

The effects of reconditioning on the slot dimensions and static frictional resistance of stainless steel brackets

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SUMMARY This study investigated the effects of reconditioning on the slot dimensions and the static frictional resistance of stainless steel brackets at 0, 5, and 10 degrees bracket/archwire angulation. A sample of 45 used, commercially reconditioned 0.018×0.030 inch stainless steel standard edgewise brackets was compared with a matched sample of 45 new brackets.

The slot dimensions of 15 new and 15 reconditioned brackets were examined using a photomicroscope. With new brackets both the occluso-gingival slot width ($\bar{x} = 0.0197$ inch) and slot depth ($\bar{x} = 0.0304$ inch) exceeded the manufacturer's nominal dimensions of 0.018×0.030 inch. The reconditioning process resulted in a further increase in slot width ($\bar{x} = 0.0205$ inch), which was statistically significant ($P = 0.028$), and a reduction in slot depth ($\bar{x} = 0.0291$ inch), which was highly statistically significant ($P = 0.002$). This may be attributable to preferential metal removal by the electro-polishing phase of the reconditioning process.

Friction testing of 30 new and 30 reconditioned brackets demonstrated that both showed an increase in binding effects as the bracket/archwire angulation was increased from 0 to 5–10 degrees. However, the changes in slot dimensions secondary to reconditioning did not result in a statistically significant difference in mean static frictional resistance when the two bracket types were compared.

Although the brackets were altered physically by the reconditioning process, their performance during simulated sliding mechanics was not adversely affected. This implies that reconditioning may not result in clinically significant effects.

Introduction

The use of reconditioned orthodontic brackets on economic grounds remains a contentious clinical practice (Coley-Smith and Rock, 1997; Jones, 1999). It requires the clinician to be satisfied that there is no infection risk between patients and that the reconditioning process does not adversely affect bracket performance (Matasa, 1989; Postlethwaite, 1992; Coley-Smith and Rock, 1997). Whilst this practice may be considered as contributing to the conservation of planetary resources and, hence, 'green', there remains an ethical dilemma related to the clinical re-use of orthodontic materials. In the light of these issues, bracket manufacturers have employed a 'single-use' disclaimer on their products.

Where a clinician re-uses a product despite the manufacturer's specific warning against doing so, the clinician may be legally responsible for any adverse events resulting from this (Department of Health, 1995; Coley-Smith and Rock, 1997; Jones, 1999).

Jones (1999) commented that in implementing EU Directive 93/42/EEC (Medical Devices Directive), the Department of Health (1995) stated that medical devices labelled as 'single-use' should not be reprocessed and re-used unless the reprocessor:

1. Can observe all stringent technical requirements needed to ensure safety of each reprocessed item.

2. Can produce evidence of successful validation studies of the reprocessing method to confirm that the method produces a safe and effective product, fit for the intended purpose.
3. Has a system for retaining full reprocessing records, should problems arise later.

Despite this, a number of commercial companies offer processes that recondition orthodontic brackets by employing heat, chemical solvents, or both to remove adhesive material from the bracket base, often incorporating final electro-polishing (Postlethwaite, 1992).

The potential effects of reconditioning a bracket are dependent upon the type of process used, the type of steel from which the bracket is constructed, and the nature of the bracket base. Reconditioning may result in a reduction in base mesh diameter with a consequent reduction in shear and tensile bond strengths (Mascia and Chen, 1982; Wheeler and Ackerman, 1983; Wright and Powers, 1985; Postlethwaite, 1992). Heat or the inclusion of an electro-polishing phase may result in an increase in corrosion susceptibility, slot enlargement and base flattening (Buchman, 1980; Hixson *et al.*, 1982; Matasa, 1989; Postlethwaite, 1992). Electro-polishing may affect brackets with an undercut base by opening up the retentive undercuts and smoothing the base, leading to a decrease in retention, although the base may be restored by the addition of an etching process (Siomka and Powers, 1985; Smith, 1986; Regan *et al.*, 1990). The physical changes induced by the reconditioning of brackets may also include an alteration in slot tolerance (Buchman, 1980; Hixson *et al.*, 1982; Matasa, 1989; Postlethwaite, 1992), which has the potential to influence sliding mechanics by affecting frictional resistance.

Friction or binding may arise in orthodontics when malaligned brackets are engaged onto an archwire, during bodily tooth movement along an archwire (sliding mechanics) or when active torque is applied (Frank and Nikolai, 1980; Tidy, 1989). Friction produces resistance to movement such that 60 per cent of the applied force may be lost in overcoming friction (Drescher *et al.*, 1989). Friction or binding may also result in inhibition of tooth movement and tooth tipping

due to distortion of the archwire (Nicolls, 1968; Frank and Nikolai, 1980; Huffman and Way, 1983). Initially, static frictional resistance between the bracket and the archwire must be overcome in order to initiate tooth movement. Once movement has been initiated, kinetic frictional resistance must then be overcome in order to maintain constant movement (Bednar *et al.*, 1991). Kinetic frictional resistance is always lower than static frictional resistance (Kajdas *et al.*, 1990). The intermittent nature of tooth movement, often termed the 'stick-slip phenomenon', implies that static friction may have greater importance to orthodontists than kinetic friction (Omana *et al.*, 1992).

A number of fixed appliance features that may contribute to friction have been investigated. These include features such as bracket material (Kusy and Whitley, 1990a; Keith *et al.*, 1993; Vaughan *et al.*, 1995), bracket width (Nicolls, 1968; Andreasen and Quevedo, 1970; Frank and Nikolai, 1980; Drescher *et al.*, 1989), and slot size (Kapila *et al.*, 1989; Tidy, 1989; Kusy and Whitley, 1999). Studies have investigated the effects of archwire material and size (Andreasen and Quevedo, 1970; Frank and Nikolai, 1980; Kusy *et al.*, 1988; Tidy, 1989), and the interactions of bracket and archwire, especially bracket/archwire angulation (Andreasen and Quevedo, 1970; Drescher *et al.*, 1989; Dickson *et al.*, 1994; Ogata *et al.*, 1996). Also investigated have been the effects of ligation force (Edwards *et al.*, 1995; Read-Ward *et al.*, 1997) and the state of lubrication of the system (Kusy *et al.*, 1991; Tselepis *et al.*, 1994; Vaz, 1995). From the standardization of a series of influencing factors, laboratory-based friction testing enables individual or groups of variables such as these to be investigated. Their comparative contributions to sliding retardation can be determined under pre-determined conditions.

In a review of the medico-legal implications of the re-use of orthodontic materials, Jones (1999) proposed that laboratory trials should be undertaken to determine whether the properties of a product would be affected by sterilization and re-use. The aim of this study was to assess dimensional changes in the bracket slot resulting from the commercial reconditioning of stainless

steel orthodontic brackets and to investigate any consequent effects on the static frictional resistance.

Materials and methods

Ninety stainless steel maxillary central incisor brackets (Ultratrim[®], Dentaaurum, Pforzheim, Germany) with 0 degree angulation and torque, and nominal slot dimensions of 0.018×0.030 inch, were used for testing. Forty-five new, unused brackets were compared with 45 used brackets that had been reconditioned by a commercial company (Orthodontic Reconditioning Company, New Orleans, USA). The process utilized by the company involves the use of a chemical solvent to remove adhesive remnants followed by electro-polishing. Brackets are sterilized and a quality assurance process removes damaged or distorted brackets.

Fifteen new and 15 reconditioned brackets were examined with a Wild M400 photomicroscope (Wild Heebrugg Limited, Heebrugg, Switzerland) to determine differences in slot dimensions, whilst 30 new and 30 reconditioned brackets were exposed to friction testing. Central incisor brackets were used since the flat surface of the bracket base facilitated mounting of the brackets into a custom-made jig used for friction measurement (Figure 1). The archwires used in this study were 0.016 inch diameter stainless steel, supplied as straight lengths (Remanium[®], Dentaaurum, Pforzheim, Germany), each of which carried the same production batch number and so had been subjected to similar manufacturing conditions.

Measurement of slot width and depth

Fifteen new and 15 reconditioned brackets were mounted with their sides uppermost on glass slides. This permitted the slot to be viewed from end-on such that both the occluso-gingival slot width and slot depth could be measured without moving the bracket. The brackets were viewed under a Wild M400 photomicroscope at a magnification of $\times 10$. A graduated eyepiece was used together with a micrometer attached to the

microscope stage, which permitted direct linear measurements to be taken.

Measurement of static frictional resistance

Thirty new brackets and 30 reconditioned brackets were tested against 0.016 inch diameter stainless steel wire at 0, 5, and 10 degrees of angulation. Each bracket was mounted in a testing jig (Figure 1), which consisted of a frictionless piston, to which an axial tensile force could be applied by a Universal Load Testing Instrument (Instron, High Wycombe, UK) such that sliding movement of the archwire relative to the bracket could be achieved. The mount was capable of rotation on set-up, allowing the angulation between the bracket slot and wire to be adjusted to 0, 5, or 10 degrees as required.

Before use, all brackets and archwires were de-greased with acetone and air dried before being soaked in an artificial saliva solution, Saliva Orthana[™] (Nycomed, Birmingham, UK) for 24 hours to permit maximum surface adsorption of lubricant (Vaz, 1995). The test archwire was placed into the jig and pre-tensioned using a 1 kg mass before being locked into position. The archwire was then seated into the bracket with the ligation force standardized at 100 g. The angulation of the bracket slot to the wire was adjusted to 0 degrees, or rotated to 5 or 10 degrees as required utilizing a pointer and mounted protractor. The assembled jig was then placed into the jaw grips of the Instron Universal Load Testing Instrument ready for measurement.

Immediately prior to a test run, the bracket/wire assembly was bathed liberally in Saliva Orthana[™]. The Instron Universal Testing Instrument was calibrated, balanced, and set to zero prior to each run. When the Instron started its run, the grips moved apart causing the bracket to slide relative to the archwire. Each run was over a distance of 0.2 mm, with a cross-head velocity of 0.5 mm/min. Each bracket/wire combination was tested only once. The Instron generated a force/displacement graph, the initial peak of which represented the force required to commence movement of the bracket and was inferred as being the static frictional resistance.

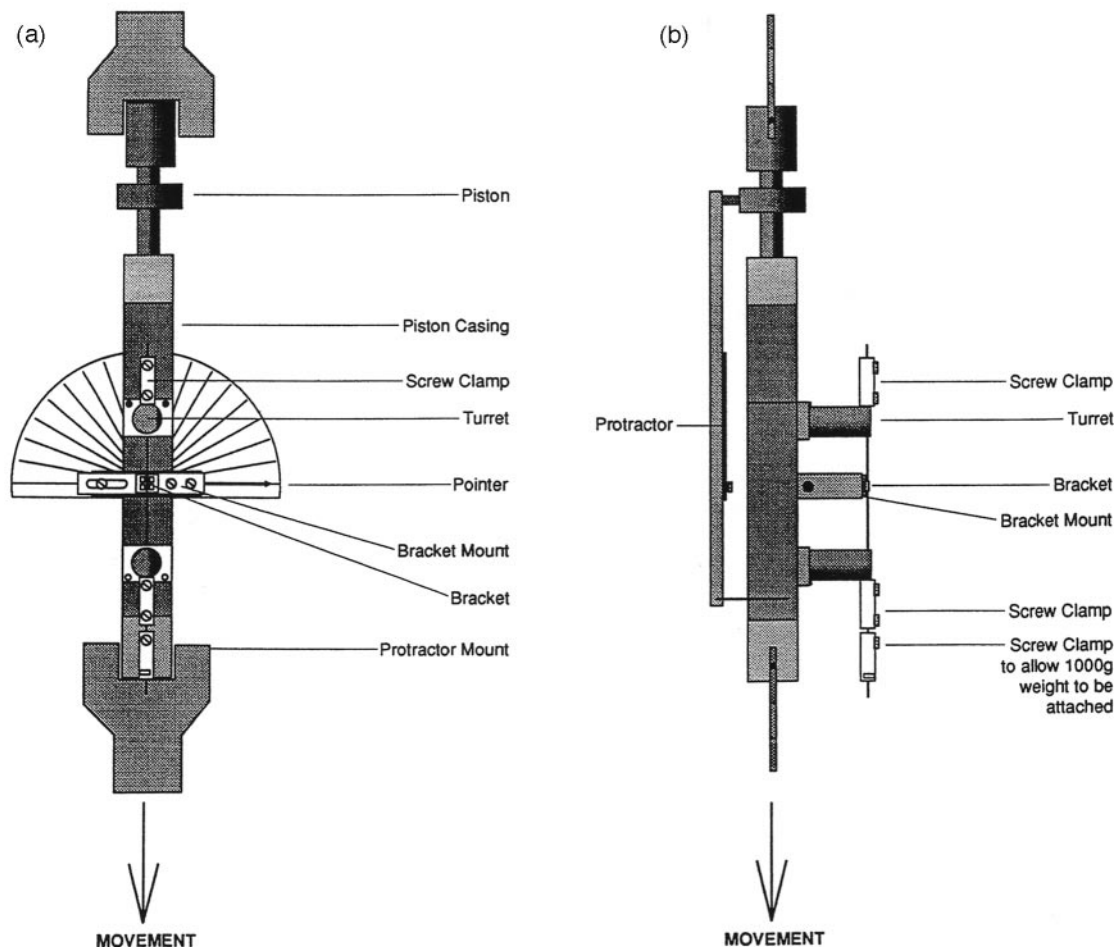


Figure 1 Diagrams illustrating (a) anterior and (b) lateral views of the friction testing jig. (Reproduced, with kind permission, from Read-Ward *et al.*, 1997.)

Results

Measurement of slot width and depth

Data from the photomicroscope are presented in Table 1. Mean values in millimetres plus standard deviation for both slot width (occluso-gingival dimension) and slot depth were recorded together with the 95 per cent confidence intervals. Data were normally distributed and so the means were compared using the unpaired Student's *t*-test, to determine whether the mean slot dimensions for new and reconditioned brackets were significantly different.

Measurement of static frictional resistance

The static frictional resistance data from the Instron machine when sliding brackets against 0.016 inch wires are presented in Table 2. Data were recorded for both new and reconditioned brackets at 0, 5, and 10 degrees of angulation. Since the data proved to be non-parametric, the Mann-Whitney *U*-test was used to compare mean static frictional resistances of both new and reconditioned brackets at each of the 0, 5, and 10 degrees of angulation. This permitted the effect of reconditioning to be investigated for a given bracket/archwire angulation.

Table 1 Slot width and slot depth data in millimetres (mm) for new and reconditioned brackets showing mean, standard deviation (SD), 95 per cent confidence interval, and significance levels from unpaired Student's *t*-tests (*n* = 15).

	Bracket	Mean (mm)	SD	95% confidence interval	<i>t</i> -value	<i>P</i> -value
Slot width	New	0.4990	0.0290	0.4829–0.5151	2.31	<i>P</i> = 0.028
	Reconditioned	0.5197	0.0189	0.5092–0.5302		
Slot depth	New	0.7707	0.0197	0.7597–0.7816	3.49	<i>P</i> = 0.002
	Reconditioned	0.7390	0.0290	0.7230–0.7550		

Table 2 Static frictional resistance in Newtons (N) for new and reconditioned brackets at 0, 5, and 10 degrees of angulation showing mean, standard deviation (SD), 95 per cent confidence interval, and significance levels from Mann–Whitney *U*-tests (*n* = 30).

Bracket	Angle (°)	Mean (N)	SD	95% confidence interval	<i>P</i> -value
New	0	0.3879	0.1878	0.3178–0.4580	<i>P</i> = 0.07 (NS)
Reconditioned		0.4879	0.2171	0.4068–0.5689	
New	5	1.0229	0.3112	0.9068–1.1391	<i>P</i> = 0.06 (NS)
Reconditioned		0.8832	0.3455	0.7542–1.0121	
New	10	2.3349	0.2356	2.2470–2.4228	<i>P</i> = 0.49 (NS)
Reconditioned		2.2948	0.1881	2.2246–2.3650	

The Kruskal–Wallis test was used to determine the effect of changing angulation from 0 to 5–10 degrees for each individual bracket type. Where a significant difference was noted, further analysis was carried out to determine which of the mean values were responsible for the significant differences between the groups. This analysis compared the differences between mean ranks and the critical difference. This permitted the effect of changing angulation to be investigated for a given bracket type.

Discussion

This study did not seek to address the morality or ethics of bracket reconditioning and the clinical re-use of materials. Its aim was to evaluate whether reconditioning affects the physical structure of brackets and their subsequent frictional performance. This is in line with the suggestions by Jones (1999) in a review of the legal position relating to the re-use of materials. In the light of the guidelines from the Department of Health (1995), this unit does not use

reconditioned brackets clinically. The test sample of reconditioned standard edgewise brackets was obtained from the Orthodontic Reconditioning Company and matched against a sample of new, unused brackets.

Measurement of slot width and depth

The mean slot width of new brackets was 0.4990 mm (0.0197 inch), which exceeded the manufacturer's reported nominal size of 0.018 inch. This is in agreement with the findings of Sebanc *et al.* (1984) and Tan (1991), who suggested that this might be to ensure that a full size archwire can fit comfortably into the slot. The reconditioned brackets demonstrated a further increase in mean slot width to 0.5197 mm (0.0205 inch), which was statistically significant (*P* = 0.028). This is in agreement with Matasa (1989), who concluded that reconditioning resulted in metal removal and slot enlargement, although the clinical significance of this was questioned.

The mean slot depth of new brackets was 0.7707 mm (0.0304 inch), which marginally exceeded the manufacturer's nominal depth of

0.030 inch. The reconditioned brackets showed a reduction in mean slot depth to 0.7390 mm (0.0291 inch), which was statistically significant ($P = 0.002$). This suggests that reconditioning, and electro-polishing in particular, does not remove metal evenly from all surfaces of the bracket, preferentially removing more of the metal from the tie wings and less from the floor of the slot. This agrees with the findings of Buchman (1980) and Matasa (1989), who concluded that, in agreement with the laws of electro-deposition, the maximum metal loss with electro-polishing is exhibited on protuberances and not on recessed areas.

Measurement of static frictional resistance

Increasing the bracket/archwire angulation from 0 to 5–10 degrees resulted in increased static frictional resistance for both new and reconditioned brackets (Table 2). When these increases were analysed statistically, the Kruskal–Wallis test demonstrated a significant increase in static frictional resistance with increasing angulation ($P < 0.05$) as the critical contact angle was exceeded and binding was produced (Table 3). For both new and reconditioned brackets these changes were statistically significant when increasing the angulation from 0 to 5 degrees and from 5 to 10 degrees ($P < 0.05$). This increase in frictional resistance with increasing bracket/archwire angulation is consistent with the findings of previous studies (Andreasen and Quevedo, 1970; Drescher *et al.*, 1989; Dickson *et al.*, 1994; Ogata *et al.*, 1996). At these angulations, the increased frictional resistance is attributable to bracket binding

rather than true friction (Dickson *et al.*, 1994; Kusy and Whitley, 1999).

When the mean static frictional resistance of new and reconditioned brackets was compared with the bracket/archwire angulation standardized at each of the three test angulations (0, 5, and 10 degrees), there were no statistically significant differences attributed to reconditioning (Table 2).

Although it might have been expected that the smoothing effects of sliding wear of the slot base resulting from previous clinical use, together with the effects of electro-polishing by the reconditioning process, would have produced a reduction in frictional resistance, this was not demonstrated by this study. This may be explained by a number of factors. In a previous investigation, Keith *et al.* (1993) demonstrated no significant effects on frictional resistance as a result of sliding wear of the AISI type 303 stainless steel brackets used in this study. Furthermore, it has been suggested that a low surface roughness may not always be a major factor in reducing frictional resistance (Kusy and Whitley, 1990b; Kusy, 1991). Similarly, the electro-polishing phase of reconditioning may have resulted in minimal effects, since previous work suggests that the process appears to exhibit greater effects on bracket protuberances and lesser effects on the slot base (Buchman, 1980; Matasa, 1989).

Hence, this study demonstrated that whilst there were statistically significant changes to the bracket slot dimensions attributable to the reconditioning process, these effects did not result in deterioration in performance when *ex vivo* sliding mechanics were utilized. This implies that

Table 3 Kruskal–Wallis test results for new and reconditioned brackets with increasing bracket/archwire angulation showing mean rank positions, Chi-square values and significance levels ($n = 30$).

	Angulation			Chi-square value	P-value
	0°	5°	10°		
New	16.43	44.57	75.50	76.7359	$P < 0.05$
Reconditioned	20.60	40.43	75.47	67.8542	$P < 0.05$

reconditioning of brackets may not result in clinically significant effects on sliding performance.

Conclusions

The slot dimensions of new brackets exceeded the manufacturer's reported nominal dimensions. The mean slot width of unused brackets at 0.0197 inch was greater than the nominal size of 0.018 inch stated by the manufacturer. Similarly, the slot depth at 0.0304 inch marginally exceeded the nominal depth of 0.030 inch.

Reconditioning resulted in changes to the slot dimensions through preferential loss of metal. There was a statistically significant increase in slot width to 0.0205 inch ($P = 0.028$) and reduction in slot depth to 0.0291 inch ($P = 0.002$).

Both new and reconditioned brackets demonstrated an increase in static frictional resistance as the bracket/archwire angulation was increased from 0 to 5–10 degrees ($P < 0.05$). These increases were related more to bracket binding than true friction.

Despite the changes in slot dimensions, there were no statistically significant differences in static frictional resistance when reconditioned and new brackets were compared at each of the 0, 5, and 10 degree bracket/archwire angulations.

Although reconditioning results in physical changes to bracket structure, including an increase in bracket slot tolerance, this does not appear to result in a significant effect on *ex vivo* static frictional resistance.

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