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Recycling effects on ceramic brackets: a dimensional, weight and shear bond strength analysis

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SUMMARY The present study investigated the effects of a recycling technique on orthodontic ceramic brackets by means of a scanning electron microscope analysis. The weight and dimension changes of brackets recycled one, five and ten times compared with new ones were evaluated. The results suggest that changes in weight (+4.27 mg), in buccal and base slot widths (–0.0013 inches), in slot depth (+0.0014 inches) and in the total bracket base area (+1.46 mm^2) are of little clinical relevance. The shear bond strengths of recycled versus new ceramic brackets were then evaluated and compared.

The mean values for new ceramic brackets and brackets recycled one, five and ten times were 15.52, 11.23, 10.10 and 10.04 MPa, respectively, indicating that recycled ceramic brackets provide shear bond strengths adequate for clinical use. Moreover, they exhibit bond failures mostly at the bracket/adhesive interface, without causing enamel damage.

Introduction

The aim of all orthodontic bracket recycling systems is to remove completely, with a short polishing stage, the adhesive from the bracket base without causing structural damage, in order to eliminate all the impurities related to the orthodontic treatment, so that the bracket can be rebonded to enamel, producing an adequate bond strength.

Since 1987, some companies have been offering a recycling service for ceramic brackets. The procedures used to recycle ceramic brackets are different from those used for stainless steel, but the methods employed have not been described in detail.

Many orthodontic manufacturers state that ceramic brackets are 'for single use only'. According to the instructions issued by GAC (GAC International, Inc., Commack, NY, USA), during debonding, ceramic microcracks could occur, causing the brackets to be broken, if recycled. Unitek (Unitek Corporation, Monrovia, CA, USA) state that ceramic bracket recycling would considerably decrease the bond strength.

Lew and Djeng (1990) described a simple chairside technique for recycling used (Transcend) ceramic brackets which involves heating the brackets to cherry red to burn off the adhesive from the bracket base. Once cooled to room temperature, the residual composite resin will turn chalky white and flaky, and can easily be removed by lightly scraping the base. The bracket is then rinsed with 100 per cent alcohol and left to dry. The bracket bases are then resilanized with a thin layer of porcelain primer, bonding the base to the adhesive system.

The purpose of this study was to evaluate the effectiveness of a ceramic bracket recycling procedure by analysing the weight, dimensions and shear bond strength changes of recycled ceramic brackets in comparison with the new ones, after one, five and ten recycling processes. The bond failures were also examined.

Materials and method

Ninety premolar ceramic brackets (Transcend 2000, Unitek Corp., Monrovia, CA, USA), conforming to a standard Ricketts technique (0.018 × 0.030 inch slot), were investigated in this study. They were bonded *in vitro* according to Lew *et al.* (1991), although a different adhesive system (Transbond, 3M/Dental Products Division, St Paul, MN) was used.

These brackets were bonded to 90 human

premolar teeth freshly extracted for orthodontic reasons and subsequently stored in normal saline at 4°C to prevent artefacts due to desiccation. Each tooth was embedded in a cylindrical acrylic block with its buccal surface exposed above the rim of acrylic and parallel to the face of the block. Cleaning of the tooth surfaces was carried out using pumice and water slurry in a rubber cup in a slow handpiece (Joseph and Rossouw, 1990; Wang and Lu, 1991). The enamel was then rinsed, etched with 37 per cent phosphoric acid for 60 seconds, rinsed with water for 30 seconds and subsequently dried with an oil-free air jet for 20 seconds. The brackets were then bonded using a light-cured resin (Transbond). The bonding material was applied strictly following the manufacturers' guidelines. The brackets were bonded under a constant force of 1.15 N and any excess material was carefully removed from around the bracket base before polymerization. Each bracket was exposed to polymerization light of 450 nm wavelength and 280 ± 5 mW/cm^2 (Heliomat H2, Vivadent, Schaan, Liechtenstein) with a 20 second burst to each of the mesial, distal, incisal and gingival margins. After bonding, all the samples were stored in normal saline at 37°C for 15 minutes before testing.

An Instron Universal Testing machine (Instron Corp., Canton, MA, USA) was used to perform the debonding test. The acrylic blocks were placed in the device and orientated so that the direction of force application was parallel to the buccal surface. A cross-head speed of 0.5 mm/minute and a load cell of 980 N were used. The samples were stressed to failure as described by Lew *et al.* (1991).

Since each recycled brackets group consisted of 20 brackets, the shear bond strengths of only 20 new brackets randomly selected were recorded in order to make comparison of groups with the same number of brackets.

After debonding, the brackets were divided into three groups of 30 units each: the groups were recycled for one, five and ten cycles, respectively.

The recycling procedure consisted of five steps. The brackets to be recycled were washed in a non-acid solution (Alpident Co., Villar Perosa (To), Italy) and then thoroughly dried. Alpident

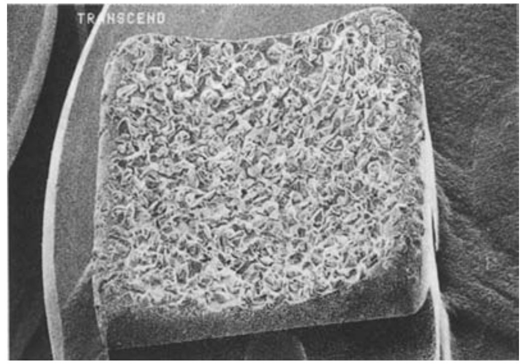

Figure 1 SEM of a new Transcend 2000 base (×20).

Co., like other companies, does not specify the composition of this solution. Also in several previous investigations carried out for other recycling methods (Buchman, 1980; Hixson *et al.*, 1982; Regan *et al.*, 1990) the composition of the solution was unknown and not specified. After drying, the adhesive burn-off was carried out at 350°C for 24 hours. The remaining inorganic filler was removed by washing the brackets twice in the non-acid solution. An ultrasonic polishing of the cleaned brackets was then performed for 20 seconds, followed by packaging. As is usually undertaken in the commercial procedure in order to eliminate risk of cross infection, recycled brackets were then sterilized at 250°C.

In addition to the 90 recycled brackets, 30 new ceramic brackets of the same type were used as a control group for comparison (Figure 1).

A precision balance (Sartorius, Type 1702, Germany) was used to perform the weight analysis of the new and recycled brackets. Each bracket was weighed five times and the mean value of these was used.

Ten new brackets and 30 recycled ones, 10 for each group, mounted on aluminium stubs, were later sputter-coated with 8 nm of gold/palladium and further examined under the Cambridge Stereoscan 200 scanning electron microscope (SEM). One of the features of the SEM is the possibility of creating two parallel lines which can be moved on the viewing screen for accurate measuring purposes. Therefore, the buccal and base slot widths, the slot depth and the bracket base area were measured by means of these

Table 1 Weight analysis of new and recycled brackets.

Sample	No.	Mean weight (mg)	SD	Weight variation (mg)
New	30	69.53	0.35	
One recycling process	30	71.83	0.43	+2.3
Five recycling processes	30	73.58	0.27	+4.05
Ten recycling processes	30	73.80	0.33	+4.27

Table 2 Analysis of variance (ANOVA) and Bonferroni's multiple comparison test (bracket weight).

ANOVA

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significance of *F* (*P* value)
Total	362.90	119.00	0.12	958.70	0.000

Bonferroni's multiple comparison test

Group	Mean difference	*t*	*P* value
1–2	–2.30	25.60	$P < 0.001$
1–3	–4.01	44.61	$P < 0.001$
1–4	–4.27	47.51	$P < 0.001$
2–3	–1.71	19.01	$P < 0.001$
2–4	–1.97	21.91	$P < 0.001$
3–4	–0.26	2.90	$P < 0.05$

Group 1: New ceramic brackets.
Group 2: Recycled ×1.
Group 3: Recycled ×5.
Group 4: Recycled ×10.

parallel straight lines, at ×130 magnification (buccal and base slot widths, slot depth) and at ×20 magnification (bracket base area).

The remaining 60 recycled brackets, 20 for each group, were rebonded to 60 freshly extracted human premolar teeth, according to the method previously described. After bonding, all the samples were stored in normal saline at 37°C for 15 minutes before testing.

An Instron Universal Testing machine was used to perform the debonding test according to the above method. The shear bond strength of each specimen was recorded. It was calculated as the force per unit area of bracket (MPa), using for the area the data in Table 5. Data collected were analysed by means of analysis of variance (ANOVA); when a statistically significant value was obtained, a multiple comparison analysis was performed. The alpha value was set at 0.05. The broken bracket-tooth assemblies were then examined with a light stereomicroscope (×10), in order to determine the type of failure. A representative sample was further examined by SEM.

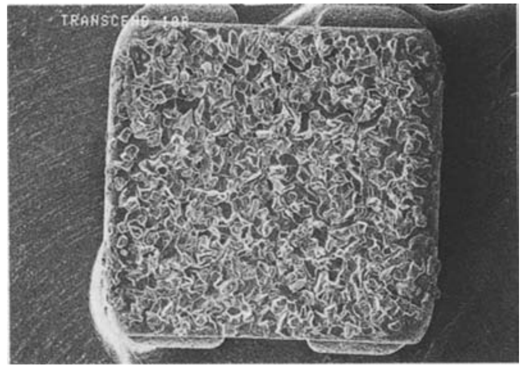

Figure 2 SEM of a bracket base recycled 10 times (×20).

Results

Weight analysis

The mean weight variation of brackets recycled one, five and ten times, compared with new ones, was +2.3, +4.05 and +4.27 mg, respectively (Table 1). Using ANOVA, significant differences among the four groups ($P < 0.001$) were found. Further analysis revealed that the weight of new ceramic brackets was significantly lower when compared with recycled brackets ($P < 0.001$) (Table 2).

SEM analysis

The recycled bracket scanning electron micrographs showed no residual adhesive in the retention system (Figure 2).

Table 3 lists the buccal and base slot widths, and the slot depth of the new and recycled brackets.

The buccal slot width changes of brackets recycled one, five and ten times, compared with

Table 3 Slot dimensions of new and recycled brackets.

Sample	No.	Mean buccal slot width (inches)	SD	Mean base slot width (inches)	SD	Mean slot depth (inches)	SD
New	10	0.0198	0.29	0.0194	0.31	0.0291	0.30
One recycling process	10	0.0193	0.36	0.0188	0.37	0.0296	0.38
Five recycling processes	10	0.0190	0.31	0.0186	0.40	0.0305	0.35
Ten recycling processes	10	0.0185	0.41	0.0181	0.43	0.0305	0.40

Table 4 Analysis of variance (ANOVA) results (slot dimensions).

Slot dimensions	Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significance of *F* (*P* value)
Buccal slot width	Total	0.000452	39	2.89	0.23	0.87
Base slot width	Total	0.000535	39	3.08	0.21	0.88
Slot depth	Total	0.000494	39	5.02	0.38	0.76

Table 5 Total bracket base area of new and recycled brackets.

Sample	No.	Total bracket base area (mm^2)	SD
New	10	9.06	0.34
One recycling process	10	10.03	0.37
Five recycling processes	10	10.51	0.42
Ten recycling processes	10	10.52	0.39

new ones, were –0.0005, –0.0008 and –0.0013 inches, respectively.

The base slot width changes of brackets recycled one, five and ten times, compared with new ones, were –0.0006, –0.0008 and –0.0013 inches, respectively.

The slot depth changes of brackets recycled one, five and ten times, compared with new ones, were +0.0005, +0.0014 and +0.0014 inches, respectively. The results of the analysis of variance for the slot dimensions are given in Table 4. No significant differences were found among the four groups ($P > 0.05$).

Table 5 lists the total bracket base area of the new and recycled brackets. The total bracket base area changes of brackets recycled one, five and ten times, compared with new ones, were +0.97, +1.45 and +1.46 mm^2, respectively. The results of the analysis of variance are given in Table 6 and showed no significant differences among the four groups ($P > 0.05$).

Table 6 Analysis of variance (ANOVA) results (bracket base area).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significance of *F* (*P* value)
Total	19.458	39	4.701	31.61	3.44

Shear bond strengths

The average shear bond strength variations of brackets recycled one, five and ten times, compared with new brackets, were –4.29, –5.42 and –5.48 MPa, respectively (Table 7).

The results of the initial analysis of variance, using bond strength (in MPa) as the dependent variable, are given in Table 8 and showed significant differences among the four groups ($P < 0.001$). The *post hoc* test (Table 9) revealed no significant difference between the bond

Table 7 Mean shear bond strength (MPa) of new and recycled ceramic brackets.

Sample	No.	Mean shear bond strength (MPa)	SD	Range
New	20	15.52	1.27	12.68–17.87
One recycling process	20	11.23	1.02	9.28–13.18
Five recycling processes	20	10.10	0.84	8.32–11.88
Ten recycling processes	20	10.04	0.95	8.22–11.86

Table 8 Analysis of variance (ANOVA) results (shear bond strength).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significance of *F* (*P* value)
Explained	316.459	3	105.486	100.69	0.000
Residual	74.379	71	1.048		
Total	390.838	74	5.282		

strength of brackets recycled five and ten times ($P > 0.05$), but the bond strength of new ceramic brackets was significantly higher when compared with recycled brackets ($P < 0.001$). However, the bond strength of recycled ceramic brackets was found to be greater than the value estimated by Reynolds (1975) to be adequate for clinical purposes.

Bond failures

The determination of bond failures was performed according to Hyer's classification (Hyer, 1989; Bordeaux *et al.*, 1994).

Recycled ceramic brackets, compared with new ones, failed mostly at the bracket/adhesive interface, showing no enamel damage after debonding (Table 10).

Table 9 Bonferroni's multiple comparison test for differences in shear bond strength between new and recycled ceramic brackets.

Group	Mean difference	*t*	*P* value
1–2	4.291	13.08	$P < 0.001$
1–3	5.421	16.53	$P < 0.001$
1–4	5.482	16.71	$P < 0.001$
2–3	1.13	3.44	$P < 0.01$
2–4	1.19	3.63	$P < 0.01$
3–4	0.06	0.183	$P > 0.05$

Group 1: New ceramic brackets.
Group 2: Recycled ×1.
Group 3: Recycled ×5.
Group 4: Recycled ×10.

Discussion

The ceramic bracket recycling procedure evaluated in this study consisted of two main steps: an adhesive burn-off stage, followed by an ultrasonic polishing stage.

As far as ceramic brackets are concerned, the use of heat is not a critical factor because it does not destroy the silica component of the bracket base and does not negatively influence the microstructure of the brackets, as detected by scanning electron micrograph examination, since the manufacturing process of ceramic brackets is performed at a high temperature (1800°C) (Swartz,1988; Laino and Cacciafesta,1994; Laino *et al.*, 1995).

However, the heating phase of the recycling process produces small changes in slot width and depth, and also in the total bracket base area, allowing a three-dimensional thermal expansion of the bracket itself. This is due to variations at the level of alumina intergranular spaces (Tables 3 and 5).

Table 10 Bond failures of new and recycled ceramic brackets.

Group	No.	Bracket/adhesive	Adhesive/enamel	Mixed	Enamel fracture	Bracket fracture
New (total sample)	90	34 (38%)	43 (47%)	5 (6%)	8 (9%)	0
New (representative sample)	20	8 (40%)	9 (45%)	1 (5%)	2 (10%)	0
One recycling process	20	10 (50%)	7 (35%)	2 (10%)	0	1 (5%)
Five recycling processes	20	11 (55%)	6 (30%)	2 (10%)	0	1 (5%)
Ten recycling processes	20	11 (55%)	6 (30%)	3 (15%)	0	0

The results of this investigation demonstrate that both the new and the recycled brackets showed a buccal slot width different from the base slot width, due to the manufacturing technique of using diamond burs and discs, which produces a countersunk slot.

As shown in Table 3, recycled ceramic brackets had a change in buccal and base slot widths no more than 0.0013 inches. Therefore, the three-dimensional increase in volume of the brackets caused the buccal and base slot widths to decrease in size proportionally, in response to the increased number of recycling processes.

Simultaneously, the slot depth changed no more than 0.0014 inches, exhibiting a small increase after five recycling processes. However, the recycled bracket slot changes were not statistically significant compared with new brackets ($P > 0.05$) (Table 4).

The amount of change in the bracket slot after ten recycling processes was thus also of little clinical relevance.

As depicted in Table 5, the total bracket base area of recycled ceramic brackets increased in size no more than 1.46 mm^2, showing no statistically significant increase after each recycling process ($P > 0.05$) (Table 6).

As listed in Table 1, recycled brackets were found to have a change in weight no more than 4.27 mg, exhibiting a statistically significant weight increase after the recycling processes ($P < 0.001$) (Table 2). The amount of weight variation, due to liquid absorption into the intergranular spaces after the adhesive burn-off, was clinically irrelevant.

The scanning electron micrograph comparison between new and recycled brackets suggests that the recycling procedure analysed was effective in providing brackets without microcracks and with a clean base surface, which closely resembles that of an unused base, as also reported by Lew and Djeng (1990). These results are in contrast to the manufacturers' recommendations, which claim that ceramic brackets are for single use only and would be damaged if recycled.

This study also evaluated the shear bond strength of both recycled and new ceramic brackets. The mean shear bond strengths of the new ceramic brackets and brackets recycled one, five and ten times were 15.52, 11.23, 10.10 and 10.04 MPa, respectively (Table 7). Although significantly lower ($P < 0.001$), the bond strength of recycled ceramic brackets was still high enough to be clinically acceptable, because it exceeds the recommended value of 60 kg/cm^2 (5.88 MPa) (Reynolds, 1975). Since the bond strength was calculated as the force per unit area of bracket (MPa), an explanation for these significantly lower shear bond strengths achieved with recycled brackets might be the increase in size of the total bracket base area after the recycling procedure.

Forty-five per cent of the new brackets failed mainly at the adhesive/enamel interface (Table 10), with most or all of the adhesive remaining on the bracket base (Figure 3). Two teeth exhibited marked damage of the enamel after debonding. On the contrary, recycled brackets showed bond failures mostly at the bracket/adhesive interface (55 per cent) with most or all of the adhesive remaining on the enamel surface (Figure 4). After recycling, the composite resin exhibited a stronger adhesion to enamel rather than to the ceramic brackets, thus allowing easy removal of the brackets without enamel damage. The different site of bond failure depended on

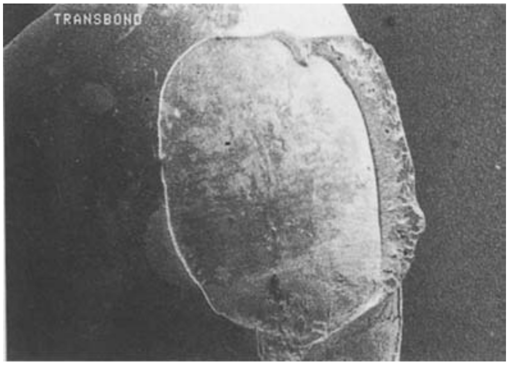

Figure 3 SEM of a specimen where debonding occurred at the adhesive/enamel interface (×20).

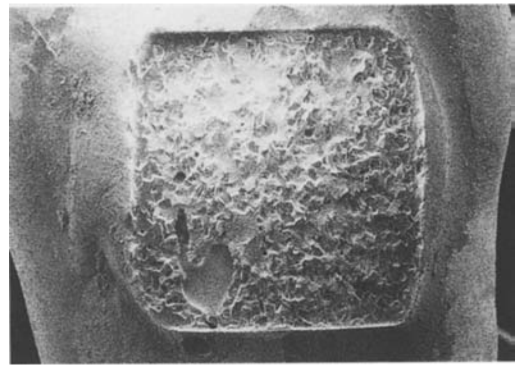

Figure 4 SEM of a specimen where debonding occurred at the bracket/adhesive interface (×20).

the reduced magnitude of bond strength of recycled brackets, as also reported by Lew *et al.* (1991). Considering the brittleness of ceramic brackets, it would appear to be a clinical advantage to have reduced shear bond strengths and most or all of the adhesive remaining on the tooth, rather than risk bracket fracture or enamel damage.

One criticism of the use of recycled products is that it may produce an increase in the risk of cross-infection. However, any contamination due to the previous use of a recycled appliance is limited as the recycling treatment effectively cleans and decontaminates the appliances (Buchman, 1980). Furthermore, most recycling companies now sterilize brackets after inspection and remarking, prior to packaging.

Conclusions

1. The change in weight of recycled ceramic brackets was statistically significant and amounted to no more than +4.27 mg.
2. Recycled bracket changes in buccal and base slot widths were no more than 0.0013 inches. The slot depth increased no more than 0.0014 inches, exhibiting no increase after five recycling processes. However, the slot changes were not statistically significant.
3. The amount of change in slot width and depth, after ten cycles, was of little clinical relevance.
4. The total bracket base area increased in size no more than 1.46 mm^2, showing no statistically significant change after recycling processes.
5. The shear bond strengths of recycled ceramic brackets were clinically adequate.
6. Recycled brackets failed mostly at the bracket/adhesive interface, without causing any enamel damage.

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