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# Shear bond strengths of buccal tubes

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*Aims:* To investigate the shear bond strengths of buccal tubes and to determine the sites of failure.

*Method:* Four orthodontic buccal tubes were selected: A, American Orthodontics; B, 3M Unitek - small base; C, 3M Unitek - large base; D, Hangzhou Dentop. Twenty buccal tubes from each group were bonded to the buccal surfaces of lower right first molars with the same light-cured composite resin. The buccal tubes were debonded with a universal testing machine and the data analysed. The amount of adhesive remaining on the teeth after debonding was classified with the modified adhesive remnant index (ARI).

*Results:* The groups ranked from the highest to lowest bond strength (MPa) were: B, A, D and C. The bond strengths of the buccal tubes, except Groups A and B, were significantly different ($p < 0.05$). The majority of the buccal tubes (63 per cent) had modified ARI scores of 1 and 2 and 25 per cent of the tubes had scores of 4 and 5. After debonding, no adhesive remained on 40 per cent of the teeth in Groups B and D.

*Conclusions:* The shear bond strengths of the buccal tubes fell below the value considered to be clinically acceptable. There were no differences between the shear bond strengths of the buccal tubes with photoetched and microetched bases. The buccal tubes with the largest base failed prematurely, possibly because the unsupported bonding pad flexed during debonding.
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## Introduction

The practice of bonding attachments to molars has not been widely accepted because it is believed that bonded buccal tubes have inadequate bond strengths.[1,2] The failure rate of bonded buccal tubes has been reported to be as high as 21 per cent.[3] The bond strength of buccal tubes can be improved by increasing the etch time to 30 seconds,[4] use of foil mesh bonding pads,[5,6] sand blasting the attachments[7] and using different resin adhesives.[8] According to one authority, bond strength is influenced by the size and design of the bonding pad, but others consider that shear bond strength is independent of the surface areas of bonding pads between 6.82 and 12.32 $mm^2$.[9,10] The limitations in previous studies are the use of bovine teeth, use of premolars rather than molars, use of attachments with different surface areas and different types of bonding pad.

Our aims were to compare the in-vitro shear bond strengths of different buccal tubes bonded to human molars, and to determine the sites of failure using the modified adhesive remnant index (ARI).

## Materials and methods

Eighty lower right first molar teeth were collected, sterilised with 0.5 per cent chloramine for one week and stored in distilled water for 24 hours. The buccal surfaces of all teeth were sound. The teeth were randomly assigned to four groups and mounted in acrylic resin blocks to facilitate debonding in a universal testing machine. Lower right MBT prescription buccal tubes from the following sources were used: A (American Orthodontics, Sheboygan, WI, USA); B (Small base; 3M Unitek, Monrovia, CA, USA); C (Large base; 3M Unitek, Monrovia, CA, USA); D (Hangzhou Dentop, Zhejiang, Hangzhou, China).

The buccal surface of each tooth was polished with fluoride-free pumice powder for 20 seconds, sprayed with water and dried with a blast of air. The buccal surfaces were then etched for 30 seconds with 35 per cent phosphoric acid gel (Transbond XT etchant gel, 3M Unitek, Monrovia, CA, USA), rinsed for 30 seconds with distilled water and dried with air for 20 seconds. A thin layer of Transbond XT primer


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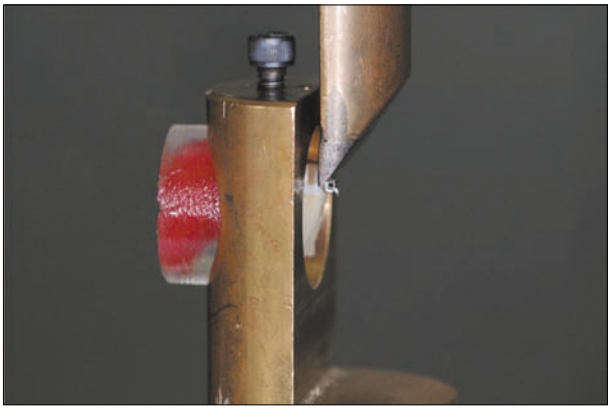


Figure 1. A specimen ready for debonding.

Table I. Base sizes and shear bond strengths of the buccal tubes.

| Group | N | Mean size ($mm^2$) | Mean SBS ± SD (MPa)* | 95 per cent CI |
|---|---|---|---|---|
| A | 20 | 26.50 | 3.88 ± 0.34 | 3.73, 4.04 |
| B | 20 | 18.20 | 4.32 ± 0.73 | 3.98, 4.66 |
| C | 20 | 32.60 | 1.71 ± 0.60 | 1.43, 1.99 |
| D | 20 | 22.70 | 3.34 ± 0.66 | 3.03, 3.65 |

A: American Orthodontics, 80 gauge photoetched foil mesh base
B: 3M Unitek (small base), 80 gauge microetched foil mesh base
C: 3M Unitek (large base), 80 gauge microetched foil mesh base
D: Hangzhou Dentop, 80 gauge microetched foil mesh base
* One-way ANOVA, $p = 0.00$

(3M Unitek, Monrovia, CA, USA) was then brushed on the etched surface. Transbond XT light-cured composite resin (3M Unitek, Monrovia, CA, USA) was placed on the bonding pad and the attachment pressed on the buccal surface by an experienced orthodontist. Surplus resin was removed with a sharp, dental instrument. The resin was cured with an Optilux 400 curing light (Demetron Research Corp, Danbury, CT, USA) at 400 $MW/cm^2$ by placing the light 10 mm from the mesial (20 seconds) and distal edges (20 seconds) of each bonding pad. The samples were stored in distilled water at 37 $^oC$ for 24 hours before debonding.

Each specimen was mounted in a Shimadzu Universal Testing Machine (Shimadzu Corporation, Kyoto, Japan) so that the middle of the buccal surface was parallel to the long axis of the blade used to debond the tubes (Figure 1). The universal testing machine had a load cell of 1 kg and crosshead speed of 1 mm/min. The shear load was applied on the occlusal side of the buccal tube, as close as possible to the base. The force required to debond a buccal tube was recorded in newtons (N) and converted to force per unit area (MPa), by dividing the force by the surface area of the base. The latter was measured by tracing the base on graph paper and counting the number of squares enclosed by the outline (Table I).

To determine the sites of failure, the teeth and buccal tubes were examined at x10 magnification (Leica Image Analyzer, Houston, TX, USA) and the amount of adhesive on the tooth surface was scored with the modified adhesive remnant index (ARI): 1, all of the adhesive remained on the enamel with an impression of the base of the buccal tube; 2, more than 90 per cent of the adhesive remained on the tooth surface; 3, less than 90 per cent but more than 10 per cent of the adhesive remained on the tooth surface; 4, less than 10 per cent of the adhesive remained on the tooth surface; 5, no adhesive remained on the tooth surface.[11,12]

### *Statistical analysis*

One-way analysis of variance (ANOVA) was used to compare the shear bond strengths of the buccal tubes. Tukey HSD post-hoc tests were employed to analyse the shear bond strength data. The distributions of residual adhesive (ARI) were compared using the chi-squared test. A significance level of 0.05 was used for all tests.

## Results

The 3M Unitek small base buccal tubes were slightly more than half the area of the large base 3M Unitek buccal tubes and 80 per cent of the area of the Hangzhou Dentop tubes. The mean base area of the Hangzhou Dentop tubes was approximately 85 per cent of the mean base area of the American Orthodontics tubes (Table I).

The highest mean shear bond strength was observed in Group B (4.32 ± 0.73 MPa) and the lowest mean bond strength in Group C (1.71 ± 0.60 MPa) (Table I). The mean shear bond strengths of the tubes were significantly different, except for the tubes in Groups A and B (Table II). The largest mean difference of 2.61 MPa occurred between the Group B and Group C buccal tubes.

**Table II.** Comparisons of the shear bond strengths.

| | | Shear bond strength (MPa) | |
|---|---|---|---|
| Group, Manufacturer | Comparison | Mean difference | *p** |
| A, American Orthodontics | B, 3M Unitek, small base | -0.44 | 0.11 |
| | C, 3M Unitek, large base | 2.18 | **0.00** |
| | D, Hangzhou | 0.54 | **0.03** |
| B, 3M Unitek, small base | A, American Orthodontics | 0.44 | 0.11 |
| | C, 3M Unitek, large base | 2.61 | **0.00** |
| | D, Hangzhou | 0.98 | **0.00** |
| C, 3M Unitek, large base | A, American Orthodontics | -2.18 | **0.00** |
| | B, 3M Unitek, small base | -2.61 | **0.00** |
| | D, Hangzhou | -1.63 | **0.00** |
| D, Hangzhou | A, American Orthodontics | -0.54 | **0.03** |
| | B, 3M Unitek, small base | -0.98 | **0.00** |
| | C, 3M Unitek, large base | 1.63 | **0.00** |

* Tukey HSD, significant differences in bold

**Table III.** Comparisons of the modified ARI scores.

| ARI | Group count (Per cent) | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | Total |
| 1 | 12 (60) | 6 (30) | 14 (70) | 2 (10) | 34 (43) |
| 2 | 4 (20) | 4 (20) | 6 (30) | 2 (10) | 16 (20) |
| 3 | 2 (10) | 2 (10) | 0 (0) | 6 (30) | 10 (13) |
| 4 | 2 (10) | 0 (0) | 0 (0) | 2 (10) | 4 (5) |
| 5 | 0 (0) | 8 (40) | 0 (0) | 8 (40) | 16 (20) |
| Total | 20 (100) | 20 (100) | 20 (100) | 20 (100) | 80 (100) |

Chi-squared test, $p < 0.05$

The distributions of ARI scores are given in Table III and were significantly different ($p < 0.05$). In Groups A and C most of the resin remained on the surfaces of the teeth, whereas in Groups B and D there was no adhesive on 40 per cent of the teeth. The ARI scores in Group D were variable: all of the resin remained on 10 per cent of the teeth, a further 10 per cent of the teeth retained 90 per cent of the resin, and 30 per cent of the teeth retained between 90 and 10 per cent of the resin (Table III).

## Discussion

We compared the shear bond strengths of four different buccal tubes under standardised in-vitro conditions and found that the buccal tubes with the largest bonding pads had the lowest bond strengths. The buccal tubes with the smallest pad area had the highest bond strength, but it fell below the value considered to be clinically acceptable. The ARI scores for buccal tubes with the smallest bonding pad were more-or-less evenly distributed between the extreme scores, whereas most of the adhesive remained on the teeth when the buccal tubes with the largest bonding pads (Groups A and C) were debonded. The buccal tubes we tested had different base areas and different types of retentive meshes, but we considered them a single independent variable in our analysis.

Several investigators have proposed that increasing the surface area of the bonding pad increases the load carrying capacity of an attachment and, presumably, results in a higher shear bond strength.[9,13] However, MacColl et al.[10] reported that shear bond strength was independent of the surface area of bonding pads above 6.82 mm$^2$. We found the smallest attachments had the highest bond strength, and postulate that the multilayer bases of the largest buccal tubes were not uniformly rigid. In our view, if the periphery of the bonding pad is not supported by the actual attachment it would be somewhat 'flexible' and relatively easily deformed by a shear force (Figure 2). On the other hand, when the buccal tube covered the bonding pad the tube-pad combination was more rigid and, therefore, less likely to fail (Figure 3).[14]

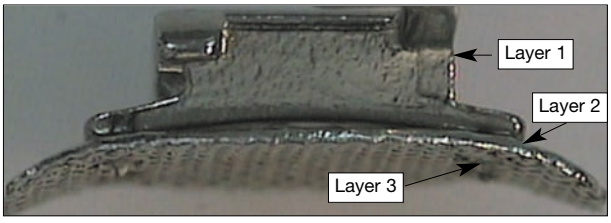



Figure 2. A multilayer buccal tube with a large base (Group C), showing the unsupported flange.



Figure 3. A buccal tube with a small base (Group B). The attachment extends almost to the edge of the bonding pad.

Other factors that may have influenced our findings are the closeness of fit of the bonding pads, the extent of polymerisation and the effect of immersion in water before testing.[15] A buccal tube with a large base area is likely to be less well-adapted to the surface of the tooth, leading to an uneven and, in parts, thick layer of adhesive.[14] The latter may include small inclusions of air and is more likely to develop cracks as the concentration of stress increases proportionally with the thickness of the resin layer.[16]

Maximum conversion of monomer to polymer is necessary for composite resin to achieve optimal physical properties.[17] Complete polymerisation of the resin beneath a buccal tube relies on the polymerising light reaching all parts of the resin. Recent studies have reported that there was no significant difference in the shear bond strengths when the tip of the curing light was positioned between 1 and 10 mm from the bases of the brackets.[18,19] We followed the manufacturers' directions and placed the light 10 mm from the mesial and distal edges of the metal bonding pads, but it is possible that resin in the most inaccessible parts of the mesh base was not completely polymerised.[20,21]

The storage media used may have influenced the bond strength. We sterilised the teeth before using them in a 0.5 per cent solution of chloramine, which according to Jaffer and coworkers[15] should not affect the shear bond strengths. After bonding, however, we simulated the oral environment by storing the teeth in water, which may have contributed to a loss of bond strength.[22]

The Group B buccal tubes may have had the highest bond strength and smallest base area, but in 60 per cent of the teeth much of the resin still remained attached to the teeth. The area of unsupported base is greater in Groups A and C (26.50 $mm^2$ and 32.60 $mm^2$, respectively) and most of the resin remained attached to the teeth in these groups, strengthening our belief that the peripheries of the buccal tubes flexed when subjected to the shear force and contributed to early failure.

## Conclusions

Within the limitations of this study the conclusions are:

1. None of the buccal tubes had sufficient shear bond strength for clinical use.

2. Increasing the area of the base did not increase the shear bond strength. The area of unsupported base may flex when subjected to a shear force and contribute to early failure.

3. There were no differences in bond strength between photoetched or microetched bases.

4. The buccal tubes in Groups B and D had the highest bond strengths and more tubes failed at the tooth-resin interface.

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