European Journal of Orthodontics 33 (2011) 521–527
doi:10.1093/ejo/cjq110
Advance Access Publication 19 November 2010

Shear bond strength after multiple bracket bonding with or without repeated etching

Daniel Rüger*, Winfried Harzer*, Zane Krisjane** and Eve Tausche*
Departments of Orthodontics, *Technical University of Dresden, Germany and **University of Riga, Latvia

Correspondence to: Prof. W. Harzer, Poliklinik für Kieferorthopädie, TU Dresden, Fetscherstraße 74, 01307 Dresden, Germany. E-mail: Winfried.Harzer@uniklinikum-dresden.de

SUMMARY The purpose of the study was to measure the *in vitro* shear bond strength (SBS) of metal brackets after multiple bonding and debonding with and without repeated etching. One hundred and twenty extracted premolars were divided into three equal groups. In group 1, the brackets were bonded and debonded three times with repeated enamel etching and in groups 2 and 3 without repeated etching. In group 2, all composite remnants were removed before bonding, while in group 3, the remnants were levelled. Analysis of variance was used to determine significant differences in SBS with Bonferroni adjustment for the multiple testing procedures.

The results showed that in group 1, the mean SBS was 11.69 MPa (SD 2.65) at the first, 14.30 MPa (SD 2.69) at the second, and 12.19 MPa (SD 2.26) at the third debonding. In group 2, SBS decreased from 12.57 MPa (SD 2.54) to below 8.0 MPa. In group 3, SBS remained constant from the first (11.93 MPa; SD 2.14) to the second (12.06 MPa; SD 1.65) debonding and only decreased significantly to 9.74 MPa (SD 1.80) at the third debonding. Less composite remained on the teeth after each debonding sequence. This was characterized by a shift from adhesive remnant index (ARI) scores 2 and 3 after the first debonding to ARI scores 1 and 2 after the second debonding to predominantly scores 0 and 1 after the third debonding.

After bracket loss and levelling of composite remnants, the SBS is sufficient for application of orthodontic forces. Repeated etching may involve a higher risk of enamel tear-outs during debonding.

Introduction

One of the most common problems clinicians face during patient treatment is accidental dislodgement of orthodontic brackets. The prevalence of bracket loss ranges between 6 and 7.2 per cent, with a predominance of premolars and molars (Millett *et al.*, 2000; Tang *et al.*, 2000; Adolfsson *et al.*, 2002; Asgari *et al.*, 2002; Elekdag-Turk *et al.*, 2008). The reasons for bracket loss include an incomplete retention pattern, unfavourable enamel morphology, and antagonist tooth contacts (Mattick and Hobson, 2000; Linklater and Gordon, 2001).

Shear bond strength (SBS) is regarded as clinically sufficient if values of approximately 8 MPa are achieved (Powers *et al.*, 1997). Values greater than 13 MPa may increase the risk of enamel tear-outs since cohesion forces of the enamel structure might be exceeded (Gwinnett and Gorelick, 1977; Brown and Way, 1978). Reports concerning SBS and rebond strength (RBS) after multiple debonding and bonding procedures are contradictory. Bishara *et al.* (2000a,b, 2002) found no significant differences between SBS and RBS, whereas Fischer-Brandies and Monsees (1993) reported increasing SBS at the second debonding sequence. They attributed this increase to a more pronounced etching pattern after repeated acid etching. They suggested that one reason for the significant decrease in RBS at the third debonding could be a result of the more scattered enamel structure with an increased risk of enamel damage.

Routine procedures for rebonding orthodontic brackets include removal of adhesive remnants, repeated use of phosphoric acid, application of bonding agents, and finally placement of the bracket with composite on the tooth. While clean-up of residual composite with rotating instruments is associated with enamel loss of 11.3–19.2 μm (Pus and Way, 1980), repeated etching leads to an additional loss of 10–50 μm and may change enamel structures up to 200 μm in depth (Legler *et al.*, 1990; Zentner and Duschner, 1996). The SBS of orthodontic brackets on tooth surfaces is dependent on the SBS of the bracket base–resin and resin–enamel interfaces. Since, in most cases, the major part of the composite remains on the enamel after bracket loss confirming sufficient compound, it is questionable if breaking up this compound and re-establishing it by repeated etching is practical. Failure type is also of clinical importance; fracture at the resin–enamel interface seems preferable since it allows for quick and easy removal of excess resin. However, fracture at the resin–bracket interface seems to be safer regarding enamel tear-outs.

The aims of the present *in vitro* study were to investigate the effect of different rebonding techniques on SBS, the incidence of enamel tear-outs, and to determine whether complete removal of adhesive remnants and re-etching is necessary with respect to sufficient RBS on the one hand and enamel protection on the other.

Materials and methods

One hundred and twenty human premolars extracted for orthodontic reasons were collected and stored in an aqueous solution of thymol (0.1 per cent). Selection criteria included a sound, non-carious buccal surface with no damage due to the extraction process, and a non-frosty natural surface gloss. Remnants of the periodontal ligament were removed with a scalpel and the enamel surface was cleaned and polished using water and fluoride-free prophylaxis paste on a rubber cup attached to a slow speed handpiece for 5 seconds. A uniform bonding procedure was used for the initial bond in all three groups: The enamel surfaces were etched with 37 per cent phosphoric acid (Dentaurum, Ispringen, Germany) for 30 seconds and then rinsed thoroughly using an air–water spray for 30 seconds. The enamel surfaces were air-dried until they appeared dull and frosty. A liberal coating of sealant (3M Unitek Transbond MIP, Monrovia, California, USA) was applied and air was blown perpendicular to the labial surface of the tooth for 5 seconds. Metal orthodontic premolar brackets (Ultratrimm, Dentaurum) were then bonded with a bisphenolglycidyldimethacrylate resin (3M Unitek Transbond XT) under a constant pressure of 3 N, which was calibrated with a pressure gauge. Excessive resin was removed with a sharp scaler. The composite was then light cured for 40 seconds (10 seconds on each side of the bracket) with a conventional halogen light polymerization device (3M Unitek Ortholux XT). The distance between the exit window and the resin surface was maintained at 5 mm in order to obtain adequate polymerization. The specimen was stored in distilled water for 1 week before thermocycling at 5000 cycles between two water baths of 5 and 55°C, respectively.

For bracket debonding, the roots of the specimen were embedded in silicon, which was mounted in an acrylic cylinder in order to obtain slight resilience comparable with the situation in the periodontal ligament. The teeth were fixed such that the bracket base was parallel to the direction of the applied force. The specimen were mounted in the jig of a universal testing machine (Tira Test 2720, force sensor 1 kN, Schalkau, Germany) and adjusted with the steel rod parallel to the disto- and mesiobuccal bracket wing. The crosshead was moved downwards at a speed of 1 mm/minute so the brackets were loaded until fracture. The forces required to shear–peel the brackets were recorded in Newtons and converted into Megapascals using the measured bracket base surface size of 10.23 mm^2.

After the first uniform bonding procedure, the teeth were randomly divided into three different groups of 40. For calculation of the adhesive remnant index (ARI; Årtun and Bergland, 1984), digital photographs were taken under ×20 magnification in an optical microscope (Zeiss, Jena, Germany) in order to determine the area covered with resin. This procedure was repeated for every tooth after the three debonding sequences.

Group 1: after calculation of the ARI, all remaining composite was removed using a tungsten carbide bur in a slow speed handpiece until the enamel had regained its natural gloss. The surface was re-etched for 30 seconds, rinsed, and air-dried as described above. New premolar brackets were bonded as in the initial bonding sequence.

Group 2: all remaining composite was removed after calculation of the ARI using a tungsten carbide bur in a slow speed handpiece until the enamel had regained its natural gloss. No re-etching was undertaken and new premolar brackets were bonded.

Group 3: in contrast to the procedures in groups 1 and 2, the composite remnants in group 3 were, after calculation of the ARI, not totally removed prior to rebonding but levelled using a tungsten carbide bur leaving an extensive area covered with resin for the following bonding. Only the thickness of the composite layer was reduced in order to minimize positioning error.

For assessment of enamel tear-outs after the third debonding sequence, all samples were divided vertically and examined using a scanning electronic microscope (XL 30 ESEM; Philips, Eindhoven, The Netherlands). This technique allowed examination in a water vapour environment without sputter coating. Enamel tear-outs exceeding 50 μm were recorded.

Descriptive statistics, including the mean, standard deviation, minimum, and maximum values, were calculated for each of the groups. Analysis of variance was used to determine whether significant differences existed in SBS in the different groups or debonding sequences. Bonferroni adjustment was performed because of multiple testing procedures. Data were analysed using the Statistical Package for Social Sciences 16.0 (SPSS Inc., Chicago, Illinois, USA).

Results

Shear bond strength

Comparisons of the mean SBS after the first debonding sequence did not show significant differences between the groups, validating the random assignment procedure. The mean RBS for the second debonding sequence in group 1 increased significantly ($P < 0.05$), while that in group 2 decreased below the clinically appropriate level of 8 MPa. The mean RBS in group 3 showed no significant difference to the recorded values in debonding sequence 1. After the third debonding sequence, the recorded RBS in group 1 did not show a significant difference compared with the initial SBS. The RBS in group 2 decreased further to 3.60 MPa, while in group 3, there was a significant decrease compared with the first two debonding sequences but this was still 9.74 MPa (Table 1).

Table 1 Shear bond strength in Megapascals after three debonding sequences with and without etching. Group 1: the brackets were bonded and debonded three times with repeated enamel etching. Groups 2 and 3: without repeated etching. In group 2, all composite remnants were removed before bonding, while in group 3, the remnants were levelled.

	Group 1					Group 2					Group 3				
	Mean	SD	Median	Maximum	Minimum	Mean	SD	Median	Maximum	Minimum	Mean	SD	Median	Maximum	Minimum
Sequence 1	11.69	2.65	11.94	16.77	5.35	12.57	2.54	12.69	18.27	4.45	11.93	2.14	12.30	16.19	8.45
Sequence 2	14.30	2.69	14.64	19.12	7.90	4.95	1.22	4.89	7.17	2.42	12.06	1.65	12.34	14.21	7.80
Sequence 3	12.19	2.26	11.92	18.29	6.06	3.60	1.13	3.50	6.69	1.15	9.74	1.80	9.74	13.21	6.29

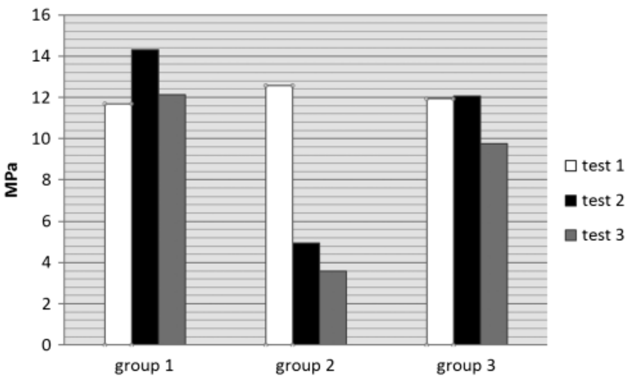

Figure 1 Mean values of shear bond strength in Megapascals (MPa) in the three groups with and without etching after multiple debonding (group 1: the brackets were bonded and debonded three times with repeated enamel etching. Groups 2 and 3: without repeated etching. In group 2, all composite remnants were removed before bonding, while in group 3, the remnants were levelled).

Summarizing the results, in group 1 there was no significant difference in SBS between the first and third debonding sequence, while values obtained for the second debonding were significantly higher. In group 2, SBS decreased continuously following the debonding sequences and the mean values did not reach a clinically sufficient SBS of 8 MPa for the second and third debonding. In group 3, there was no significant difference in the mean SBS between the first and second debonding although the samples were not etched repeatedly. Only for sequence 3, was there a significant decrease in SBS, but the values still exceeded 8 MPa (Figure 1).

Adhesive remnant index

ARI scores assessed after the first debonding sequence did not show significant differences between the groups. All, or at least, more than half, of the bonding area in all samples remained covered with composite (ARI scores 2 and 3). In group 1, similar ARI patterns were found after the second and third debonding sequence with a slight shift to ARI score 3 after the second debonding. In contrast, the samples in group 2 had no or less than half of the bonding area covered with composite after debonding sequences 2 and 3 (ARI scores 0 and 1). This is probably due to the reduced micromechanical retention when no repeated etching is carried out. The samples in group 3 showed lower ARI scores and less composite remaining after each debonding sequence, characterized by a shift from ARI scores 2 and 3 after the first debonding to ARI scores 1 and 2 after the second debonding to predominantly scores 0 and 1 after the third debonding (Figure 2).

Structure of the bracket–composite–enamel interfaces and enamel tear-outs

The pronounced etching pattern after multiple acid application was confirmed in this investigation. Several microscopic islands of residual composite did not seem to have a significant influence the retention (Figure 3). Enamel tear-outs occurred predominantly at the margins of remnant covered and remnant-free areas and followed the direction of the prisms. In group 1 with threefold etching, seven tear-outs with a mean depth of 79 μm occurred. In groups 2 and 3 without repeated etching, one and two tear-outs with depths of 89 and 95 μm, respectively, were measured (Figure 4).

In contrast to the procedure in group 2, the enamel adhesive junction was not dissolved but the adhesive layer was only thinned out in group 3 so that correct positioning of brackets could be performed and first order error was minimized. Conditioning with a tungsten carbide bur seemed to create a sufficiently rough remnant surface providing adequate SBS at the second and third debonding (Figures 5 and 6).

Discussion

The SBS and ARI scores in group 1 following repeated etching showed no significant differences between debonding sequences 1 and 3. Values for debonding sequence 2, however, were significantly higher and there was an increased number of samples with ARI score 3, indicating more adhesive remaining on the enamel. These findings are in agreement with those of Fischer-Brandies and Monsees (1993) who used Concise™ as a highly filled but chemically curing composite. Those authors explained

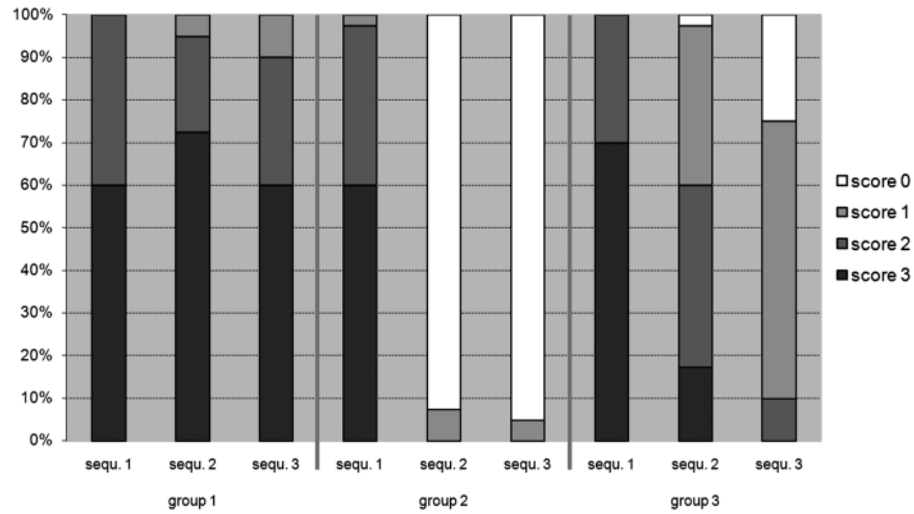

Figure 2 Adhesive remnant index scores in the three groups with and without etching after multiple debonding: score 0: no resin left on the tooth surface, implying that bond fracture occurred purely at the resin/enamel interface; 1: less than half the resin left on tooth, implying that bond fracture occurred predominantly at the resin/enamel interface; 2: more than half the resin left on tooth, implying that bond fracture occurred predominantly at the bracket/resin interface; 3: all the resin left on tooth, with a distinct impression of the bracket, implying that bond fracture occurred purely at the bracket/resin interface.

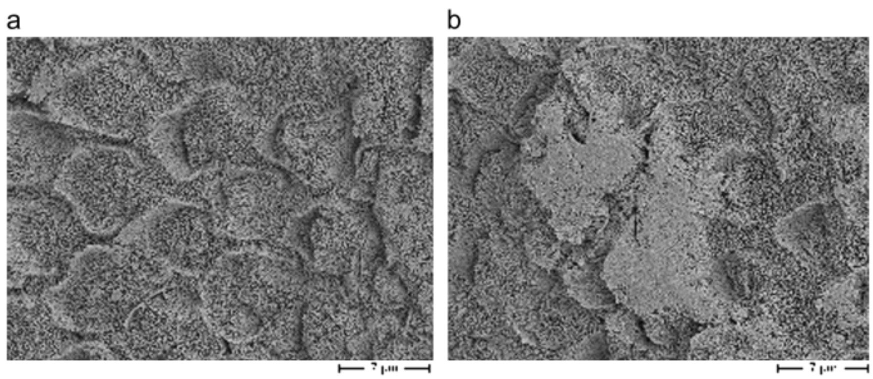

Figure 3 (a) Repeated etched enamel (magnification ×1000) and (b) bonding residuals after repeated etching (magnification ×3000).

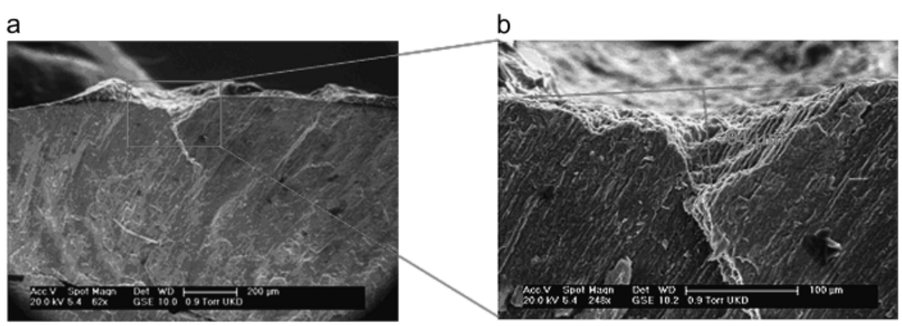

Figure 4 Enamel tear-out in group 1 (a) magnification ×62 and (b) spot magnification ×248.

the higher SBS at the second debonding sequence as being due to the more pronounced etching pattern as a result of the increased coverage of acid resistant enamel structures after repeated etching. The significant decrease in SBS in that study at the last debonding was due to partial destruction of the etching pattern, which was confirmed in this study, with

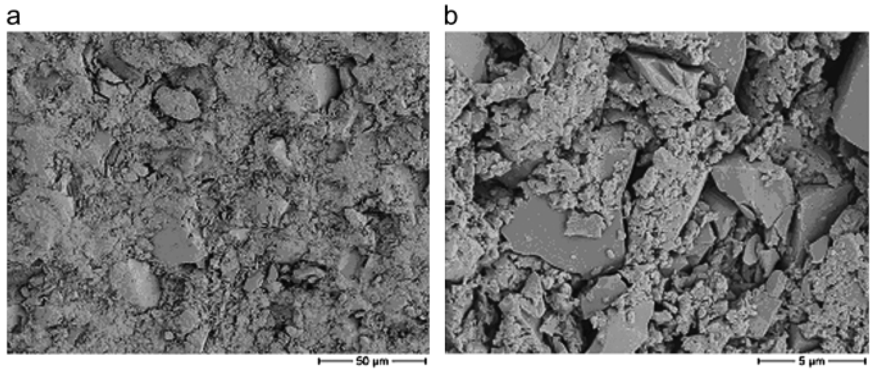

Figure 5 Adhesive remnants after levelling in group 3 (a) magnification ×500 and (b) spot magnification ×5000.

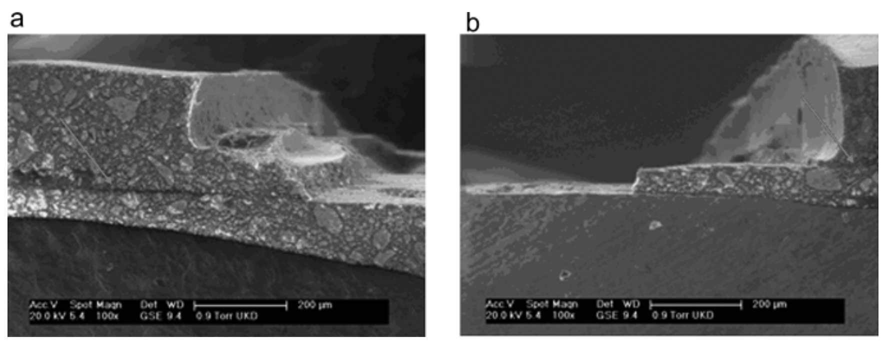

Figure 6 Composite–composite interface in group 3 after repeated bonding (a and b magnification ×100).

a higher incidence of enamel tear-outs in group 1. This also confirms the higher etching aggression. Mui *et al.* (1999), who investigated SBS with respect to different reconditioning methods, also found significantly higher values for the second debonding sequence after repeated etching, with four samples out of 52 showing enamel fractures. Eminkahyagil *et al.* (2006) confirmed these findings using Sof Lex finishing discs and tungsten carbide burs for remnant removal and reconditioned brackets.

In contrast, other studies found no significant differences or significantly weaker RBS than the initial SBS if repeated etching was performed. This was explained by the weaker retentive enamel morphology due to microscopic bonding remnants (Regan *et al.*, 1993; Bishara *et al.*, 2002; Heravi and Naseh, 2006; Montasser *et al.*, 2008a,b). These results are confirmed by the findings in group 1 with repeated etching.

The SBS in group 2, without repeated etching after complete removal of macroscopic adhesive remnants, fell below the clinically appropriate value of 8 MPa at the second and third debonding sequences. This was due to the weak micromechanical retention. The recorded enamel tear-outs presumably occurred during the first debonding process after acid etching because the SBS at the second and third debonding never exceeded the adhesion forces of the enamel structure (Bowen and Rodriguez, 1962; Gwinnett and Gorelick, 1977). Numerous studies have demonstrated that acid etching cannot be substituted by any other preparation procedure, such as silica blasting with respect to adequate SBS (Reisner *et al.*, 1997; Perry, 1980; Matos *et al.*, 2003).

Regarding the SBS in group 3, there were no significant differences between the first and second debonding; this is surprising because no acid etching was performed after the first debonding. In contrast to the procedure in group 2, the enamel adhesive junction was not dissolved but the adhesive layer was only thinned so that correct positioning of the brackets could be performed and first order error was minimized.

Smaller amounts of adhesive remnants remaining after the second debonding in groups 1 and 3 could explain the significant decline of SBS at the third debonding sequence. However, this effect was not confirmed statistically by a positive correlation between the amount of adhesive remnant (ARI score) and SBS in the following debonding sequence. The two enamel tear-outs in group 3 compared with the seven in group 1 are an indication of enamel preservation but did not reach a statistically significant level because of the small number of brackets. There are however many studies confirming the enamel stress capacity of repeated etching (Fischer-Brandies *et al.*, 1993; Fitzpatrick and Way, 1977; Montasser *et al.*, 2008a,b).

Several investigations have examined the tensile or SBS of rebonded brackets when adhesive remnants are left on the enamel surface prior to rebonding. The results were inconsistent, showing higher, lower, or not significantly different values for SBS at the second debonding sequence. Predominantly, highly filled chemically curing adhesive systems were used. The authors emphasized that compatibility and the type of bonding and composite influenced SBS rather than reconditioning methods (Perry, 1980; Rosenstein and Binder, 1980; Zennyu, 1988).

Basically, there is a composite–composite interface if repeated bonding is performed without eliminating adhesive remnants, which resembles a repair of a restoration. Surface texture, covalent bonding with unreacted methacrylate groups, and penetration of bonding into the adhesive matrix are factors influencing microtensile bond strength (Dall'oca *et al.*, 2008). Although mechanical interlocking is considered to be the most important factor contributing to composite repair strength (Kupiec and Barkmeier, 1996; Shahdad and Kennedy, 1998), grinding of the composite substrate might decrease tensile bond strength due to filler exposure (Bouschlicher *et al.*, 1999). In order to improve micromechanical interlocking, the use of aluminium oxide air abrasion or different types of diamond or tungsten carbide burs have been suggested (Brosh *et al.*, 1997; Frankenberger *et al.*, 2000; Ozcan *et al.*, 2005, 2007). However, the penetration depth of adhesive is limited to 2.5 μm and therefore new composite can only be applied after prior use of bonding agents.

The procedures overall result in sufficient tensile bond strength in repair of restorations; application of these findings on bonding procedures for orthodontic brackets may be taken into consideration since necessary SBS is much lower and the bond is only temporary.

Conclusions

Levelling adhesive remnants on the enamel surface and rebonding of brackets without repeated etching is a viable option with respect to SBS, provided that the greater part of the area to be rebonded is covered with composite, e.g. ARI score 2 or 3.

Removal of adhesive remnants and re-etching are necessary if less than half of the bonding area is covered with composite; however, there is an increased risk of enamel tear-outs. Removal of adhesive remnants and rebonding brackets without repeated etching does not provide adequate SBS.

Clinical rebonding protocols without complete removal of adhesive remnants improve workflow due to avoidance of time-consuming measures, such as etching and rinsing. They provide sufficient SBS if indications are respected.

Funding

This project was supported by Dental Forschung e.v.

References

Adolfsson U, Larsson E, Ogaard B 2002 Bond failure of a no-mix adhesive during orthodontic treatment. American Journal of Orthodontics and Dentofacial Orthopedics 122: 277–281

Årtun J, Bergland S 1984 Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. American Journal of Orthodontics 85: 333–340

Asgari S, Salas A, English J, Powers J 2002 Clinical evaluation of bond failure rates with a new self-etching primer. Journal of Clinical Orthodontics 36: 687–689

Bishara S E, Laffoon J F, Vonwald L, Warren J J 2002 The effect of repeated bonding on the shear bond strength of different orthodontic adhesives. American Journal of Orthodontics and Dentofacial Orthopedics 121: 521–525

Bishara S E, Vonwald L, Laffoon J F, Jakobsen J R 2000a Effect of altering the type of enamel conditioner on the shear bond strength of a resin-reinforced glass ionomer adhesive. American Journal of Orthodontics and Dentofacial Orthopedics 118: 288–294

Bishara S E, Vonwald L, Laffoon J F, Jakobsen J R 2000b Effect of changing enamel conditioner concentration on the shear bond strength of a resin-modified glass ionomer adhesive. American Journal of Orthodontics and Dentofacial Orthopedics 118: 311–316

Bouschlicher M R, Cobb D S, Vargas M A 1999 Effect of two abrasive systems on resin bonding to laboratory-processed indirect resin composite restorations. Journal of Esthetic Dentistry 11: 185–196

Bowen R L, Rodriguez M S 1962 Tensile strength and modulus of elasticity of tooth structure and several restorative materials. Journal of the American Dental Association 64: 378–387

Brosh T, Pilo R, Bichacho N, Blutstein R 1997 Effect of combinations of surface treatments and bonding agents on the bond strength of repaired composites. Journal of Prosthetic Dentistry 77: 122–126

Brown C R, Way D C 1978 Enamel loss during orthodontic bonding and subsequent loss during removal of filled and unfilled adhesives. American Journal of Orthodontics 74: 663–671

Dall'oca S, Papacchini F, Radovic I, Polimeni A, Ferrari M 2008 Repair potential of a laboratory-processed nano-hybrid resin composite. Journal of Oral Science 50: 403–412

Elekdag-Turk S, Isci D, Turk T, Cakmak F 2008 Six-month bracket failure rate evaluation of a self-etching primer. European Journal of Orthodontics 30: 211–216

Eminkahyagil N, Arman A, Cetinsahin A, Karabulut E 2006 Effect of resin-removal methods on enamel and shear bond strength of rebonded brackets. Angle Orthodontist 76: 314–321

Fischer-Brandies H, Monsees M 1993 [Enamel damage from multiple debonding in the bracket adhesion technic]. Fortschritte der Kieferorthopädie 54: 143–147

Fischer-Brandies H, Kremers L, Reicheneder C, Kluge G, Husler K 1993 [Enamel damage depending on the method of bracket removal]. Fortschritte der Kieferorthopädie 54: 64–70

Fitzpatrick D A, Way D C 1977 The effects of wear, acid etching, and bond removal on human enamel. American Journal of Orthodontics 72: 671–681

Frankenberger R, Kramer N, Sindel J 2000 Repair strength of etched vs silica-coated metal-ceramic and all-ceramic restorations. Operative Dentistry 25: 209–215

Gwinnett A J, Gorelick L 1977 Microscopic evaluation of enamel after debonding: clinical application. American Journal of Orthodontics 71: 651–665

Heravi F, Naseh R 2006 A comparative study between bond strength of rebonded and recycled orthodontic brackets. Dental Research Journal 2: 1–6

Kupiec K A, Barkmeier W W 1996 Laboratory evaluation of surface treatments for composite repair. Operative Dentistry 21: 59–62

Legler L R, Retief D H, Bradley E L 1990 Effects of phosphoric acid concentration and etch duration on enamel depth of etch: an *in vitro* study. American Journal of Orthodontics and Dentofacial Orthopedics 98: 154–160

Linklater R A, Gordon P H 2001 An *ex vivo* study to investigate bond strengths of different tooth types. Journal of Orthodontics 28: 59–65

Matos A B, Tate W H, Powers J M 2003 Influence of enamel surface preparation on composite bond strength. American Journal of Orthodontics and Dentofacial Orthopedics 16: Special Issue No: 37A–40A

Mattick C R, Hobson R S 2000 A comparative micro-topographic study of the buccal enamel of different tooth types. Journal of Orthodontics 27: 143–148

Millett D T, McCluskey L A, McAuley F, Creanor S L, Newell J, Love J 2000 A comparative clinical trial of a compomer and a resin adhesive for orthodontic bonding. Angle Orthodontist 70: 233–240

Montasser M A, Drummond J L, Evans C A 2008a Rebonding of orthodontic brackets. Part I, a laboratory and clinical study. Angle Orthodontist 78: 531–536

Montasser M A, Drummond J L, Roth J R, Al-Turki L, Evans C A 2008b Rebonding of orthodontic brackets. Part II, an XPS and SEM study. Angle Orthodontist 78: 537–544

Mui B, Rossouw P E, Kulkarni G V 1999 Optimization of a procedure for rebonding dislodged orthodontic brackets. Angle Orthodontist 69: 276–281

Ozcan M, Alander P, Vallittu P K, Huysmans M C, Kalk W 2005 Effect of three surface conditioning methods to improve bond strength of particulate filler resin composites. Journal of Materials Science: Materials in Medicine 16: 21–27

Ozcan M, Barbosa S H, Melo R M, Galhano G A, Bottino M A 2007 Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions. Dental Materials 23: 1276–1282

Perry A C 1980 Rebonding brackets. Journal of Clinical Orthodontics 14: 850–854

Powers J M, Kim H B, Turner D S 1997 Orthodontic adhesives and bond strength testing. Seminars in Orthodontics 3: 147–156

Pus M D, Way D C 1980 Enamel loss due to orthodontic bonding with filled and unfilled resins using various clean-up techniques. American Journal of Orthodontics 77: 269–283

Regan D, LeMasney B, van Noort R 1993 The tensile bond strength of new and rebonded stainless steel orthodontic brackets. European Journal of Orthodontics 15: 125–135

Reisner K R, Levitt H L, Mante F 1997 Enamel preparation for orthodontic bonding: a comparison between the use of a sandblaster and current techniques. American Journal of Orthodontics and Dentofacial Orthopedics 111: 366–373

Rosenstein P, Binder R E 1980 Bonding and rebonding peel testing of orthodontic brackets. Clinical Preventive Dentistry 2: 15–17

Shahdad S A, Kennedy J G 1998 Bond strength of repaired anterior composite resins: an *in vitro* study. Journal of Dentistry 26: 685–694

Tang A T, Bjorkman L, Lindback K F, Andlin-Sobocki A, Ekstrand J 2000 Retrospective study of orthodontic bonding without liquid resin. American Journal of Orthodontics and Dentofacial Orthopedics 118: 300–306

Zennyu T 1988 Effects of four rebonding procedures on *in vitro* tensile bond strength of four adhesives used on orthodontic brackets. Journal of Osaka Dental University 22: 111–129

Zentner A, Duschner H 1996 Structural changes of acid etched enamel examined under confocal laser scanning microscope. Journal of Orofacial Orthopedics 57: 202–209