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Office reconditioning of stainless steel orthodontic attachments

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SUMMARY An investigation was conducted to determine a simple, effective method for reconditioning stainless steel orthodontic attachments in the orthodontic office. In total, 100 new brackets were bonded to premolar teeth, then debonded and the bond strength recorded as a control for the reconditioning process. The debonded brackets were divided into six groups and each group reconditioned using different techniques as follows: attachments in four groups were flamed and then either (1) sandblasted, (2) ultrasonically cleaned, (3) ultrasonically cleaned followed by silane treatment, (4) rebonded without further treatment. Of the two remaining groups, one was sandblasted, while the brackets in the other were roughened with a greenstone. The brackets were rebonded to the premolar teeth after the enamel surfaces had been re-prepared, and their bond strengths measured.

The results indicated that sandblasting was the most effective in removing composite without a significant change in bond strength compared with new attachments. Silane application did not improve the bond strength values of flamed and ultrasonically cleaned brackets. Attachments that had only been flamed had the lowest bond strength, followed by those that had been roughened with a greenstone.

Introduction

Recycling orthodontic brackets is an option available to practitioners, either on an individual basis where brackets need to be rebonded back onto a tooth, or as part of a wider practice philosophy. Postlethwaite (1992) reported that as many as 75 per cent of American orthodontists were recycling their brackets in the early 1990s. The major advantage of recycling is the economic saving, which could be as high as 90 per cent, due to the fact that a single bracket can be reused up to five times (Matasa, 1989). Other advantages include a smoother, more corrosion-resistant bracket after electropolishing, and sterility as a result of the temperatures employed in the recycling process.

The disadvantages of recycling may include a reduction in bracket quality, loss of identification marks, lack of sterility and increased risk of cross-infection (Unkel, 1987). Commercial recycling, whether by heat or chemical means, leads to a degree of metal loss in certain areas of the bracket and a reduction in the diameter of the mesh strands (Mascia and Chen, 1982; Wheeler and Ackerman, 1983; Postlethwaite, 1992). Most investigators have reported a reduction in bond strength after commercial recycling, varying between 6 and 20 per cent (Wheeler and Ackerman, 1983; Wright and Powers, 1985), although this may be as high as 35 per cent for finer-meshed bases (Mascia and Chen, 1982). In 1986, as reported by Postlethwaite (1992), Smith found that there was no significant decrease in bond strength after the recycling process by two companies. There was, however, a significant decrease in the mesh wire diameter. This appears to be in agreement with Wheeler and Ackerman (1983), who reported that there was no correlation between the decrease in mesh wire diameter and bond strength.

Further criticism of commercial recycling is the long turnaround time of the process and the inability to recognize brackets that have been recycled more than once. Brackets are labelled for single use only, and there is the possibility of litigation as a result of the reuse of brackets (Di Pasquale, 1992a, b). In addition, commercially recycled brackets are more prone to corrosion, particularly brackets made from type 304 (AISI) stainless steel (Maijer and Smith, 1986).

To overcome the delays associated with commercial recycling, various chairside techniques have been developed. Roughening a debonded attachment with a greenstone has been reported to lead to a smoother surface devoid of undercuts (Regan *et al.*, 1993; Wright and Powers, 1985) and reduced the chemically active groups available for bonding (Davidson *et al.*, 1981). Brackets have also been flamed in a Bunsen flame (approximately 1200°C) for 3–5 seconds, quenched in water, sandblasted for 5–10 seconds to remove the remaining debris, then electropolished for 20 seconds (Buchman, 1980; Regan *et al.*, 1993). Regan *et al.* (1993) reported a 41 per cent decrease in the bond strength of flamed brackets, which was equal to the decrease seen with brackets that had been roughened with a greenstone only. Air abrasion has also been used to recondition debonded brackets; a bracket was held approximately 5 mm from the tip of a microetcher and etched with 90 μm aluminium oxide at 90 psi until all visible bonding material was removed from the bracket base. This usually took 15–30 seconds (Sonis, 1996). The results indicated no significant difference in the shear bond strengths of new and sandblasted brackets.

Various bond-enhancing agents have also been applied with a view to increasing bond strength. Siomka and Powers (1985) and Newman *et al.* (1995) found that the application of silane improved the bond strength of new meshed brackets by as much as 21 per cent. Silanation and etching together also led to an increase in bond strength. Certain bond enhancers, such as Enhance Adhesion Booster and Enhance LC (Reliance Orthodontic Products) failed to improve bond strength when debonded brackets had their composite bases roughened or sandblasted (Egan *et al.*, 1996; Chung *et al.*, 2000). All-Bond 2 (Bisco, Schaumburg) significantly increased the bond strength of sandblasted rebonded brackets, but did not increase the bond strength of new brackets (Chung *et al.*, 2000).

The objective of this study was to find a rapid office method of treating recently debonded brackets to produce clinically acceptable bond strengths with minimal changes in the physical properties of the brackets. This would be of clinical value where replacements are unavailable or expensive, and at the same time would avoid the delays associated with commercial recycling. An ultrasonic bath was included in some of the recycling processes where the brackets were flamed to burn off the composite material. The hypothesis was that removing the debris in an ultrasonic bath eliminated the need to sandblast the fragile mesh areas for long periods, thus preserving the undercut area for rebonding. Various reconditioning techniques were compared.

Materials and method

Human premolar teeth that had been stored in a weak thymol solution were cleaned of all debris, using pumice and a polishing lathe. The crown of each tooth was split vertically using a diamond disc and water coolant in order that both the buccal and lingual surfaces could be utilized. The teeth were then prepared for mounting in PVC plastic cups according to accepted techniques (Knoll *et al.*, 1986; Harris *et al.*, 1992). Undercuts were carefully prepared in the pulp chamber areas of each half using inverted conical burs in a slow handpiece in order to provide retention for mounting. The tooth section was then mounted in a PVC cup using self-curing acrylic resin, ensuring that the surface of the enamel projected at least 1 mm above the lip of the cup and the level of the resin. While the acrylic was curing, the PVC cup and teeth were kept submerged under water to minimize the effect of the exothermic curing reaction. Once set, flat surfaces were prepared in the enamel by wet grinding using 200, 400 and 600 grit silicon carbide paper (silicon carbide paper on a Metaserv Universal Polisher, Metallurgical Services, Betchworth, Surrey, UK) in order to create a standard flat surface for bonding. The ground surface of each premolar section was visually inspected under a stereoscopic microscope to verify that no dentine had been exposed, and that the surface was sufficiently wide to allow the brackets to be completely seated (Joseph and Rossouw, 1990; Harris *et al.*, 1992).

One hundred new lower incisor twin 0.018 inch stainless steel attachments (Mini Diamond Twin, 0 degrees torque and angulation, Ormco Corp., Glendora, California, USA) were bonded to the prepared surfaces. Prior to bonding, the teeth were polished using a pumice slurry, washed and then etched for 30 seconds using 35 per cent orthophosphoric acid. The etchant was removed by washing the tooth section under running tap water for 20 seconds. The tooth was then blow dried with uncontaminated air from a Chip syringe. The etched surfaces were then coated with Ortho-Concise (batch no. 19950707, 3M Unitek, Monrovia, California, USA) primer (liquids A and B mixed on a pad for 5 seconds), and then blown lightly with an air stream to disperse the primer evenly over the tooth surface. The two pastes of Ortho-Concise were mixed for 20 seconds and applied to the base of the bracket. The brackets were then placed onto the flat surfaces of the teeth, and seated using a Dontrix-Richmond intra-oral strain gauge (3M Unitek) that had been modified to apply 85 g of pressure. Excess adhesive was carefully removed using a hand scaler. The material was allowed to bench cure for 10 minutes.

The teeth were stored in sterile saline (0.9 per cent) for 4 days at 37°C. Thereafter the PVC cups were clamped in a universal testing machine (Instron Corp., Canton, Massachusetts, USA) and positioned such that the blade would strike in the tie wing groove, as described by Sonis (1996). The brackets were then subjected to shear in the occluso-gingival direction until failure. In order to express bond strengths in megaPascals (MPa; which equates to 1 N/mm^2), the average surface area of the brackets used was determined. This was undertaken by mounting 10 brackets under a high magnification video camera (Sony, Tokyo, Japan) linked to an IBM-compatible computer, which calculated the base surface area of each bracket, from which the average could be calculated. The mean base area was determined as 8.18 mm^2 (standard deviation 0.046 mm^2). Katona (1997) stated that bond strength is better described as shear peel rather than shear because the force applied acts through a moment arm to create tensile stress that tends to peel the bracket away from the tooth.

After debonding, the amount of adhesive remaining on the base of the bracket was observed under a stereoscopic microscope and scored using the Adhesive Remnant Index (ARI) (Årtun and Bergland, 1984). The index was modified (shown below) to be more sensitive, especially in the range where there was minimal residue on the bracket:

Score	Description
1	No adhesive on the bracket
2a	Less than 10 per cent of the base covered with adhesive
2b	Less than 25 per cent of the base covered with adhesive
3	25–50 per cent of the base covered with adhesive
4	50–75 per cent of the base covered with adhesive
5	75–100 per cent of the base covered with adhesive

The enamel tooth surfaces were reconditioned for rebonding by regrinding with the 200, 400 and 600 grit paper until no adhesive remained on the surface. The surfaces were again checked under a stereoscopic microscope.

Eighty-four of the brackets that had been debonded were recoated with Ortho-Concise, and bonded to a 3M mixing pad. Equal pressure was applied to each attachment as before. This procedure was undertaken in order to ensure that each bracket had identical amounts of composite adhering to the base prior to being subjected to a reconditioning technique. Once the material had set (after 10 minutes), the attachments were removed from the mixing pad and divided into six groups of 14 brackets each. The brackets in each group were then reconditioned using different techniques: group A, the brackets were flamed for 10 seconds until the base became red hot, then quenched in water, ultrasonically cleaned for 5 minutes and electropolished for 10 seconds; group B, the brackets had the remaining adhesive roughened using a greenstone bur in a slow handpiece until most of the residue had been removed; group C, the brackets were flamed for 10 seconds until the base became red hot, then quenched in water, ultrasonically cleaned for 5 minutes, electropolished for 10 seconds and treated with silane; group D, the brackets were flamed for 10 seconds until the base became red hot, then quenched in water, sandblasted for 10 seconds (50 μm aluminium oxide granules at a pressure of 4.5 bar) and electropolished for 10 seconds; group E, the brackets were flamed for 10 seconds until the base became red hot, then quenched in water and electropolished for 10 seconds; group F, the brackets were sandblasted for 15 seconds (50 μm aluminium oxide granules at a pressure of 4.5 bar) to remove all the adhesive from the mesh. The remaining 16 brackets were used in a corrosion experiment (not reported). The flow chart in Figure 1 illustrates the method used.

After the brackets had been reconditioned, each was randomly bonded to the enamel surfaces that had been re-prepared for bonding, using the same method as for the new brackets. The teeth were stored in saline at 37ºC for 4 days before the brackets were debonded, as described previously. Shear peel bond strengths were again recorded in MPa. The debonded brackets were inspected under a stereoscopic microscope, and the amount of adhesive remaining of the base scored using the modified ARI.

Results

The shear peel bond strength of new brackets acted as a baseline against which the bond strengths of reconditioned brackets could be measured. The mean shear peel bond strength of the new brackets was 7.78 MPa (standard deviation 1.33). The distribution of the adhesive remaining on the mesh bases is given in Table 1.

The bond strengths for the treated bracket groups A–F are recorded in Table 2. The bond strengths were compared with each other and with the bond strength obtained when new brackets were debonded (control). A statistical analysis was performed using a κ-sample Welch test, tested at the 95 per cent level of significance. The results of the Welch test were $F_{(5,35)} = 29.2$, $P < 0.05$ (Welch, 1951). The results of the statistical analysis are shown in Table 2. ANOVA was not performed, as the criteria were not met. Further details of the statistical analysis are given in the Appendix.

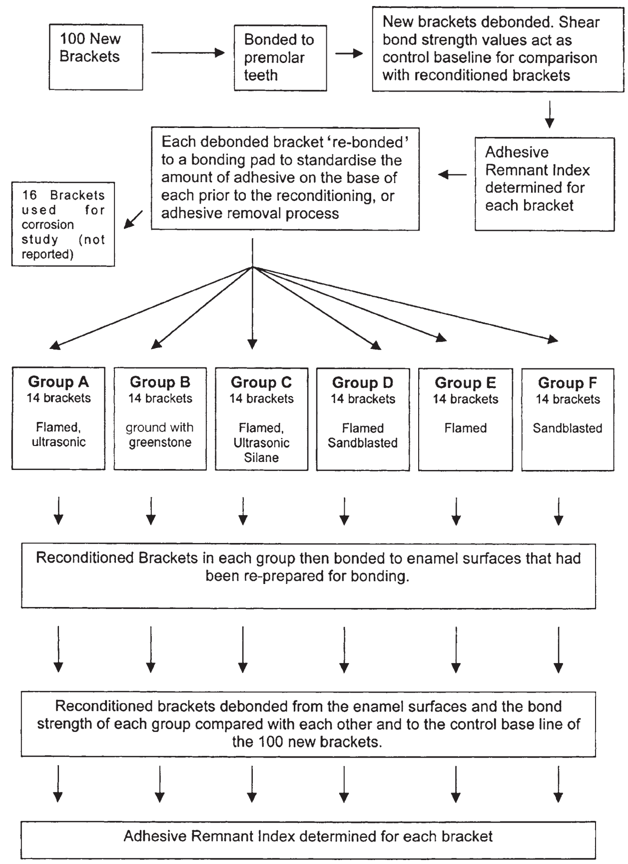

Figure 1 Flow chart to illustrate the methods used.

Discussion

This study examined the effect of ultrasonically cleaning flamed brackets in an attempt to dislodge residual char without resorting to sandblasting, which may abrade too much of the softer, annealed metal. Sandblasting alone, without flaming, was of concern in that the period of time needed to remove all the residual composite has been reported to be as long as 15–30 seconds (Sonis, 1996). It was felt that this was a relatively long period in which some of the valuable undercut area may have been abraded to such an extent that bond strength may have been compromised, although Sonis (1996) reported no significant difference in bond strength between treated and new brackets.

The results of the bond strength tests show that flamed, ultrasonically cleaned brackets had a significantly lower

Table 1 The amount of adhesive remaining on the brackets in groups A–F compared with the initial debond of new brackets (second column).

Modified ARI category	Control	Group A	Group B	Group C	Group D	Group E	Group F
1	17	2	0	0	1	3	0
2a	66	9	3	9	7	9	8
2b	15	3	11	4	4	1	3
3	1	0	0	0	0	1	0
4	1	0	0	0	0	0	1
5	0	0	0	1	2	0	2
Total number of brackets	100	14	14	14	14	14	14

ARI, Adhesive Remnant Index.

Table 2 Bond strengths (MPa) of the new brackets and reconditioned bracket groups A–F. The results of two-sample sign tests when each group was compared with the control are also shown.

	New brackets	Group A	Group B	Group C	Group D	Group E	Group F
n	100	14	14	14	14	14	14
Mean	7.78	4.24	4.61	4.72	7.37	2.71	7.28
SD	1.33	2.54	1.17	2.62	1.38	0.91	1.58
SEM	0.13	0.68	0.31	0.70	0.37	0.24	0.42
P-value		0.0002	0.000	0.0009	0.31	0.000	0.28

SD, standard deviation; SEM, standard error of the mean.

bond strength than new brackets, indicating either that flaming for 10 seconds was insufficient to combust all the composite, or that ultrasonically cleaning for 5 minutes was insufficient to dislodge the residue. Figure 2 shows residual char that remained on the composite after the reconditioned brackets had been debonded.

Scoring the amount of adhesive remaining on the base of the brackets after debonding, using the modified ARI, indicated that in the majority of cases the amount of adhesive on the base was in category 2b or less, i.e. less than 25 per cent of the base covered with adhesive. This illustrates that bonding between the adhesive and the tooth surface was adequate and that the primary failure site during the debonding process occurred at the base–adhesive interface.

It has been reported that the application of silane may increase bond strength by as much as 21 per cent (Siomka and Powers, 1985). The results of this study show that there was a slight, but not statistically significant, increase in bond strength of 11 per cent when silane was applied to the brackets that had been flamed and ultrasonically cleaned. However, the bond strengths for these brackets were still significantly lower than for new brackets.

The lowest bond strength recorded was for brackets that had been flamed only (group E), which significantly differed from new brackets and also from the group that had been roughened with a greenstone only (group B). The bond strengths of brackets treated with a greenstone (group B), flamed and ultrasonically cleaned (group A), as well as flamed, ultrasonically cleaned and with silane treatment (group C) were all in the same region of 4.2–4.7 MPa. In all these cases, the mechanical retentive areas were

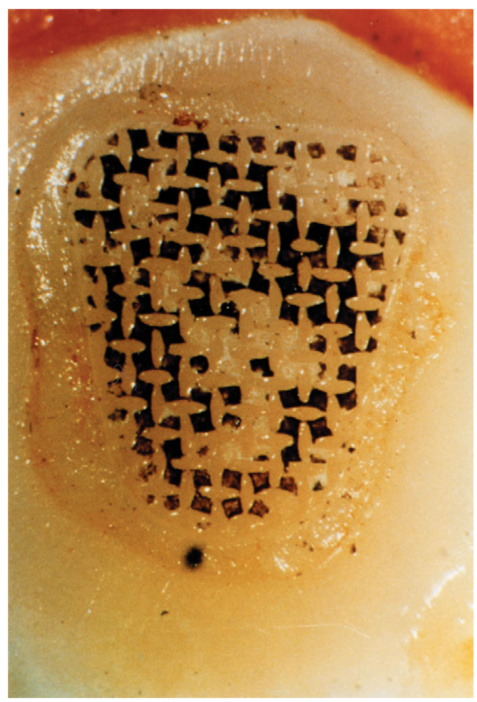

Figure 2 Composite remaining on the tooth after the bracket that was flamed and ultrasonically cleaned had been debonded, showing the char that remained (×20).

obstructed by material–composite in the case of roughened bases, and char in the case of the flamed brackets. The only brackets that did not significantly differ from the controls were those that had been flamed and sandblasted, and those that had been sandblasted only. This agrees with Sonis (1996), who found that air abrasion of the mesh did not significantly affect the shear bond strength, but differs from the findings of Regan *et al.* (1993), who reported a significant reduction in tensile bond strength by as much as 41.4 per cent following sandblasting. The time taken to sandblast the flamed mesh is shorter than that required to remove unburned composite. This study indicates that the mesh base of flamed brackets is sufficiently resilient to withstand sandblasting, and that the time required to remove unburned composite is not sufficient to compromise the bond strength. The disadvantage of burning off the composite is that the bracket discolours, unless it is electropolished afterwards. Furthermore, the metal is softened by the heating process, and is thus more vulnerable to masticatory damage.

Conclusions

The following conclusions can be drawn from this study:

1. Sandblasting flamed or unflamed metal mesh bases to remove composite residue had no significant effect on the shear peel bond strength.
2. Flaming alone led to significantly lower shear peel bond strengths that were even lower than those obtained when grinding the base with a greenstone only.
3. The effect of silane application to the brackets that had been flamed, ultrasonically cleaned and electropolished was not statistically significant, although there was an 11 per cent increase in the shear peel bond strength.
4. Flaming the bracket appears to provide no real advantage to the clinician, and probably can be eliminated as a chairside recycling method.
5. Sandblasting for a period of 15 seconds using 50 μm aluminium oxide granules at a pressure of approximately 4.5 bar was adequate to remove the residual composite without compromising bond strength. This study confirms sandblasting as the simplest, most efficient manner of immediately recycling debonded brackets.

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References

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

Buchman D J L 1980 Effects of recycling on metallic direct bond orthodontic brackets. American Journal of Orthodontics 77: 654–668

Chung C-H, Fadem B W, Levitt H L, Mante F K 2000 Effects of two adhesion boosters on the shear bond strength of new and rebonded orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 118: 295–299

Davidson C L, Duysters P P E, De Lange C, Bausch J R 1981 Structural changes in composite surface material after dry polishing. Journal of Oral Rehabilitation 8: 431–439

Di Pasquale T J 1992a Reconditioning and reuse of orthodontic devices. American Journal of Orthodontics and Dentofacial Orthopedics 102: 187–189

Di Pasquale T J 1992b Reconditioning and reuse of orthodontic devices. American Journal of Orthodontics and Dentofacial Orthopedics 102: 285–287

Egan F R, Alexander S A, Cartwright G A 1996 Bond strengths of rebonded brackets. American Journal of Orthodontics and Dentofacial Orthopedics 109: 64–70

Harris A M P, Joseph V P, Rossouw P E 1992 Shear peel bond strengths of esthetic orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 102: 215–219

Joseph V P, Rossouw P E 1990 The shear bond strengths of stainless steel and ceramic brackets used with chemically and light activated composite resins. American Journal of Orthodontics and Dentofacial Orthopaedics 97: 121–125

Katona T R 1997 A comparison of the stresses developed in tension, shear peel, and torsion strength testing of direct bonded orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 112: 244–251

Knoll M, Gwinnett A J, Wolff M S 1986 Shear strength of brackets bonded to anterior and posterior teeth. American Journal of Orthodontics 89: 476–479

Maijer R, Smith D C 1986 Biodegredation of the orthodontic bracket system. American Journal of Orthodontics and Dentofacial Orthopedics 90: 195–198

Mascia V E, Chen S 1982 Shearing strengths of recycled direct-bonding brackets. American Journal of Orthodontics 82: 211–216

Matasa C G 1989 Pros and cons of the reuse of direct bonded appliances. American Journal of Orthodontics and Dentofacial Orthopedics 96: 72–76

Newman G V, Newman R A, Sun B I, Ha J-L J, Ozsoylu S A 1995 Adhesion promoters, their effect on the bond strength of metal brackets. American Journal of Orthodontics and Dentofacial Orthopedics 108: 237–241

Postlethwaite K M 1992 Recycling bands and brackets. British Journal of Orthodontics 19: 157–164

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

Siomka LV, Powers J M 1985 *In vitro* bond strength of treated direct-bonding metal bases. American Journal of Orthodontics 88: 133–136

Sonis A 1996 Air abrasion of failed bonded metal brackets: a study of shear bond strength and surface characteristics as determined by scanning electron microscopy. American Journal of Orthodontics and Dentofacial Orthopedics 110: 96–98

Unkel T 1987 Recycling orthodontic products. Journal of Clinical Orthodontics 21: 871–872

Welch B L 1951 On the comparison of several mean values: an alternative approach. Biometrika 38: 330–336

Wheeler J J, Ackerman J R 1983 Bond strength of thermally recycled metal brackets. American Journal of Orthodontics 83: 181–186

Wright W L, Powers J M 1985 *In vitro* tensile bond strength of reconditioned brackets. American Journal of Orthodontics 87: 247–252

Appendix

In Table 2 there are substantial differences between the standard deviations of the groups. The important prerequisites for valid ANOVA are normality of the within-group distributions, and equality of the within-group variances. Of these, the latter is the more important, the F-test being reasonably robust against departures from normality. The so-called Bartlett test is a formal test of equality of the within-group variances. Applying it to the data in Table 2 gave an observed chi-squared statistic of 21.8 at 5 degrees of freedom, $P < 0.001$, so the hypothesis of equal variances was clearly rejected. Furthermore, there was no apparent correlation between the group means and the within-group variances, so that a variance stabilizing transformation, such as taking logarithms or using a Box–Cox transform was not applicable. However, if the evidence of the Bartlett test was ignored and ANOVA was performed, the result was $F_{(5.78)} = 14.10$, $P < 0.05$. A global test of equality of means, taking into account individual within-group variances, resulted in an observed approximate chi-squared statistic of 156.8 at 5 degrees of freedom, $P < 0.05$. Thus, according to both of the global tests, the hypothesis of equality of group means was clearly rejected.

Then, either by examining confidence limits for the individual group means, or by conducting pairwise comparisons, it was obvious that the means of groups A, B and C did not differ significantly from each other, nor those of groups D and F.

The mean of group E was significantly smaller than the rest, the means of groups D and F significantly greater. It was notable that the two ‘ultrasonically cleaned’ groups showed significantly large variances.