of the 5-point index, but Oliver used the original index. Lamour *et al.* also changed the original index.(70) They reported that in the original index no score was available for fracture of the bracket when ceramic brackets were used. Both indexes give a rough idea about the amount of adhesive left. For comparison reasons it is advisable to use only one index.

Resin composite materials intended for orthodontic bonding have some disadvantages. The bonding is, as described in chapter 1, micromechanical. This means that prior to curing the fluid bonding agent penetrates the etched enamel. After curing the formed resin tags provide retention in the undercuts of the etched enamel prisms. After treatment this hybrid layer has to be removed which always causes some enamel damage. Another disadvantage of a resin composite is the ease of bacteria colonization on the rough surfaces, which hampers optimal oral hygiene.

Many variables are not taken into account in this review. The most important reason is the lack of data about a particular variable. This lack of standardization is probably the reason for the variability of the results in different studies. Uniformity in testing is often proposed, but “it is simply said although, in real life difficult to perform”.

2.6 Conclusions

Based on the published literature from January 1996 to July 2008 the *in vitro* measured shear bond strength between a bracket and enamel bonded with Transbond XT is between 9.3 and 15.4 MPa. Newly developed materials for bracket bonding should have a shear bond strength in this range, because Transbond XT functions sufficiently from a clinical point of view. Based on the available data there is no effect from the used substrate, (human or bovine), the crosshead speed of loading the specimens, and the bracket surface area. It is remarkable that about 25% of the reviewed articles did not report data on mode of failure, such as the ARI score or the amount of adhesive residue left on the debonded enamel surface however.

2.7 References

1. Bishara SE, Olsen M, Von Wald L. Comparisons of shear bond strength of precoated and uncoated brackets. *Am J Orthod Dentofacial Orthop* 1997 **112**:617-21.
2. 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**:410-3.
3. Amra I, Samsodien G, Shaikh A, Lalloo R. Xeno III self-etching adhesive in orthodontic bonding: the next generation. *Am J Orthod Dentofacial Orthop* 2007 **131**:160 e11-5.
4. Arhun N, Arman A, Sesen C, Karabulut E, Korkmaz Y, Gokalp S. Shear bond strength of orthodontic brackets with 3 self-etch adhesives. *Am J Orthod Dentofacial Orthop* 2006 **129**:547-50.
5. Arici S, Caniklioglu CM, Arici N, Ozer M, Oguz B. Adhesive thickness effects on the bond strength of a light-cured resin-modified glass ionomer cement. *Angle Orthod* 2005 **75**:254-9.
6. Arnold RW, Combe EC, Warford JH, Jr. Bonding of stainless steel brackets to enamel with a new self-etching primer. *Am J Orthod Dentofacial Orthop* 2002 **122**:274-6.
7. Bishara SE, VonWald L, Zamtua J. Effects of different types of light guides on shear bond strength. *Am J Orthod Dentofacial Orthop* 1998 **114**:447-51.
8. 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.
9. Bishara SE, Ajlouni R, Laffoon J, Warren J. Effects of modifying the adhesive composition on the bond strength of orthodontic brackets. *Angle Orthod* 2002 **72**:464-7.
10. Bishara SE, Oonsombat C, Ajlouni R, Laffoon JF. Comparison of the shear bond strength of 2 self-etch primer/adhesive systems. *Am J Orthod Dentofacial Orthop* 2004 **125**:348-50.
11. Bishara SE, Soliman MM, Oonsombat C, Laffoon JF, Ajlouni R. The effect of variation in mesh-base design on the shear bond strength of orthodontic brackets. *Angle Orthod* 2004 **74**:400-4.

12. 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.
13. Bulut H, Turkun M, Turkun LS, Isiksal E. Evaluation of the shear bond strength of 3 curing bracket bonding systems combined with an antibacterial adhesive. *Am J Orthod Dentofacial Orthop* 2007 **132**:77-83.
14. Buyukyilmaz T, Usumez S, Karaman AI. Effect of self-etching primers on bond strength--are they reliable? *Angle Orthod* 2003 **73**:64-70.
15. Cacciafesta V, Sfondrini MF, Klersy C, Sfondrini G. Polymerization with a micro-xenon light of a resin-modified glass ionomer: a shear bond strength study 15 minutes after bonding. *Eur J Orthod* 2002 **24**:689-97.
16. Cacciafesta V, Sfondrini MF, De Angelis M, Scribante A, Klersy C. Effect of water and saliva contamination on shear bond strength of brackets bonded with conventional, hydrophilic, and self-etching primers. *Am J Orthod Dentofacial Orthop* 2003 **123**:633-40.
17. Cacciafesta V, Sfondrini MF, Barina E, Scribante A, Garino F, Klersy C. Effect of different light sources and guides on shear bond strength of brackets bonded with 2 adhesive systems. *Am J Orthod Dentofacial Orthop* 2005 **128**:99-102.
18. Cal-Neto JP, Carvalho F, Almeida RC, Miguel JA. Evaluation of a new self-etching primer on bracket bond strength in vitro. *Angle Orthod* 2006 **76**:466-9.
19. Chamda RA, Stein E. Time-related bond strengths of light-cured and chemically cured bonding systems: an in vitro study. *Am J Orthod Dentofacial Orthop* 1996 **110**:378-82.
20. Coups-Smith KS, Rossouw PE, Titley KC. Glass ionomer cements as luting agents for orthodontic brackets. *Angle Orthod* 2003 **73**:436-44.
21. Damon PL, Bishara SE, Olsen ME, Jakobsen JR. Bond strength following the application of chlorhexidine on etched enamel. *Angle Orthod* 1997 **67**:169-72.
22. D'Attilio M, Traini T, Di Iorio D, Varvara G, Festa F, Tecco S. Shear bond strength, bond failure, and scanning electron microscopy analysis of a new flowable composite for orthodontic use. *Angle Orthod* 2005 **75**:410-5.
23. Dorminey JC, Dunn WJ, Taloumis LJ. Shear bond strength of orthodontic brackets bonded with a modified 1-step etchant-and-primer technique. *Am J Orthod Dentofacial Orthop* 2003 **124**:410-3.
24. Dunn WJ. Shear bond strength of an amorphous calcium-phosphate-containing orthodontic resin cement. *Am J Orthod Dentofacial Orthop* 2007 **131**:243-7.

25. Elvebak BS, Rossouw PE, Miller BH, Buschang P, Ceen R. Orthodontic bonding with varying curing time and light power using an argon laser. *Angle Orthod* 2006 **76**:837-44.
26. Evans LJ, Peters C, Flickinger C, Taloumis L, Dunn W. A comparison of shear bond strengths of orthodontic brackets using various light sources, light guides, and cure times. *Am J Orthod Dentofacial Orthop* 2002 **121**:510-5.
27. 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.
28. Gronberg K, Rossouw PE, Miller BH, Buschang P. Distance and time effect on shear bond strength of brackets cured with a second-generation light-emitting diode unit. *Angle Orthod* 2006 **76**:682-8.
29. Hajrassie MK, Khier SE. In-vivo and in-vitro comparison of bond strengths of orthodontic brackets bonded to enamel and debonded at various times. *Am J Orthod Dentofacial Orthop* 2007 **131**:384-90.
30. Kim MJ, Lim BS, Chang WG, Lee YK, Rhee SH, Yang HC. Phosphoric acid incorporated with acidulated phosphate fluoride gel etchant effects on bracket bonding. *Angle Orthod* 2005 **75**:678-84.
31. Klocke A, Korbmacher HM, Huck LG, Kahl-Nieke B. Plasma arc curing lights for orthodontic bonding. *Am J Orthod Dentofacial Orthop* 2002 **122**:643-8.
32. Klocke A, Shi J, Kahl-Nieke B, Bismayer U. Bond strength with custom base indirect bonding techniques. *Angle Orthod* 2003 **73**:176-80.
33. Klocke A, Shi J, Vaziri F, Kahl-Nieke B, Bismayer U. Effect of time on bond strength in indirect bonding. *Angle Orthod* 2004 **74**:245-50.
34. Korbmacher HM, Huck L, Kahl-Nieke B. Fluoride-releasing adhesive and antimicrobial self-etching primer effects on shear bond strength of orthodontic brackets. *Angle Orthod* 2006 **76**:845-50.
35. Korbmacher H, Huck L, Adam T, Kahl-Nieke B. Evaluation of an antimicrobial and fluoride-releasing self-etching primer on the shear bond strength of orthodontic brackets. *Eur J Orthod* 2006 **28**:457-61.
36. Kula KS, Nash TD, Purk JH. Shear-peel bond strength of orthodontic primers in wet conditions. *Orthod Craniofac Res* 2003 **6**:96-100.
37. Mavropoulos A, Staudt CB, Kiliaridis S, Krejci I. Light curing time reduction: in vitro evaluation of new intensive light-emitting diode curing units. *Eur J Orthod* 2005 **27**:408-12.

38. Montasser MA, Drummond JL, Evans CA. Rebonding of orthodontic brackets. Part I, a laboratory and clinical study. *Angle Orthod* 2008 **78**:531-6.
39. Nemeth BR, Wiltshire WA, Lavelle CL. Shear/peel bond strength of orthodontic attachments to moist and dry enamel. *Am J Orthod Dentofacial Orthop* 2006 **129**:396-401.
40. Oesterle LJ, Shellhart WC, Belanger GK. The use of bovine enamel in bonding studies. *Am J Orthod Dentofacial Orthop* 1998 **114**:514-9.
41. Owens SE, Jr., Miller BH. A comparison of shear bond strengths of three visible light-cured orthodontic adhesives. *Angle Orthod* 2000 **70**:352-6.
42. Oztoprak MO, Isik F, Sayinsu K, Arun T, Aydemir B. Effect of blood and saliva contamination on shear bond strength of brackets bonded with 4 adhesives. *Am J Orthod Dentofacial Orthop* 2007 **131**:238-42.
43. Pithon MM, Dos Santos RL, de Oliveira MV, Ruellas AC, Romano FL. Metallic brackets bonded with resin-reinforced glass ionomer cements under different enamel conditions. *Angle Orthod* 2006 **76**:700-4.
44. 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.
45. Rajagopal R, Padmanabhan S, Gnanamani J. A comparison of shear bond strength and debonding characteristics of conventional, moisture-insensitive, and self-etching primers in vitro. *Angle Orthod* 2004 **74**:264-8.
46. Sayinsu K, Isik F, Sezen S, Aydemir B. Effect of blood and saliva contamination on bond strength of brackets bonded with a protective liquid polish and a light-cured adhesive. *Am J Orthod Dentofacial Orthop* 2007 **131**:391-4.
47. 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.
48. Sfondrini MF, Cacciafesta V, Klersy C. Halogen versus high-intensity light-curing of uncoated and pre-coated brackets: a shear bond strength study. *J Orthod* 2002 **29**:45-50.
49. Signorelli MD, Kao E, Ngan PW, Gladwin MA. Comparison of bond strength between orthodontic brackets bonded with halogen and plasma arc curing lights: an in-vitro and in-vivo study. *Am J Orthod Dentofacial Orthop* 2006 **129**:277-82.

50. Staudt CB, Krejci I, Mavropoulos A. Bracket bond strength dependence on light power density. *J Dent* 2006 **34**:498-502.
51. Su J, Hobson RS, McCabe JF. Effect of impression technique on bond strength. *Am J Orthod Dentofacial Orthop* 2004 **125**:51-5.
52. 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.
53. Tecco S, Traini T, Caputi S, Festa F, de Luca V, D'Attilio M. A new one-step dental flowable composite for orthodontic use: an in vitro bond strength study. *Angle Orthod* 2005 **75**:672-7.
54. 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.
55. Usumez S, Buyukyilmaz T, Karaman AI. Effect of light-emitting diode on bond strength of orthodontic brackets. *Angle Orthod* 2004 **74**:259-63.
56. Valente RM, De Rijk WG, Drummond JL, Evans CA. Etching conditions for resin-modified glass ionomer cement for orthodontic brackets. *Am J Orthod Dentofacial Orthop* 2002 **121**:516-20.
57. 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* 2005 **75**:109-13.
58. Vicente A, Bravo LA, Romero M, Ortiz AJ, Canteras M. Effects of 3 adhesion promoters on the shear bond strength of orthodontic brackets: an in-vitro study. *Am J Orthod Dentofacial Orthop* 2006 **129**:390-5.
59. Vicente A, Bravo LA. Shear bond strength of precoated and uncoated brackets using a self-etching primer. *Angle Orthod* 2007 **77**:524-7.
60. Webster MJ, Nanda RS, Duncanson MG, Jr., Khajotia SS, Sinha PK. The effect of saliva on shear bond strengths of hydrophilic bonding systems. *Am J Orthod Dentofacial Orthop* 2001 **119**:54-8.
61. Zeppieri IL, Chung CH, Mante FK. Effect of saliva on shear bond strength of an orthodontic adhesive used with moisture-insensitive and self-etching primers. *Am J Orthod Dentofacial Orthop* 2003 **124**:414-9.
62. 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.
63. Bishara SE, Khowassah MA, Oesterle LJ. Effect of humidity and temperature changes on orthodontic direct-bonding adhesive systems. *J Dent Res* 1975 **54**:751-8.

64. Bishara SE, Trulove TS. Comparisons of different debonding techniques for ceramic brackets: an in vitro study. Part II. Findings and clinical implications. *Am J Orthod Dentofacial Orthop* 1990 **98**:263-73.
65. Nakamichi I, Iwaku M, Fusayama T. Bovine teeth as possible substitutes in the adhesion test. *J Dent Res* 1983 **62**:1076-81.
66. Reis AF, Giannini M, Kavaguchi A, Soares CJ, Line SR. Comparison of microtensile bond strength to enamel and dentin of human, bovine, and porcine teeth. *J Adhes Dent* 2004 **6**:117-21.
67. Krifka S, Borzsonyi A, Koch A, Hiller KA, Schmalz G, Friedl KH. Bond strength of adhesive systems to dentin and enamel--human vs. bovine primary teeth in vitro. *Dent Mater* 2008 **24**:888-94.
68. El Zohairy AA, de Gee AJ, de Jager N, van Ruijven LJ, Feilzer AJ. The influence of specimen attachment and dimension on microtensile strength. *J Dent Res* 2004 **83**:420-4.
69. Oliver RG. The effect of different methods of bracket removal on the amount of residual adhesive. *Am J Orthod Dentofacial Orthop* 1988 **93**:196-200.
70. Larmour CJ, McCabe JF, Gordon PH. Notching of orthodontic bonding resin to facilitate ceramic bracket debond--an ex vivo investigation. *Br J Orthod* 1998 **25**:289-91.