An investigation into the bonding of orthodontic attachments to porcelain

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SUMMARY This study assessed bonding of orthodontic brackets to porcelain teeth using two different surface preparation techniques and comparing two bonding systems, Fuji Ortho L.C.™ and Transbond™.

Four groups of 20 porcelain premolar teeth were bonded with metal orthodontic brackets (0.022 inch Minitwin, 3M Unitek) according to the following protocol: Transbond™ with a phosphoric acid etch (group 1), Transbond™ with a hydrofluoric acid etch (group 2), Fuji Ortho L.C.™ with a hydrofluoric acid etch (group 3), and Fuji Ortho L.C.™ with a phosphoric acid etch (group 4). All groups were bonded with a silane coupling agent. The teeth were debonded with an Instron universal testing machine. Bond strength, site of bond failure and adhesive remnant index (ARI) were recorded for each group. Differences between groups were analysed statistically.

The composite resin groups (groups 1 and 2) had the highest mean bond strength values at 7.9 and 9.7 MPa, respectively. The resin-modified glass ionomer cement groups (RMGIC; groups 3 and 4) had the lowest mean bond strength values at 6.3 and 1.8 MPa, respectively. The mean bond strength of group 3 was significantly lower than all other groups ($P < 0.0001$). The Fuji groups had also significantly ($P < 0.001$) lower ARI scores than the composite groups (groups 1 and 2). Most samples experienced porcelain surface damage, except group 4.

In conclusion, the highest bond strength levels were achieved with a conventional composite resin cement (groups 1 and 2). No significant differences in bond strength were found between the hydrofluoric and phosphoric acid etch technique.

Introduction

Ceramic and metal-ceramic restorations are commonly used to restore damaged or missing teeth or to enhance the aesthetics of the natural dentition. With an increase in the number of adult patients undergoing orthodontic treatment, the likelihood of orthodontic bonding to these surfaces has increased (Kahn and Horrocks, 1991). Banding is an alternative but is considered aesthetically unacceptable, particularly with anterior teeth. When bonding to restored surfaces, adequate bond strength is desirable during treatment to minimize bracket failure. The brackets should also be easy to remove at the end of treatment to avoid damage to the restoration. In practice this can be difficult to achieve, with evidence of greater failure during treatment (Zachrisson, 2000) and damage to the restored surface on debond (Gillis and Redlich, 1998).

Techniques described previously for bonding brackets to porcelain surfaces vary in terms of the surface preparation technique and type of bonding agent used. The use of both phosphoric acid (Whitlock *et al.*, 1994) and hydrofluoric acid (Zachrisson *et al.*, 1996) preparation techniques have been described and would suggest higher bond strengths with hydrofluoric acid. However, there are concerns over possible toxicity and the protection required during clinical use. Studies have now confirmed that the use of a silane coupling agent significantly increases bond strength (Whitlock *et al.*, 1994; Bourke and Rock, 1999). It has been suggested previously that it is necessary to also roughen the porcelain surface mechanically prior to bonding (Bourke and Rock, 1999). Other studies have, however, shown that this is unnecessary and will lead to unacceptable damage to the porcelain surface (Messer *et al.*, 1991).

A number of different materials now exist for the bonding of orthodontic brackets; these include conventional light- and chemically cured composite resins cements. Studies have suggested that resin-modified glass ionomer cements (RMGIC) might also have suitable bond strengths for orthodontic bonding (Compton *et al.*, 1992; McCarthy and Hondrum, 1994) although surface etching with phosphoric acid has been shown to enhance bond strength (Larmour and Stirrups, 2001). In addition, it has been shown that brackets cemented with RMGICs will tend to fail at the enamel/resin interface (Larmour and Stirrups, 2001). This has the potential advantage of making clean up at debond easier and decreasing the risk of damage to the enamel or restored surface.

This study aimed to assess a currently available resin-modified glass ionomer adhesive (Fuji Ortho L.C.™,

G.A.C. Corporation, Tokyo, Japan) to determine its bond strength to porcelain using both hydrofluoric and phosphoric acid surface preparation techniques, and to compare this with conventional composite resin control groups (Transbond™, 3M Unitek, St Paul, Minnesota, USA). The null hypothesis tested was that there would be no difference in bond strength between the groups irrespective of bonding material or surface preparation technique.

Materials and methods

This study used porcelain denture teeth as the porcelain samples as described in previous studies (Newman *et al.*, 1984; Wood *et al.*, 1986). Eighty identical porcelain premolar teeth (Ivoclar-Vivadent, Leicester, UK) were divided randomly into four groups of 20 teeth. This is the minimum number recommended previously for laboratory bond strength testing (Fox *et al.*, 1994). They were mounted in polyester blocks with the long axis of each tooth vertical. A retentive wire extension was fabricated for each tooth to increase the retention in the polyester block. The teeth were then bonded with 0.022 inch pre-adjusted edgewise brackets (Minitwin™, 3M Unitek) using the following bonding techniques:

Group 1: The brackets were bonded with Transbond™ using 37 per cent phosphoric acid for 60 seconds and primed with a silane coupling agent according to the manufacturers' instructions. This group served as the control.
Group 2: The brackets were bonded with Transbond™ using 9.6 per cent hydrofluoric acid for 60 seconds and primed with a silane coupling agent according to the manufacturers' instructions.
Group 3: The brackets were bonded with Fuji Ortho L.C.™ using 9.6 per cent hydrofluoric acid for 60 seconds and primed with a silane coupling agent according to the manufacturers' instructions.
Group 4: The brackets were bonded with Fuji Ortho L.C.™ using 37 per cent phosphoric acid for 60 seconds and primed with a silane coupling agent according to the manufacturers' instructions.

Curing was carried out with a 20-second exposure to a blue light source (Ortholux 2™, 3M Unitek). The bonded teeth were stored in distilled water for 24 hours at 37°C before being debonded using a Universal Testing Machine (Instron Ltd, High Wycombe, Bucks., UK) as recommended previously (Fox *et al.*, 1995). Following debond, each tooth was examined under ×10 magnification and the site of bond failure recorded together with the Adhesive Remnant Index (ARI; Årtun and Bergland, 1984).

This index consists of the following scoring: 0 = no retained resin, 1 = <50 per cent retained resin, 2 = >50 per cent retained resin, and 3 = all resin retained with bracket imprint. The index was modified by including a score of 4 for samples with a damaged porcelain surface.

Results

The bond strength characteristics of the test groups are illustrated in Table 1. The composite resin groups (groups 1 and 2) had the highest mean debond values at 7.9 and 9.7 MPa, respectively. Group 4 (RMGIC/phosphoric acid) had the lowest mean debond value at 1.8 MPa. ANOVA (Table 2) and Tukey tests (Table 3) confirmed that the bond strength results of group 4 were significantly lower than all the other groups ($P < 0.0001$).

Table 4 shows the Weibull analysis of the test groups. The reliability of the material is a function of the Weibull modulus and normalizing parameter (characteristic strength). The data is presented graphically in Figure 1 and consists of the cumulative probability of bond failure plotted against applied load. The probability of bond failure at 7.9 MPa was calculated for each group as this was the mean debond force level required to debond the control group. The probability of bond failure was calculated at 55 per cent for group 1, 31 per cent for group 2, 61 per cent for group 3 and 100 per cent for group 4.

Table 1 Bond strength (MPa) values for test groups.

	Group 1	Group 2	Group 3	Group 4
Mean	83.4	103.2	66.3	18.7
Standard deviation	45.2	45.8	37.0	6.9
Standard error	10.1	10.3	8.3	1.6
Maximum value	155.7	178.5	126.2	34.5
Minimum value	13.4	11.4	9.4	6.7

Group 1 = Transbond/phosphoric acid (control); group 2 = Transbond/hydrofluoric acid; group 3 = Fuji/hydrofluoric acid; group 4 = Fuji/phosphoric acid.

Table 2 Analysis of variance between test groups.

	Sum of squares	Degrees of freedom	Mean square	F	Significance
Source of variation between groups	78305.2	3.0	26101.7	18.7	<0.00001

Table 3 Statistical comparison of bond strengths (Tukey).

| Means compared	Difference between means	Significance
Groups 1–2	19.8	Not significant
Groups 1–3	17.1	Not significant
Groups 1–4	64.7	<0.00001
Groups 4–2	84.6	<0.00001
Groups 4–3	47.6	<0.0001
Groups 2–3	36.9	<0.001

Details of the groups are given in Table 1.

Table 4 Weibull analysis of test groups.

	Weibull modulus	Normalizing parameter	Probability of failure (83N)
Group 1	1.74	94.32	0.55
Group 2	1.98	118.7	0.61
Group 3	1.60	74.77	0.31
Group 4	3.00	20.93	1.00

Details of the groups are given in Table 1.
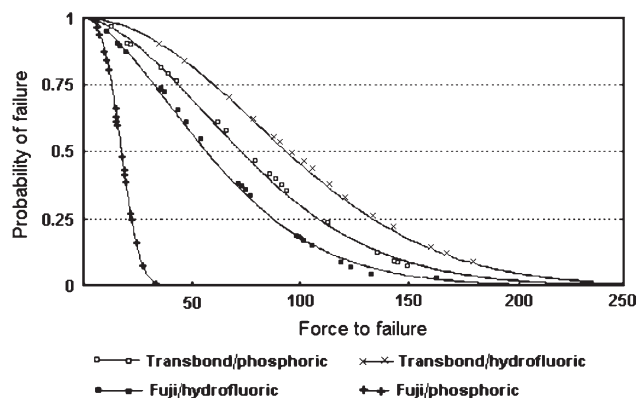
Figure 1 Weibull plots and data distribution.

The sites of bond failure (percentages for each group) are presented in Table 5 together with the ARI scores. The porcelain/resin interface was the commonest site of failure for all groups. The composite groups (groups 1 and 2) had the highest percentages of damaged porcelain surfaces at 40 and 35 per cent, respectively. The RMGIC/phosphoric acid group (group 4) was the only group with no visible porcelain surface damage. Chi-square testing (Table 6) demonstrated that the RMGIC groups (groups 3 and 4) had significantly ($P < 0.001$) lower ARI scores than the composite groups (groups 1 and 2).

Discussion

The results of the present study suggest that adequate bond strengths to porcelain surfaces can be achieved with conventional composite bonding agents without the need for mechanical preparation of the surface. This is in agreement with Messer *et al.* (1991). Preparation with hydrofluoric acid in conjunction with a silane primer (group 2) produced the highest bond strength but was not significantly higher than that achieved with phosphoric acid (group 1). As hydrofluoric acid is a more toxic material, the results of this study suggest that its routine use would appear to be unnecessary as similar bond strengths can be achieved with the less toxic phosphoric acid.

Conversely, the results of this study would suggest that lower bond strengths will be achieved when bonding to porcelain surfaces with RMGIC using phosphoric acid

Table 5 Site of bond failure for test groups.

	Porcelain/resin (%)	Bracket/resin (%)	Adhesive Remnant Index (total)
Group 1	75	25	45
Group 2	65	35	49
Group 3	70	30	26
Group 4	60	40	9

Details of the groups are given in Table 1.

Table 6 Chi-square test for adhesive remnant index scores.

	Score 1	Score 2	Score 3	Score 4
Group 1	3	7	2	8
Group 2	4	2	5	9
Group 3	9	6	0	5
Group 4	11	9	0	0

Groups 1–4: chi-square = 29.4; degrees of freedom = 9; $P < 0.0005$.
Details of the groups are given in Table 1.

(group 4). However, using hydrofluoric acid enhances the bond strength levels (group 3), and reliability assessment with Weibull analysis suggests this may be adequate for use in the clinical situation, although this could only be confirmed by a randomized clinical trial. However, a more careful clinical technique would be required to ensure adequate isolation to protect the oral tissues from the toxic effects of the hydrofluoric acid.

A significant problem highlighted by the study was the high incidence of porcelain surface damage visible at debond. This was particularly the case with the composite resin (groups 1 and 2) with 40 and 35 per cent of the samples having visible damage, respectively. The problem was less evident with the RMGIC (groups 3 and 4) at 25 and 0 per cent, respectively. The very low bond strength levels recorded for group 4 probably accounted for the lack of damage.

From a clinical perspective, therefore, it would appear prudent to warn patients about the risk of damage to porcelain surfaces prior to bonding and the need for possible repair/replacement following orthodontic treatment.

Similar problems have been reported with porcelain brackets when bonded to enamel with silane coupling agents (Viazis *et al.*, 1990). Silane coupling agents are no longer recommended when bonding porcelain brackets to enamel, and new bracket base designs have been developed to achieve adequate bracket retention but allow removal without damage (Bishara *et al.*, 1999).

It may be that future developments should concentrate on modifying bracket base design for bonding to porcelain surfaces. The ideal bracket would achieve adequate bond strength levels during treatment but facilitate easy removal

at debond. Ideally, this would leave any residual bonding resin intact on the porcelain surface which could be removed easily without damage to the porcelain surface.

Conclusions

1. The null hypothesis that there would be no difference in bond strength between the groups was rejected.
2. The highest bond strength levels were achieved with a conventional composite resin cement (groups 1 and 2).
3. No significant differences in bond strength were found between the hydrofluoric and phosphoric acid etch techniques.
4. No mechanical surface preparation was required to achieve these bond strength results.
5. Lower bond strength levels were achieved with the RMGIC (groups 3 and 4) although the levels achieved with a hydrofluoric etch procedure (group 3) may be adequate from a clinical point of view.
6. A high percentage of samples experienced porcelain surface damage in all groups except group 4 (RMGIC/phosphoric acid). This showed no damage but also had significantly lower bond strength levels than all the other groups.

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