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Comparative bond strength of new and reconditioned brackets and assessment of residual adhesive by light and electron microscopy

B. Wendl*, P. Muchitsch*, M. Pichelmayer*, H. Droschl* and W. Kern**
*Department of Clinical Orthodontics, University Dental Clinic and **Department of Chemical Technology of Organic Materials, University of Technology, Graz, Austria

Correspondence to: Dr B. Wendl, Department of Clinical Orthodontics, University Dental Clinic, Auenbruggerplatz 12, A-8036 Graz, Austria. E-mail: dr.b.wendl@tele2.at

SUMMARY An average rate of bracket loss of between 4.7 and 6 per cent is to be expected in daily clinical orthodontic practice during a typical 2 year treatment period. For reasons of economy, detached brackets are commonly reattached after sandblasting to remove adhesive, or replaced with used brackets reconditioned by specialist companies. In the present study, sandblasting and specialist bracket-reconditioning procedures were systematically compared by comparative shear testing of rebonded, reconditioned, and new brackets ($n = 160$) using light- and chemically cured adhesives. Statistical analysis was carried out with Kruskal–Wallis and Mann–Whitney tests.

The mean bond strength of reconditioned brackets was, in each case, lower than that of new brackets, with the lowest value obtained with sandblasted brackets. This nevertheless exceeded the minimum recommended value of 5–8 MPa. Bond strength was generally higher with chemically than with light-curing adhesive; the chemically curing adhesive provided bond strength on previously bonded enamel higher than the light-curing adhesive on intact teeth. Consistent with this, the results of the adhesive remnant index (ARI) demonstrated improved bonding with the chemically curing than the light-curing adhesive to the bracket base.

Despite resulting in a weaker bond strength compared with new brackets, sandblasting brackets accidentally detached during orthodontic treatment will generally allow effective reattachment to be achieved. Bond strength can be improved with the use of a chemically cured adhesive. Used brackets reconditioned by specialist companies provide a second alternative to new brackets and higher bond strengths than sandblasted brackets.

Introduction

Average rates of bracket loss of between 4.7 and 6 per cent are to be expected in daily clinical orthodontic practice for light- and chemically cured adhesives, respectively (for a 6 month treatment period; O'Brien *et al.*, 1989; Read and O'Brien, 1990). The frequency of bracket loss varies significantly according to the type of bracket used, the tooth being bonded, the treating orthodontist, and the eating habits of individual patients (Mizrahi, 1982; Kinch *et al.*, 1988). For example, bracket loss from incisors and canines is less frequent than from premolars. Bonding to maxillary canines moreover tends to be more successful than to those in the mandible (Mizrahi, 1982). The breaking surface is influenced by the bracket design and the type of adhesive (O'Brien *et al.*, 1988). The bracket/adhesive bond, which is mainly mechanical and proportional to the remaining undercuts and surface roughness, nevertheless remains the weakest connection (Faust *et al.*, 1978; Matasa, 1989; Surmont *et al.*, 1992).

For reasons of economy, detached brackets are commonly rebonded following sandblasting to remove attached adhesive. A second option is to employ used brackets that have been reconditioned by specialist companies. These procedures, however, leave variable amounts of adhesive on the bracket base, which could potentially reduce the strength of the new bond and lead to repeated loss of the bracket. Furthermore, bond strength is likely to be lower because the etching process penetrates the tooth to a depth of 28 m (Legler *et al.*, 1990) making complete removal of the adhesive unlikely with both hand and mechanical instruments (Oliver, 1991).

There is thus some uncertainty surrounding the reuse of brackets. The goal of the present study was to provide objective data to assist informed decision. To this end, sandblasting and specialist bracket reconditioning procedures were systematically compared by comparative shear testing of rebonded, reconditioned, and new brackets using light and chemically cured adhesives. In addition, the amount of residual adhesive/bracket damage caused by the reconditioning process was assessed using light and electron microscopy.

Materials and methods

The study was conducted using 80 healthy molar teeth extracted in the course of orthodontic or surgical treatment and obtained with informed consent from each donor. The teeth were stored in a 10 per cent formaldehyde solution at room temperature for several weeks prior to use. Four hours before use they were transferred into distilled water, cleansed with a non-fluoride-containing paste (pumice stone) and rubber cup for 15 seconds at low speed, rinsed with water (15 seconds), and dried with oil-free compressed air.

The enamel surfaces were etched for 30 seconds with 37 per cent phosphoric acid gel and rinsed for 30 seconds with water. The bonding agent, Scotchbond (3M Unitek, Perchtoldsdorf, Austria), was applied to the dry enamel surface.

Optimesh molar brackets (XRT 340-6807; Ormco Corporation, Glendora, California, USA) were bonded to the enamel surface using either Enlight LV, a light-curing adhesive (Ormco Corporation) or the chemically curing adhesive, Concise (3M Espe, Perchtoldsdorf, Austria) using the acid etch technique. To ensure reproducible debonding, a casting mould made of square stainless steel wire for bracket positioning with a bridge in the middle, which was fastened parallel to the casting mould surface (Figure 1) was constructed. Shear testing with the universal testing machine (Shimadzu Autograph, AGS-D-Series, 10 kND; Instron Corp., Canton, Massachusetts, USA) was performed at a feed rate of 0.5 mm/minute. Deformation of the bracket wings when shearing off was avoided by placing a square steel wire in the bracket slot. By aligning the vertical surfaces of the acrylic block and the mounting device of the machine, it was possible to transfer the achieved parallelism and to position the shear knife parallel to the seat of the bracket base. The knife was led up to the bracket base so that there was no lever action. Shear force was registered in Newtons and recorded as force per surface in megapascals (MPa). The shearing test was conducted 1 hour after bonding for all test configurations.

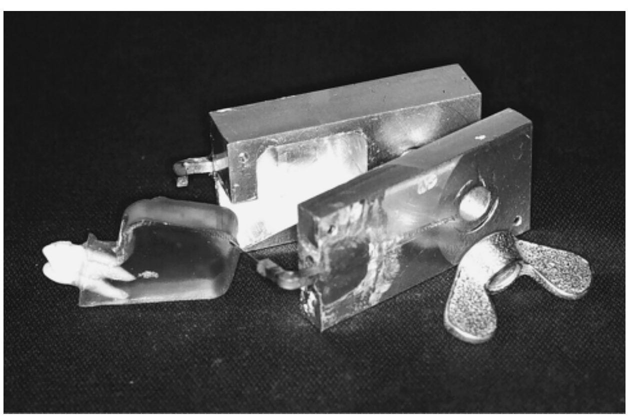

Figure 1 Casting mould with the test specimen.

Detached used brackets were either stripped of adhesive mechanically with a green stone followed by sandblasting (CoJet ™ System Set; 3M Espe) or reconditioned by one of two different procedures by specialist companies. The first of these was a cold solvent-based process (Ortho Clean International: Hamburg, Germany) and the second a solvent-free method, which employs a powerful laser to generate plasma at the interface between the carbon atom-containing adhesive and the bracket metal to trigger an exothermic process that heats the metal surface to approximately 200°C. As well as removing the composite from the bracket, this procedure can also 'etch' the bracket base, enabling micro-retentions to be formed during rebonding (Ortho Service, Verrières le Buisson, France).

A matrix study was performed to assess the effect of reconditioning on bracket bond strength with the chemical- and light-curing adhesives. Thus, new brackets and brackets reconditioned by each of the three procedures (10 teeth per group) were bonded to intact teeth (i.e. not previously bonded) and later to the teeth from which the brackets used for the intact section were recovered (rebonding), using chemically curing and light-curing adhesives, respectively. These teeth were stored in artificial saliva (Glandosane—cell-pharm, 16.749 Stada GmbH, Vienna, Austria) while the brackets were sent to the two reconditioning companies.

An atomic force microscope 3100 (Atomic Force F&E GmbH, Mannheim, Germany) was used to assess the adhesive residues and bracket base after reconditioning. To determine the adhesive remnant index (ARI), the brackets were examined under a stereolight microscope with a ×10 to ×66 magnification (Zeiss SV11; Carl Zeiss Corp., Göttingen, Germany).

The results were statistically evaluated using the Statistical Package for Social Sciences (SPSS Inc., Chicago, Illinois, USA). To compare the groups, Kruskal–Wallis and Mann–Whitney tests were used with a significance threshold of $P < 0.05$.

Results

An overview of the bracket bond strength data is provided in Table 1, which also contains the mean bond strength and standard deviation for each experimental group. Table 2 compares the results obtained with reconditioned brackets with those of new brackets.

Analysis using a Kruskal–Wallis test showed the differences between the groups to be statistically significant ($P = 0.010$). The reduction in bond strength associated with reconditioning was least for brackets serviced by Ortho Service, followed by Ortho Clean, with the weakest bonds obtained with sandblasted brackets. In Table 3, the data are presented in order to show the different bond strengths

Table 1 Overview of bond strength data (megapascals) for all experimental groups ($n = 10$).

Tooth surface	Curing	Brackets	Minimum	Maximum	Mean value	SD
Intact	Chemical	New	10.3	14.8	12.33	1.59
		Sandblasted	6.3	14.2	10.47	2.64
		Reconditioned (Ortho Service)	9.8	14.2	11.76	1.53
		Reconditioned (Ortho Clean)	7.5	14.0	10.96	2.12
	Light	New	8.1	13.9	10.99	2.06
		Sandblasted	6.6	13.9	9.38	2.08
		Reconditioned (Ortho Service)	7.0	13.4	10.73	2.29
		Reconditioned (Ortho Clean)	6.6	14.1	9.79	2.35
Rebonded	Chemical	New	8.9	13.4	10.95	1.61
		Sandblasted	8.4	12.5	9.66	1.35
		Reconditioned (Ortho Service)	7.9	15.2	9.98	2.04
		Reconditioned (Ortho Clean)	7.3	14.2	10.57	2.21
	Light	New	7.1	12.7	9.08	1.95
		Sandblasted	6.2	9.8	7.75	1.27
		Reconditioned (Ortho Service)	7.4	11.3	8.82	1.21
		Reconditioned (Ortho Clean)	6.6	9.8	8.09	1.11

Table 2 Bond strength (megapascals) and bracket reconditioning process ($n = 40$).

Brackets	Minimum	Maximum	Mean value	SD
New	7.1	14.8	10.838	2.098
Sandblasted	6.2	14.2	9.315	2.099
Reconditioned (Ortho Service)	7.0	15.2	10.323	2.056
Reconditioned (Ortho Clean)	6.6	14.2	9.853	2.229

Table 3 Bond strength (megapascals) on previously bonded and intact tooth surfaces ($n = 40$).

Tooth surface	Curing	Minimum	Maximum	Mean value	SD	*P*-value
Intact	Chemical	6.3	14.8	11.380	2.071	0.015
	Light	6.6	14.1	10.223	2.216	
Rebonded	Chemical	7.3	15.2	10.290	1.833	<0.001
	Light	6.2	12.7	8.435	1.472	

observed on teeth from which a bracket had been detached compared with non-bonded teeth ($P < 0.001$). The data confirm that rebonding to a previously bonded enamel surface creates a weaker bond than to an intact tooth surface. The reduction in bond strength due to rebonding was less marked with the chemically than the light-cured adhesive. This latter observation is shown more clearly in Table 4 in which the mean bond strengths obtained with the chemical and light-curing adhesives are compared.

Adhesive residues on reconditioned brackets and their general condition compared with unused brackets were assessed by electron microscopy. Representative photographs are shown in Figure 2. Minor adhesive residues were observed following both the Ortho Service and the Ortho Clean process procedures. For Ortho Clean treated brackets (Figure 2a), the residual adhesive was more 'bundled' in the bracket grid base, whereas following Ortho Service reconditioning (Figure 2b), this could be seen individually in the mesh of the bracket base. Grid fractures were observed for both the reconditioned and new brackets (Figure 2c).

Table 4 Bond strengths with chemical curing and light-curing adhesives ($n = 80$).

Curing	Minimum	Maximum	Mean value	SD
Chemical	6.3	15.2	10.835	2.019
Light	6.2	14.1	9.329	2.075

According to the Mann–Whitney test, there was a statistically significant difference ($P < 0.001$) between bond strengths with the chemically and light-curing adhesives.

Following bracket detachment, the distribution of adhesive between the tooth enamel and bracket base was assessed for each experimental group by determination of the ARI (Årtun and Bergland, 1984). In this study, a modification of the ARI (Oliver, 1988) was used. The results are shown in Table 5. Reconditioning had no apparent effect on the ARI. Clear differences were however observed between the two adhesive types. While chemically cured adhesive was fairly evenly distributed between the bracket base and tooth enamel, the light-cured adhesive remained largely attached to the tooth surface.

Discussion

For reasons of economy, brackets that are detached in the course of orthodontic treatment are commonly reattached following the removal of composite adhesive by

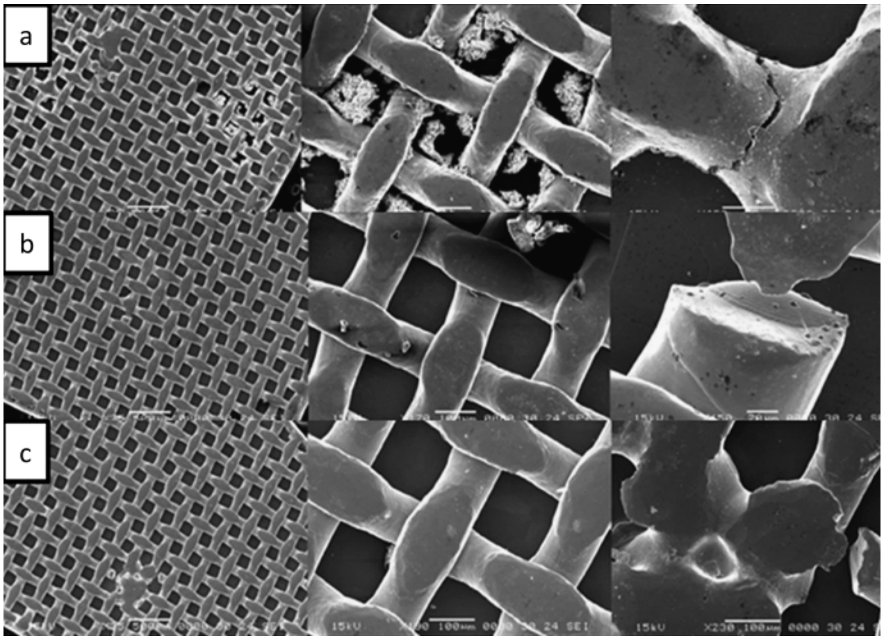

Figure 2 Evaluation of residual adhesive on reconditioned brackets by electron microscopy. (a) Ortho Clean reconditioned bracket, (b) Ortho Service reconditioned bracket, (c) new bracket.

Table 5 Adhesive remnant index (ARI) score with direct and indirect bonding using different adhesive coatings (V = no adhesive on enamel; IV = less than 10 per cent adhesive on enamel; III = less than 90 per cent but more than 10 per cent; II = more than 90 per cent but less than 100 per cent; I = 100 per cent adhesive on enamel).

	ARI				
	V	IV	III	II	I
Intact tooth surface					
Chemical-curing					
New		4	4	2	
Sandblasted		4	3	3	
Reconditioned (Ortho Service)		3	4	3	
Reconditioned (Ortho Clean)		4	2	4	
Light-curing					
New		1	3	6	
Sandblasted		3	3	4	
Reconditioned (Ortho Service)		2	3	5	
Reconditioned (Ortho Clean)		3	2	5	
Re-bonded tooth surface					
Chemical-curing					
New		4	3	3	
Sandblasted		3	4	3	
Reconditioned (Ortho Service)		2	4	4	
Reconditioned (Ortho Clean)		3	3	4	
Light-curing					
New		1	2	6	
Sandblasted		1	2	7	
Reconditioned (Ortho Service)		1	3	6	
Reconditioned (Ortho Clean)		2	3	5	

sandblasting. More generally, used brackets are retained after treatment, sent to companies offering specialist adhesive removal services, and then reused. The goal of the present study was to objectively evaluate the effectiveness of sandblasting and two specialist reconditioning methods using a standardized bracket debonding procedure to determine bond strength, and examination of adhesive residues by microscopy.

The mean bond strength of reused brackets was lower than that of new brackets, with the lowest value observed for the sandblasted brackets. Of the specialist-reconditioned brackets, those processed by Ortho Service showed the greatest bond strength. The relatively weak bond strength of sandblasted brackets was attributed to less effective composite removal. Despite this relative weakness, the mean bond strength nevertheless exceeded the minimum recommended value of 5–8 MPa (Reynolds, 1975), implying that this rapid and simple procedure will generally enable effective bracket reattachment within a treatment session.

The data also clearly show that the strength of bracket bonding to previously bonded enamel is generally lower than to intact enamel. Different instruments can be used to polish the composite remaining on the enamel surface after bracket detachment. Hand scalers are useful for rough excesses but will scratch the enamel surface (Burapavong *et al.*, 1978). Rotating instruments, such as green stones or diamond burs, can also damage the enamel (Retief and Denys, 1979).

Ultrasonic scalers are efficient but cause unacceptable damage to the enamel surface (Walmsley *et al.*, 1989).

Zachrisson and Årtun (1979) stated that no method allows complete adhesive removal, and when rebonding, they recommended extending etching time by 60 seconds and the use of a chemically curing adhesive to compensate for the presence of residual composite on the enamel. The present data are consistent with the latter recommendation. Bond strength was found to be generally higher with the chemically than with a light-cured adhesive. Most notably, the chemically curing adhesive provided bond strength on previously bonded enamel higher than that of light-curing adhesive to intact teeth. The results of the ARI study were consistent with this finding. According to Ødegaard and Segner (1990), the weakest bond of metal brackets is between the adhesive and bracket base and this is most pronounced for light-curing adhesive. The data demonstrated improved bonding of the chemically than the light-cured adhesive to the bracket base.

Examination of the specialist-reconditioned brackets by electron microscopy revealed minor adhesive residues and also grid fractures. These grid fractures were however also observed at a similar frequency in new brackets, implying that they were not caused by the reconditioning process.

Conclusions

A weaker bond strength compared with new brackets is achieved with sandblasted recycled brackets. However, brackets accidentally detached during orthodontic treatment will generally allow effective reattachment sufficient for orthodontic purposes. Bond strength can be improved with the use of a chemically cured adhesive. Brackets reconditioned by specialist companies provide a second alternative to new brackets and higher bond strengths than sandblasted brackets.

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