

The effects of sandblasting on the bond strength of molar attachments—an *in vitro* study

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SUMMARY This study evaluated the effect of sandblasting foil mesh molar tube bases on the shear bond strength obtained when bonding to first molar teeth. Fifty-two recently extracted first molar teeth were etched with 35 per cent phosphoric acid gel for 30 seconds. Twenty-six sandblasted 'A' Company molar tube attachments and 26 non-sandblasted attachments were then bonded to the teeth using Phase II orthodontic bonding resin. After storage in water for 24 hours at 37°C, the specimens were debonded in a direction parallel to the buccal surface.

Survival analysis using the Weibull function revealed that for a 90 per cent probability of survival, the predicted bond strengths for sandblasted and non-sandblasted bases were 1.76 and 1.66 MPa, respectively. For larger shear stresses, the probabilities of bond survival with sandblasted molar tubes were greater than with non-sandblasted molar tubes although the differences were small, which may be explained by the large proportion of bond failures which occurred at the resin to enamel interface in both groups. It was concluded that sandblasting foil mesh bases is likely to provide only a minimal improvement in clinical performance when bonding to molar teeth.

Introduction

Bonding of molar tubes rather than placing bands reduces plaque accumulation, with a consequent reduction in gingival inflammation and interproximal loss of attachment during treatment (Boyd and Baumrind, 1992). However, the reported higher failure rate of bonded molar attachments compared with banded attachments (Zachrisson, 1977; Gorelick, 1979) means that most clinicians still prefer to place bands on molar teeth. The high failure rate experienced with bonded molar attachments is likely to be due to many factors, including larger masticatory forces posteriorly in the mouth, problems with obtaining adequate isolation (Knoll *et al.*, 1986) and difficulty in obtaining an adequately etched enamel surface on molars (Johnston *et al.*, 1996).

Sandblasting has been shown to enhance resin bonding to gold, porcelain and amalgam (Zachrisson and Buyukyilmaz, 1993). Diedrich and Dickmeiß (1983) observed that sandblasting the bases of coarse mesh brackets produced an improvement in bond strength when using

unfilled resin, while Millett *et al.* (1993) found that sandblasting brackets reduced the probability of failure compared with a non-sandblasted sample when using glass ionomer cement.

As molar bonding appears to present a significant clinical problem due to a higher failure rate when compared with the use of molar bands it is important to evaluate any possible means of reducing the rate of failure. The present study assessed the effects of sandblasting molar buccal tube attachment bases on shear bond strength when using a filled composite resin bonding system.

Materials and methods

Fifty-two recently extracted first molar teeth were obtained from patients with a maximum age of 16 years. All the teeth included in the study had sound undamaged buccal surfaces and had been stored in distilled water at room temperature before use. The roots of the teeth were mounted in a base of acrylic resin

(Orthoresin, De Trey, Dentsply, Weybridge, UK) to facilitate positioning of the teeth in the debonding apparatus. To ensure that the debonding force was parallel to the mid-buccal surface, each tooth was mounted with the mid-buccal surface of the crown parallel to the long axis of the cylindrical acrylic base.

The enamel was cleansed with a prophyl brush and a plain pumice/water slurry. The teeth were then etched for 30 seconds with 35 per cent phosphoric acid (Ultra Etch viscous solution, Ultradent Products Inc.), washed for 20 seconds, and dried in an oil-free airstream. Fifty-two standard double convertible buccal tube attachments with foil mesh bases ('A' Company Orthodontics, San Diego, USA) were used in the study. Twenty-six molar tube bases were sandblasted using aluminium oxide (50 μm) for 3 seconds at 80 p.s.i. in a Micra 2 Sandblaster (Dentalfarm, Torino, Italy). They were then agitated in ethyl acetate for 3 minutes using a Sonorex RK102P ultrasonic cleaning bath, to remove any debris, and were allowed to dry before bonding. Teeth were randomly assigned to either the sandblasted or non-sandblasted group and bonding was carried out using Reliance Phase II dual cure filled resin (Reliance Orthodontic Products Inc., Itasca, Illinois).

The buccal tubes were bonded to the molars by one of the investigators (PFM) and excess resin was removed using a dental probe. The composite bond was allowed to cure at room temperature for 15 minutes. The specimens were then stored in distilled water at 37°C for 24 hours before bond strength testing.

Specimens were mounted by their acrylic bases in a mechanical testing machine (J J Instruments 2000S, Lloyds Instruments PLC, Fareham, UK) and the shear bond strength was tested by debonding the attachments using a cross-head speed of 1 mm/min with the force applied parallel to the mid-buccal surface using a wire loop below the bracket wings.

For each specimen the maximum load at failure was recorded, and the enamel and buccal tube attachment surfaces were examined using a magnifying glass at approximately five times magnification to determine the site of bond failure. The site of failure was classified as resin

to enamel, combined (a combination of resin-enamel and resin-attachment) or resin to molar tube base.

The failure stresses for the sandblasted and non-sandblasted groups were examined using a *t*-test, to compare the means, and Weibull analysis.

Weibull analysis

The data obtained for stress at failure were ranked within the sandblasted and non-sandblasted groups and the experimental values of probability of survival (P_{SE}) were calculated according to the equation:

$$P_{SE} = (N + 1 - n)/(N + 1)$$

where n = the number of specimen when ranked in ascending value, and N = total number of specimens per group (McCabe and Carrick, 1986)

The Weibull distribution predicts the probability of survival of a bonded attachment at a given stress using the equation:

$$P_s = \exp - (\sigma - \sigma_u / \sigma_o)^m$$

where P_s is the probability of survival, σ is the stress applied, σ_o is a constant known as the characteristic value, and m is the Weibull modulus, a constant (Ashby and Jones, 1988). σ_u is the threshold stress, the stress at which the first bond failure occurs. The value of σ_u was taken as zero as in theory there is no minimum stress at which failure may occur due to a poor bond or a defect within the resin.

If the equation is rearranged and natural logarithms are taken of both sides twice, the equation is that of a straight line: $\ln[\ln(1/P_s)]$ against \ln (stress at failure). The gradient of the line is m (the Weibull modulus) and the intercept with the y axis is $m \ln(\sigma_o)$.

To allow calculation of the predictive Weibull functions for the two experimental groups, Weibull regression lines were constructed by plotting $\ln[\ln(1/P_{SE})]$ against \ln (stress at failure) for each specimen. Correlation coefficients of the regression lines for the sandblasted and non-sandblasted groups were calculated, indicating the degree of fit of the Weibull function for each

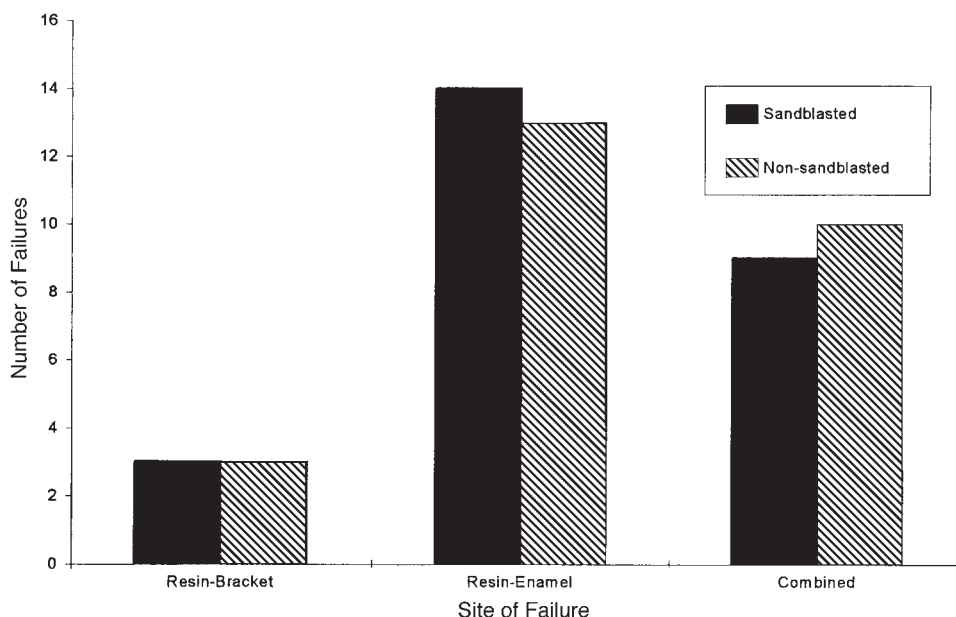


Figure 1 Observed sites of bond failure.

experimental group. The Weibull modulus (m) and the characteristic value (σ_0) were derived from the straight line gradients and y-axis intercepts as described above.

Results

The relative frequencies of the sites of failure are shown in Figure 1. Approximately half of the failures in each group occurred at the enamel-resin interface (13 cases in the non-sandblasted group and 14 in the sandblasted group), with combined failure (enamel to resin and resin to attachment base) being slightly less frequent. Failure occurring entirely at the resin to attachment interface was relatively uncommon (three out of 26 failures in each of the sandblasted and non-sandblasted groups).

Table 1 shows the mean and standard deviations for each group and also the results of the Weibull analysis. Comparison of the mean failure stresses for the two groups using a *t*-test revealed that the difference between the means was not statistically significant ($P = 0.147$). Using the Weibull modulus (m) and the characteristic value (σ_0), the functions predicting the probabilities of sandblasted and non-sandblasted molar tubes surviving a given stress are plotted in Figure 2. This allows the probability of survival for a sandblasted and non-sandblasted molar tube to be compared for any given stress. The Weibull modulus gives an indication of the reliability of the shear bond strength for each group, with a high value indicating a narrow distribution of results and a high level of reliability (Nkenke *et al.*, 1997). Thus, the non-sandblasted attachments

Table 1 Bond strength data and Weibull analysis.

Bracket Base	Range (MPa)	Mean (MPa)	SD (MPa)	Weibull Modulus m	Characteristic value σ_0 (MPa)	Correlation coefficient
Non-sandblasted	1.48–6.89	3.66	1.52	2.65	4.12	0.977
Sandblasted	0.73–10.05	4.42	2.18	2.01	5.09	0.967

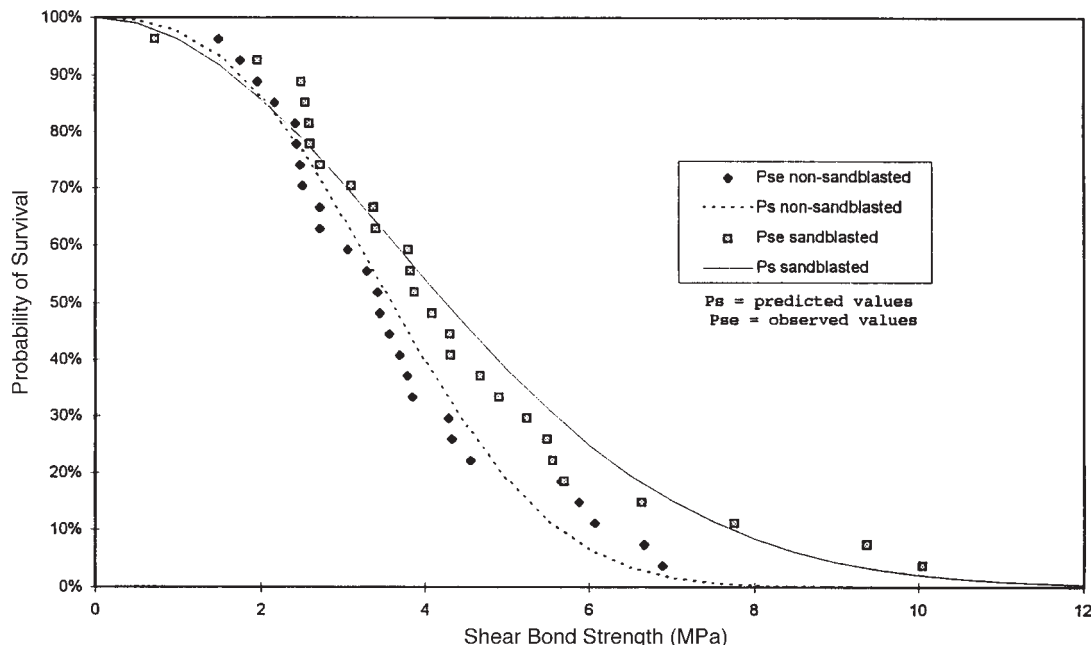


Figure 2 Probability of bond survival with stress.

had a narrower distribution of bond strengths than the sandblasted attachments, despite having a lower mean stress at failure (3.66 MPa compared with 4.42 MPa for the sandblasted attachments).

Discussion

In the current study the mean stress at failure for the sandblasted group was 4.42 MPa, compared with 3.66 MPa for the non-sandblasted attachments. While this difference was not statistically significant when examined using a *t*-test, comparison of the mean values of orthodontic bond strength data has been criticized by Fox *et al.* (1994), and it has been shown that the Weibull distribution is a more appropriate model for orthodontic bonding systems (Mitchell *et al.*, 1995; Nkenke *et al.*, 1997). The Weibull function takes into account the weaker values in the distribution which are important clinically, as even with a bonding system of high mean bond strength a proportion of bond failures will occur at lower forces.

Interpreting the Weibull analysis of the current study, the characteristic value for the sandblasted group (5.09 MPa) was greater than the non-sandblasted attachments (4.12 MPa). A higher characteristic value indicates a greater bond strength (McCabe and Walls, 1986). The results therefore indicate that sandblasting molar attachment bases increases the bond strength to molars with Phase II bonding resin. However, the lower Weibull modulus of the sandblasted group indicates a wider range of stress values at failure.

The probability of bond survival under typical orthodontic forces is important as this indicates how the bonding system is likely to perform in a clinical situation (Fox *et al.*, 1994). Keizer *et al.* (1976) suggested that a bond strength of at least 2.9 MPa is required to resist orthodontic forces, although Newman (1964) reported that 1.38 MPa was sufficient. With the molar attachment and resin combination evaluated in the current study, at a stress of 2.9 MPa as suggested by Keizer *et al.* (1976), the probability of survival was greater for sandblasted (72 per cent) than

for non-sandblasted attachments (67 per cent). For stresses greater than 2.9 MPa, the sandblasted attachments had a higher predicted probability of survival than the non-sandblasted group.

Further examination of the results (Figure 2) shows that for a 90 per cent survival probability (i.e. a 10 per cent probability of failure), predicted bond strengths for sandblasted and non-sandblasted attachments were similar at 1.66 and 1.76 MPa, respectively. This indicates that for a probability of survival of at least 90 per cent, there is minimal advantage in sandblasting molar tube attachment bases.

An unexpected finding of the current study was that a relatively large proportion of failures occurred between the resin and enamel. This may explain why the differences between the sandblasted and non-sandblasted groups in the Weibull analysis were small, as any differences in the resin to metal bond strengths between the two experimental groups will not have been apparent in the specimens which failed entirely at the resin to enamel interface. Previous *in vitro* studies have shown that the observed mode of failure is often inconsistent and the possibility of failure at several interfaces complicates the interpretation of debonding stress values. Wang and Lu (1991) observed failure at the resin to enamel interface in 32–40 per cent of their sample, while McSherry (1996) reported that 50 per cent of specimens debonded between resin and enamel. Reviewing 66 published *in vitro* bonding studies, Fox *et al.* (1994) reported that only 40 papers stated the mode of failure, with failure occurring at the resin to enamel interface or in a combined mode in 12 of these studies. Further investigations which include only the resin to metal interface in the experimental design would help to clarify the factors influencing resin to metal bond strength.

Bond failures involving the enamel to resin interface are undesirable clinically as the risk of enamel damage when debonding may be increased (Yapel and Quick, 1994). The observation of the high resin to enamel failure rate differs from the results of other studies which have used premolar teeth rather than molars. Nkenke *et al.* (1997) reported that the bond between the resin

and bracket base was the weakest link when using a variety of premolar brackets and bonding resins with bovine enamel. Studies using human premolars have also shown that bond failure of orthodontic attachments usually occurs at the bracket-resin interface or at the resin-enamel interface (Wang and Lu, 1991; Wang *et al.*, 1994), although McSherry (1996) reported that enamel to resin was the predominant failure mode when testing a variety of bonding resins on premolars. The enamel structure may be a factor in explaining the differences between the current results and those from premolar studies. The prismless enamel often present on the cervical two-thirds of molars is believed to be particularly difficult to etch (McLaughlin, 1986). Johnston *et al.* (1996) reported that the production of a good etch pattern on molars (assessed using scanning electron microscopy) required an etch time of longer than the 15 seconds commonly recommended for anterior teeth (Cartensen, 1986; Kinch *et al.*, 1988; Sadowsky *et al.*, 1990). The present study used an etching time of 30 seconds which has also been shown *in vitro* to produce higher shear bond strengths than a 15-second etch when using Concise resin on molar enamel (Johnston *et al.*, 1998).

An important consideration with regard to the high proportion of resin to enamel failures is the design of the experimental debonding apparatus and, in particular, the mode of force application used. There are several possible methods of force application which can be used in bracket debonding studies, including tensile, shear, and torsional tests. In a clinical situation, brackets may be subjected to varying combinations of archwire forces, occlusal forces from teeth in the opposing arch, and forces used when intentionally debonding brackets. A shear mode of force application can be used to model the effects of occlusal forces from opposing teeth, which have been suggested to be important in bracket bond failure on posterior teeth (Knoll *et al.*, 1986), and also to model the effects of orthodontic mechanics to move teeth vertically (i.e. extrusion and intrusion), or horizontally along archwires. However, with the wire loop in the experimental testing apparatus being placed below the wing of the buccal tube, there is a small distance between

the point of application of the debonding force and the enamel surface. This results in a 'peel' element in the debonding force (Fox *et al.*, 1994) due to a leverage effect, despite the force being applied parallel to the long axis of the tooth. This creates a stress concentration at the resin to enamel interface which increases the likelihood of failure at this site. In addition, the rigidity of molar tube attachments compared with premolar brackets means that they may be less likely to deform under loading with a wire loop which may also contribute to the concentration of stress at the resin to enamel interface rather than at the resin to metal interface. Nevertheless, the method of force application used in the present study is similar to clinical situations where occlusal and archwire forces may act on the buccal tube at a distance from the enamel surface, rather than directly at the enamel to resin or metal to resin interface. Investigations using different modes of force application to produce the maximum stress at the resin to metal interface may help to further assess the effects of sandblasting attachment bases.

Conclusions

For a predicted 90 per cent probability of bond survival, sandblasting provided only a minimal improvement in predicted bond strengths (1.76 compared with 1.66 MPa for non-sandblasted). At higher loading forces however, the difference in the probabilities of survival between the two groups became larger. Nevertheless, at a suggested typical maximum clinical loading of 2.9 MPa the probabilities of survival were poor in both groups (72 per cent for sandblasted and 67 per cent for non-sandblasted). Assuming that this previously suggested typical clinical loading of 2.9 MPa is realistic, a large number of failures would be expected during orthodontic treatment regardless of whether or not the bases were sandblasted.

A large proportion of observed failures occurred at the resin-enamel interface in both groups and indicates that, when using Phase II resin and sandblasted bases, the enamel to resin bond is often the weaker link in the system. The use of a shear mode of force application in the study may have increased the likelihood of a

resin to enamel failure by generating high tensile stresses at the resin to enamel interface, and may therefore partially explain why the difference in bond strengths between the groups was small. Although no visible enamel damage was observed in the study, the high incidence of resin to enamel failures may be of some concern as the potential for enamel damage during debonding could be increased.

Attempts to improve molar buccal tube survival under higher stresses by increasing the bond strength of resin to buccal tube bases appear to be limited by the strength of the resin to enamel bond. On the basis of the current results, sandblasting appears to offer some improvement in attachment survival rates on molars *in vitro* under shear forces. The difference is unlikely to be of clinical importance under shear loading conditions. Further studies are indicated to assess the frequency of molar attachment failure under other loading conditions and *in vivo*, and also to establish the bond strengths required to resist occlusal forces in the molar region.

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