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The use of debonding microspheres in electrothermal debonding

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SUMMARY The aim of this study was to investigate if debonding microspheres (DM) could enhance electrothermal orthodontic debonding, and specifically to evaluate if the addition of DM, in varying concentrations to the orthodontic adhesive process, will affect bond strength.

Bovine teeth ($n = 8$) were mounted in acrylic using a silicone mould. Four test groups of three preparations of primer (Rely-a-Bond) with DM and a control were examined. Five incisor brackets were bonded to each tooth using the assigned primer and cold cure composite (Rely-a-Bond). Bracket tensile bond strength was measured *in vitro* in an Instron machine and recorded as debonding force (N). Differences between the groups were statistically analysed using analysis of variance, and repeatability was assessed.

The mean debonding force of the control group was statistically significantly greater than all the other groups to which DM had been added ($P < 0.001$). Comparison of the mean debonding forces of 1, 2.5, and 5 per cent concentrations of DM revealed no statistically significant difference between the groups.

The addition of DM to orthodontic adhesive produced a highly statistically significant reduction in debonding force. There was no statistical difference in debonding force between varying concentrations of DM.

Introduction

Traditional bracket debonding is achieved by applying a sufficiently large force to break the bond. The disadvantages of this technique include adhesive remnants being left on the tooth surface and potential enamel damage. Various alternative debonding techniques have been reported in the literature. Sheridan *et al.* (1986) defined electrothermal debonding as the controlled application of heat to the bracket bulk. This heat is transferred, in most cases, by a blade being placed in the bracket slot. The heat deforms the bracket–adhesive interface, melting the resin component of the adhesive. This leads to a reduction in the force required to remove the bracket, allowing debonding to be completed without excessive force (Sheridan *et al.*, 1986). Electrothermal debonding can reduce the force required for debonding by up to 50 per cent (Rueggeberg and Lockwood, 1990). Its advantages include a reduction in the incidence of ceramic bracket failure, a relatively short debonding time, and a minimal potential for enamel damage (Bishara and Trulove, 1990).

The risk of pulpal injury has always been the perceived drawback of electrothermal debonding (Jost-Brinkmann *et al.*, 1992) and has contributed to the lack of uptake of this practice. A number of studies have investigated the effect of electrothermal debonding on pulpal tissue. Lisanti and Zander (1952) have shown that teeth *in vivo* are capable of dissipating heat efficiently and all pulps showed healing despite temperature increases, although this research was carried out on dogs. Supporting this theory, it has been shown that electrothermal debonding *in vivo* does not produce any histological evidence of pulpal injury (Kraut *et al.*, 1991). Further research *in vivo* has demonstrated that minimal pulpal inflammation occurs without any loss or damage to odontoblasts (Jost-Brinkmann *et al.*, 1997). However that study had a small sample and only looked at short-term changes.

While the associated rise in temperature of the pulp appears to be within currently established biologically acceptable limits, additional research is required in this area before a definitive conclusion can be reached (Kearns *et al.*, 1997). The temperature human teeth can withstand before irreversible pulp damage occurs remains unknown (Crooks *et al.*, 1997).

Over the last 20 years, adhesives have been increasingly used in all areas of industry and manufacturing for bonding joints and layers at interfaces. Product research and development has concentrated mainly on the modification of adhesives to provide optimum performance on a wide range of material surfaces and in varying climatic conditions.

Debonding microspheres (DM) are manufactured gas polymeric copolymer drops, which can be added to an adhesive or mixed with any primer. They act as a catalyst for faster curing of adhesives. They not only contribute to strengthening the physical–chemical bond, but when an appropriate level of heat is applied, the microspheres debond by expanding to over 100 times their volume, acting as a pressure activator to cleanly break the bond at the interface.

DM are a commercial product and are used in many areas of industry. In car manufacturing, DM have been added to the adhesive used to fix windscreens. This has revolutionized the ability to remove the windscreens. When heat is applied to the margins of the windscreen where the adhesive lies, the bond is broken and the windscreen is simply lifted off saving time and clean-up costs.

Therefore, could the addition of DM to the primer used in the orthodontic bonding process allow electrothermal debonding to be clinically more effective? Prior to answering the above question, the effect of DM on the bond strength between the enamel, adhesive, and bracket needs to be investigated. There would be no clinical relevance of DM enhancing electrothermal debonding if brackets fail during a course of orthodontic treatment. Thus, the aims of this study were to investigate if the addition of DM to the adhesive system affects the bond strength of orthodontic brackets, and to determine if different concentrations of DM affect the bond strength of orthodontic brackets.

Materials and methods

Specimen preparation in vitro

A bovine upper jaw was obtained from a local abattoir. The animal was approximately 18 months old. The teeth were extracted using forceps and any attached periodontal tissue was removed. The criteria for tooth selection included teeth with intact buccal surfaces without voids, visible cracks, or fractures. The selected teeth were stored in deionized water to which a few crystals of thymol had previously been added to prevent bacterial and fungal growth. The teeth were stored in a refrigerator at 4°C for 1 week.

Mounting the specimens

A specially designed mould was constructed using silicone (Figure 1a). The mould consisted of four separate cylindrical holes each 15 mm in diameter. Each hole was filled with cold cure acrylic resin (Orthoresin, Degudent, Hanau-Wolfgang, Germany). Each bovine root was embedded into the acrylic up to its cementoenamel junction, leaving the labial crown exposed to facilitate bonding (Figure 1b). The crowns were positioned at 90 degrees to the ring of the mould. This specific method of mounting the teeth was adopted in order to co-ordinate with the jigs available for the Instron machine and to allow for accurate application of a tensile/peel debonding force.

The mould was placed in a hot water compressor (Palamat Practic, Heraeus-Kulzer, Hanau, Germany) at 55°C for 30 minutes to allow the resin to set. The mould was then removed from the compressor and allowed to cool. Once cool, each mounted tooth was removed from the mould.

Preparation of the primer solutions

Four bottles of primer (Rely-a-Bond, Reliance Orthodontic Products Inc., Itasca, Illinois, USA) were used to prepare the following solutions: group 1: primer (control), group 2: primer + 1 per cent DM, group 3: primer + 2.5 per cent DM, and group 4: primer + 5 per cent DM.

The primer for group 1 required no preparation, being the control. For groups 2–4, a weighing scale was used to measure the quantity of DM (De-Bonding Ltd, Tingley, Yorkshire, UK). A bottle of primer solution weighed 16 g. The correct volume of DM required for each solution was calculated from this weight. Once measured, the correct weight of DM was added to the bottle of primer and then shaken to mix.

Sample size calculation

A sample size calculation revealed that 10 brackets would be required per group in order to achieve results with a 95 per cent confidence interval.

Bonding

Five orthodontic brackets (Affinity MBT lateral incisor brackets 0.022 × 0.028 inches, Hawley Russell Ltd, Potters Bar, Hertfordshire, UK) were cemented to each of the eight selected bovine teeth. The manufacturer's instructions were followed for each material used. The teeth were etched, rinsed, and primed individually. A uniform thin coat of primer was applied with a disposable minibrush onto the etched area of enamel. The correct primer solution was applied in accordance to which group the teeth had been allocated. A small amount of no-mix chemical cure resin composite (Rely-a-Bond, Reliance Orthodontic Products

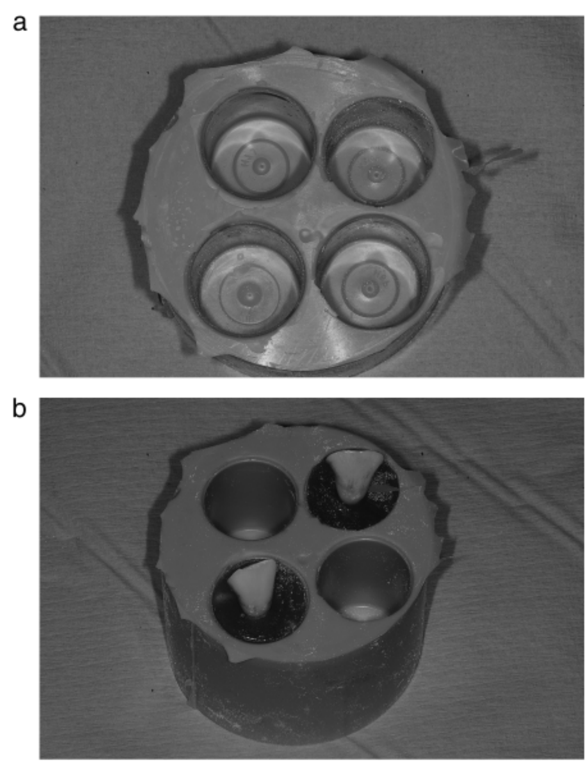

Figure 1 Silicone mould (a) and bovine teeth embedded in acrylic (b).

Inc.) was dispensed from a syringe onto the centre of the bracket base. The bracket was then carefully positioned onto the labial crown surface. This was repeated until five brackets were placed on each tooth (Figure 2). After bonding, the specimens were stored in fresh deionized water with thymol crystals at room temperature for 1 week.

Bond strength testing

All samples were tested in tensile mode with an Instron machine (LRX 2V5 Tensometer, Lloyd Instruments, Leicester, UK). The specimens were inserted into a steel cylindrical jig, which was screwed into the lower part of the Instron machine. Prior to testing of each bracket, the mould was positioned so that the bracket base lay at approximately 90 degrees to the upper part of the machine (Figure 3a). By positioning the bracket at right angles to the pulling force of the testing machine, a tensile force was created.

Tension was applied to the bracket samples via a 0.016 inch round stainless steel wire. The wire was fabricated as three loops, which were soldered together. The upper loop was attached to a machined hook, which was itself attached to the upper part of the Instron machine (Figure 3b). The two lower loops were positioned under the bracket wings (Figure 3c).

Tensile bond strength testing was carried out using the Nexygen software program (Ametek S.A.S, Elancourt, France) under a ‘pull to break test setup’. A crosshead speed of 0.5 mm per minute was selected as this speed has been recommended for consistency (Eliades and Brantley, 2000).

During testing, an increasing tensile force could be observed in graphical form on the connected monitor. Tensile bond strength values were calculated based on the peak load at failure. The tensile bond strength was recorded as debonding force in Newtons (N). Before each test, the machine was calibrated.

This complete method was repeated for one group (control) 1 month later to assess the repeatability of the technique. In order to keep all variables the same, the two bovine incisors to which the original control group brackets had been bonded were reused. A debonding bur in a slow handpiece removed any residual composite left on the enamel after the first test.

Results

A one-way analysis of variance was used to establish if the variations found in debonding force (N) between the groups were statistically significant (Table 1).

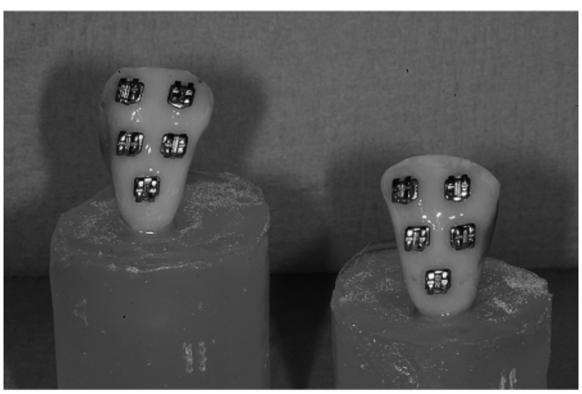

Figure 2 Five brackets bonded per tooth.

a

b

c

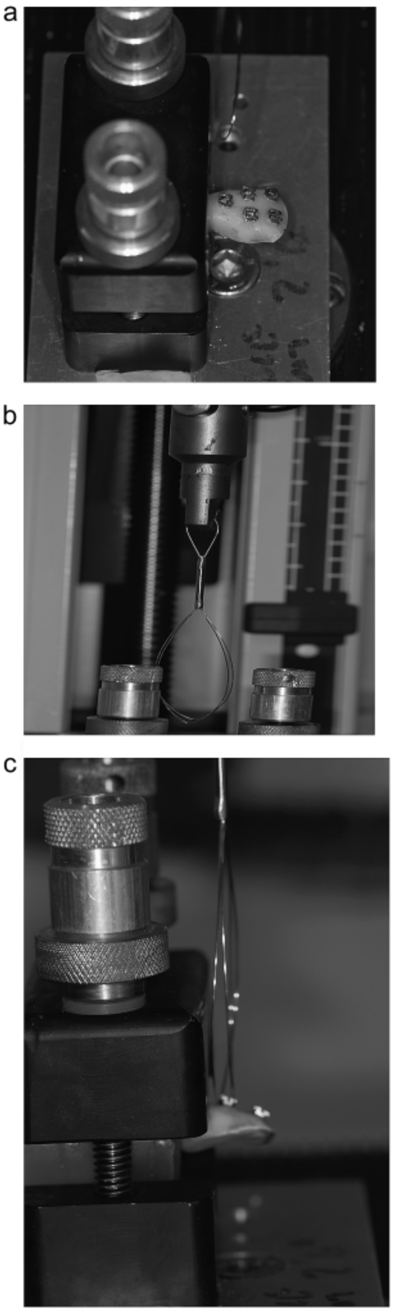

Figure 3 Tooth mounted in jig (a), wire loops (b), and wire loops engaging bracket wings (c).

The mean debonding force for the control group of 22.2 N was significantly greater than the other three groups (Figure 4). The three DM groups displayed similar mean debonding forces, ranging between 4.7 and 6.4 N. The control showed a normal standard deviation, but for the other three groups this was large (Table 1).

Repeatability

The repeatability data of 10 measurements of the control group carried out 1 month apart are shown in Table 2 alongside the original control group data. A scattergram (Figure 5) illustrates moderate agreement between the two sets of measurements.

A Bland–Altman test was conducted to determine any error associated with the method (Figure 6). The results indicate that there was a small amount of systematic error as the mean difference was 1.22 and not 0. However, this was not significant. There was an acceptable amount of random error with only one result beyond the 95 per cent limits of agreement.

Table 1 Results of analysis of variance [mean debonding force (N), standard deviation, and 95% confidence intervals (CI)]

Group	Mean debonding force (N)	Standard deviation	Lower bound 95% CI for mean	Upper bound 95% CI for mean
Control	22.2	2.7	20.2	24.1
1% DM	6.4	4.0	3.5	9.3
2.5% DM	4.7	3.0	2.6	6.8
5% DM	5.6	2.5	3.8	7.4

DM, debonding microspheres.

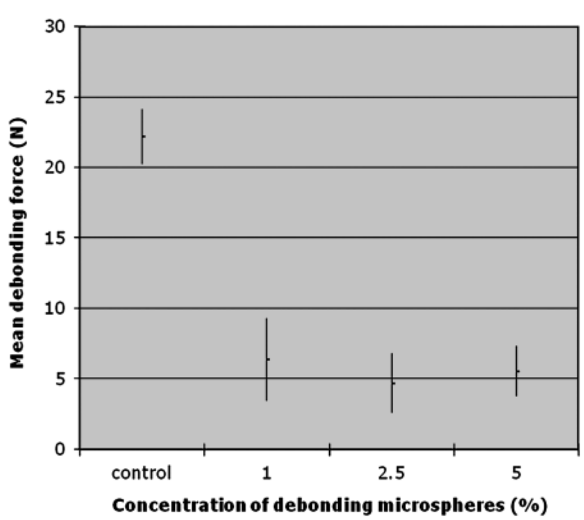

Figure 4 Histogram of mean debonding forces (N) with confidence intervals.

Discussion

Bovine teeth

The ideal material for this type of study would be human teeth; however, bovine teeth were used as a substitute. Multiple teeth were required for this experiment and it is difficult to obtain intact extracted human teeth for laboratory studies. Bovine teeth have been proven to be an acceptable substitute for human teeth in bond strength tests (Nakamichi *et al.*, 1983). They have the advantage of being easily attainable and possess a similar microstructure, both histochemically and anatomically, to human enamel. Nakamichi *et al.* (1983) found no statistically significant difference in enamel bonding values between bovine and human enamel, although the bovine values were all slightly lower.

A standardized bonding surface is needed to eliminate variations that might affect bond strength results. Bovine teeth provide more uniform samples than human teeth (Oesterle *et al.*, 1998). Human enamel surfaces show changes caused by exposure to saturated calcium phosphate in the saliva. A standardized surface is especially important

Table 2 Control group data—10 repeated measurements.

Bracket no.	Debonding force (N) Control—original data	Control—repeated data
1	23.4	26.2
2	25.8	22.0
3	25.0	24.0
4	19.4	23.2
5	17.5	17.3
6	21.8	20.5
7	21.2	18.3
8	24.9	16.4
9	22.6	19.8
10	20.0	21.9

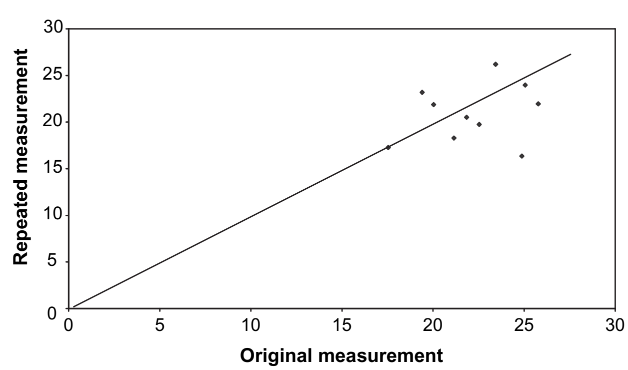

Figure 5 Scattergram demonstrating the extent of agreement between 10 repeated measurements of the control group.

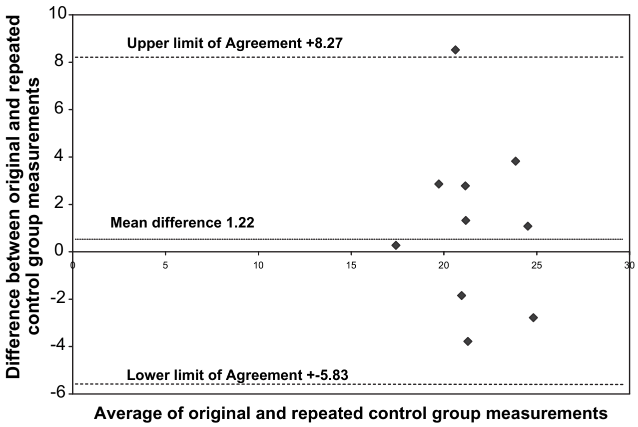

Figure 6 Plot of differences between the original and repeated control group measurements against the average of each measurement showing the 95 per cent limits of agreement.

when the relative difference between the results is more important than the absolute values as in this experiment (Oesterle *et al.*, 1998). For this reason, five brackets were bonded onto each tooth in order to minimize the number of surfaces utilized. To minimize variation further, the eight bovine teeth used came from the same animal.

A previous study has shown that bovine teeth can be reused for bonding studies multiple times with no significant degradation of bond strength (Oesterle *et al.*, 1998). Therefore, the same two bovine teeth were reused in the repeatability part of this experiment.

Use of chemical cure composite

Chemical cure composite was selected as the resin of choice for this experiment. It would not have been possible to use a light-cured system as during the addition of the DM to the primer, the primer would have been exposed to light, thus altering its properties. Light- and chemically cured composites have been shown to produce similar bracket failure rates (Sunna and Rock, 1998).

Use of jigs on the Instron machine

The use of jigs for *in vitro* bond strength testing helps to standardize the debonding process. Mounting and debonding the specimens is quicker and more consistent, and there is a reduction in the wide variations in results often seen during laboratory bond testing (Littlewood and Redhead, 1998). Therefore in this study, the bovine teeth were mounted in acrylic. Each mould was then placed securely in a jig before bond strength testing. The position of the mould was standardized prior to the testing of each individual bracket in order to achieve maximum standardization of the debonding process.

Bond strengths

The main finding of this experiment was that the addition of DM profoundly affected the debonding force of orthodontic brackets. The mean debonding force of the control group was statistically significantly greater than that of all three groups containing DM in the adhesive system ($P < 0.001$).

The second aim of this experiment was to investigate if different concentrations of DM affect the debonding force of orthodontic brackets. A concentration of 1 per cent DM resulted in the same reduction in debonding force as a concentration of 5 per cent. It would seem no matter how small a quantity of DM is mixed with the primer, bond strength is affected.

The findings concerning the clinical relevance of the results of any *in vitro* investigation carried out under standard laboratory conditions should be interpreted with caution. However, due to the highly statistically significant results ($P < 0.001$) in this study, there is a clear clinical relevance. It would not be feasible to bond brackets to human teeth if DM were added to the adhesive. The resultant reduction in bond strength would increase the risk of bracket failure during the course of orthodontic treatment.

The reason for the DM producing a profound reduction in the debonding force could be due to a disturbance in the chemical structure of the resin bond. DM either weaken or prevent the formation of a regular cross-link pattern that consolidates the bond. Fillers in composites are silane treated to ensure that a good bond is achieved between the filler particles and the resin. Without the silane coating, the fillers will act as defects and the properties of the composite deteriorate. If DM were to be silane treated, the results might be quite different. In summary, the simple addition of DM causes a reduction in the strength and toughness of the adhesive, which in turn causes a reduction in debonding force.

Repeatability

If any study using measurements is to be of value, it is imperative that error analysis is undertaken and reported (Houston, 1983). The Bland–Altman test revealed some systematic errors with a mean difference between the original and repeated control data at 1.22 and not 0. However, this discrepancy was minor as was the random error, confirming the consistency of the method described.

Conclusions

1. There is a highly statistically significant reduction in bond strength of orthodontic brackets when DM are added to the orthodontic adhesive system.
2. There is no statistical difference in the bond strength of orthodontic brackets bonded with varying concentrations of DM added to the adhesive system.
3. There is no clinical relevance of investigating the potential of DM enhancing electrothermal debonding, as brackets

bonded with adhesive containing DM would fail during the course of orthodontic treatment.

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