The Bond Strength of Resin Bonded Bridge Retainers to Abutments of Differing Proportions of Enamel and Composite

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ABSTRACT:

Four groups of specimens were constructed using bovine enamel and composite resin. After a period of ageing, the specimens were roughened and acid etched before they were cemented to air abraded base metal alloy beams with a universal resin cement. After further ageing, tensile peel testing was carried out using a Universal Testing Machine. The force required to produce failure increased as the amount of composite resin on the bonding surface of the abutment increased. This difference reached statistical significance (p<0.5) when the abutments contained >50% composite.

The mode of failure was mixed on the majority of retainers. Within the limitations of the study, findings suggest that RBB retainers can be cemented to abutments restored with composite resin without a reduction in bond strength.

INTRODUCTION

Since the introduction of the Rochette bridge in 1977,[1] resin bonded bridges (RBBs) have undergone significant developments. Attempts have been made to enhance retention by utilising different tooth preparations, introducing different surface preparations for the retainers and employing new types of cements. RBBs are now more predictable, given good case selection, but their role as definitive restorations remains controversial due to a lack of long term prospective data regarding success.

As a result of this, some authors suggest they are best suited as short to medium term restorations,[2] for example in cases where the patient is not old enough to undergo dental implant placement. One particular group of patients to whom this may apply is those with hypodontia. These patients often present with potential abutment teeth that are small with unusual morphology and hence do not provide the optimum surface area required to bond the retainers. These teeth can be built up with composite resin to improve the aesthetics and this may have the beneficial effect of increasing the surface area for bonding.[3] The addition of composite does, however, change the nature of the bonding surface of the abutment, and there is little information as to the effect this would have on the bond strength of the wing of the retainer.

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Several authors advise that the use of RBBs should be restricted to unrestored or minimally restored abutment teeth[4-6] However, in vitro work has shown that the tensile bond strength of resin cement to a test surface composed of 50% composite and 50% enamel is not markedly lower than the bond strength to all enamel surfaces.[7] If this is the case RBBs may have wider applications. In fact, if bond strength is not adversely affected, building up microdont teeth before RBB placement may improve retention as the surface area available for bonding of the retainer is increased.[5]

The incremental placement of composite restorations is possible due to the presence of unpolymerised methacrylate molecules in the oxygen inhibited surface layer[8] of the previously cured composite increment. These molecules are capable of forming resin bonds with the next increment of material. However, when a composite restoration has been polished and exposed to the oral environment, this outer layer of reactive methacrylate groups usually responsible for bonding is lost. Water sorption also occurs which may result in the hydrolysis of bonds and the leaching of reactive monomer.[9, 10] In this circumstance, achieving an effective bond between existing composite restorations and new increments relies primarily on micro-mechanical retention.[11-16] This is relevant to RBBs as there will inevitably be a delay between restoring the abutment tooth and cementation of the bridge due to the time taken for laboratory construction of the bridge. During this time the resin composite will be exposed to the oral environment.

In vitro, several different methods have been used in an attempt to simulate the ageing of composite resin as it takes place in the oral environment. These include storage in solutions such as citric acid, water or saliva at a constant temperature, thermocycling and occlusal loading. There is little standardisation in terms of protocol, however it has been suggested that storage is currently the most validated method.[17]

Several authors have described the use of different chemical and mechanical surface treatments to enhance the bond strength between old and new composite.[18] These include the use of an appropriate composite adhesive system and mechanical roughening of composite. Roughening may be with a diamond bur[19] or air abrasion.[12, 15, 18, 20]

Van Dalen[21] described an in vitro set up using tensile peel testing to assess the effect of different surface preparations and cements on the bond strength of resin bonded bridge retainers to bovine enamel. The use of bovine enamel in vitro to simulate human enamel is well established in a variety of different experimental set ups and has practical advantages over the use of human tissue.[22] The mode of failure reported by van Dalen[21] in this study is considered to be closest to that of the clinical environment: failure is seen to occur mainly at the resin-metal interface so that resin cement is left on the tooth.

It has been speculated that this type of failure may be due to the increased flexibility of the CoCr retainer relative to the enamel abutment as during peel testing deflection of the retainer generates, higher amounts of strain at the metal-resin interface.[23]

A number of authors have carried out Finite Element Mapping (FEM) analysis to investigate the distribution of force across the abutment during tensile peel testing and have identified a complex situation, where force is not distributed evenly but concentrated at the pontic-abutment interface.[24-26] If the abutment is constructed of two materials, enamel and composite, with different values of elastic modulus and flexural strength[27, 28, 28, 29] this is likely to increase complexity further. Differences in the distribution of forces during peel testing may alter the mode of failure and consequently the amount force required to produce failure of the bridge.

This study aims to investigate the bond strengths of resin bonded retainers when cemented to abutments with differing surface areas of composite and enamel.

METHODS AND MATERIALS

In this study, alloy beams *(the retainers)* were cemented to blocks of differing proportions of bovine enamel and composite *(the abutments)* with universal dual cure resin cement. Using a universal static testing machine, a peel force was applied to the retainer, until failure occurred.

Four test groups were investigated, the dimensions and proportion of enamel to composite surface were as noted in *Table 1*. It was not possible to perform a power calculation based on information available in the literature and therefore this study was run as a pilot. Similar studies in this field, employing tensile peel testing have small specimen sizes, the largest being 12.[21, 24, 30, 31] It was decided to prepare the maximum number of specimens possible from the bovine enamel available, with a minimum of 15 specimens in each group.

ABUTMENTS

To produce the abutments, blocks of bovine enamel were prepared from the buccal surfaces of 36 freshly extracted bovine permanent incisor teeth. All teeth were stored in 1% Thymol solution after extraction.

Sections of bovine enamel of the dimensions required for each group (*Table 1*) were cut using a water cooled diamond disc in an Accutom-5 machine. The resultant blocks were ground flat with wet and dry silicone carbide paper of grit size 1200 (Silicone Carbide Paper - WS flex 18 C) and hand finished as required with rotary diamond discs under x2 magnification.

Table 1: Composition of abutments in each experimental group

	Composition of Bonding Surface	Dimensions
Group 1	100% Enamel	8x8mm enamel
Group 2	25% Composite	6x8mm enamel; 2x8mm composite
Group 3	50% Composite	4x8mm enamel; 4x8mm composite
Group 4	100% Composite	8x8mm composite

The specimens were inspected with x2 magnification under an operating light for dentine fenestrations; if any were identified the slab was rejected.

The width and length of the specimens were measured at three points in each dimension in millimetres to 2 decimal places with a set of digital calipers (Am-tech Digital Vernier Caliper P2600). A standard error of 10% was accepted; specimens measuring outside this range were rejected.

The surfaces of the enamel blocks to be bonded were etched for 30 seconds with 37% Phosphoric acid gel (Super Etch). This was rinsed and an enamel-dentine bonding agent (OptiBond SoloPlus) applied and light cured for 10 seconds on each surface, prior to composite placement

To facilitate the placement of composite, a silicone matrix of internal dimensions 8mm by 8mm by 5mm was produced using silicone putty material (President Putty).

To ensure that all groups of specimens achieved a uniform thickness of 4.5mm the 100% enamel abutments were placed in the matrix and the surface not to be bonded to the retainer was veneered, in increments, with composite resin using a flat plastic instrument with finger pressure (one operator, KD).

To produce the composite-enamel hybrid abutments (Groups 2 and 3), the enamel blocks of lesser dimensions (8x6mm; 8x4mm) were placed in the matrix and composite resin packed in as described previously to produce specimens of the same overall dimensions (8x8x4.5mm). The same template was used to form the 100% Composite resin specimen.

Each increment of composite resin was light cured for 40 seconds. Dimensions were checked with calipers at three points along the width, length and depth of each specimen and adjustments made as required. As previously described, a 10% error was accepted and specimens measuring outside this range were rejected. Once prepared all the specimens were placed in sealed vials containing double distilled water at a temperature of 37˚C, maintained by an incubator for 7 days to age the specimens.

RETAINERS

The retainers were cast in a non-precious ceramic bonding alloy (Heraenium Pw), which is an alloy of cobalt (55.2%), chromium (24%), manganese (0.8%), silica (1%), iron (4%) and tungsten (15%). Initially these were cast as a sheet of metal, 0.75mm thick, which was then sectioned in a lathe to produce specimens of the required 8x16mm dimensions.

Retainer thickness was set at 0.75mm to reduce the possibility of flexion[24, 30] as would be desired in a clinical situation. To ensure standardisation, the thickness of each retainer was measured with the digital calipers at 3 points across its length. The length and the width of each specimen were also recorded in three places. The points for measurement were standardised using a template.

The three recorded values for each dimension were then used to calculate a mean value for the width, length and thickness for each beam. Only beams in which the mean length was 16+/-0.5mm, mean width was 8+/-0.5mm and mean thickness was 0.75+/-0.05mm were included in the study.

ASSEMBLING THE SPECIMENS

Before bonding, the metal surfaces were air abraded with aluminium oxide particles of 50μm and primed with the alloy primer (Panavia F 2.0 (Tooth Coloured). The abutments were roughened with 2 complete strokes with a high speed diamond crown bur (FG Diamond Burs (Flat-end taper, 173-016C)).

The roughened surfaces were etched with 37% phosphoric acid gel which was applied for 30 seconds (Super Etch) after which the specimens were rinsed and air dried. The Panavia F abutment primers (Primer A and B) were mixed and then applied to the specimens, left for 20 seconds and then airdried lightly, as per the manufacturer's guidelines.

The A and B components of the Panavia Translucent luting cement paste were mixed for 20 seconds and applied to the metal retainer. The abutment was then positioned on the retainer to leave a pontic of dimensions 8x7x0.75mm, and excess cement was removed. Once the position had been veri-

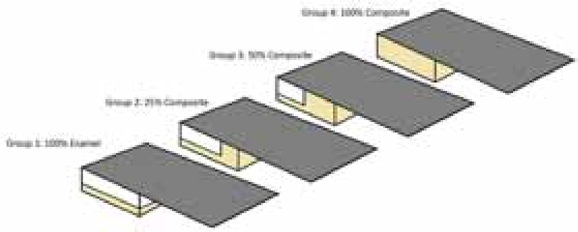

Figure 1: Schematic representation of specimens bonded to the retainers

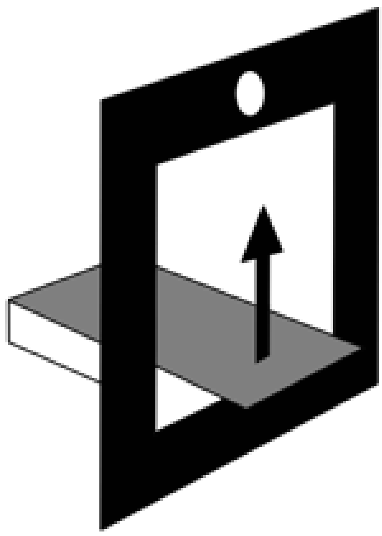

Figure 2: Schematic to show the positioning of specimen and the cradle. Direction of application of force is arrowed.

fied, constant finger pressure was applied whilst each surface was light-cured for 20 seconds.

Abutments in Groups 2 and 3, abutments with composite resin and enamel, were arranged so that the composite resin was closest to the pontic (*Figure 1*). As force is concentrated at the pontic-abutment interface during tensile peel testing[24-26] it was considered, therefore that placing composite resin adjacent to the pontic would have the most critical effect on bond strength. Once the cement had set, the edges of the specimens were inspected to ensure that the surfaces to be gripped by the clamp of the testing machine were free from excess luting cement.

The specimens were then submerged in double distilled water for 48 hours at 37°C.

Table 2: Raw data for tensile load at failure

Tensile Load at Failure (N)

100% Enamel n=13	25% Composite n=14	50% Composite: n=15	100% Composite n=13
34.87	48.26	42.09	48.41
29.55	43.17	68.51	54.13
36.22	38.07	55.83	53.58
36.95	41.95	48.39	36.48
41.55	36.26	66.21	57.04
50.88	39.13	83.43	65.20
35.2	51.75	61.87	31.42
36.79	59.44	65.49	44.41
40.53	33.26	69.57	59.44
27.31	37.71	43.15	45.10
23.94	47.07	39.51	49.17
46.31	40.93	56.92	40.83
28.39	51.54	72.35	38.28
	33.75	54.24	
		36.47	

APPLICATION OF FORCE

The specimens were positioned in a static force universal testing machine (Lloyd LR10K Plus Materials Testing Machine) so that a tensile peel test could be performed. A schematic representation of the application of force is shown in (*Figure 2*).

Once accurate position had been checked, a tensile peel force was applied using a load cell of 500N and a cross head speed of 1mm/minute, until failure. Failure was defined as fracture of the abutment or retainer, debond of the retainer or permanent deformation of the retainer. The load at failure (Newtons) for each specimen was recorded and the resultant data was analysed using SPSS Statistics v19 (IBM Corporation).

MODE OF FAILURE

All failed retainers were examined under the stereomicroscope at 0.8X magnification (Nikon Microscope) to assess the mode of failure. High resolution digital photographs were also taken with a digital camera (Nikon D300, 12.3 MP Camera).

The images captured under the stereomicroscope (Motic Moticam 2300 3.0 MP Camera) were analysed in conjunction with the high resolution photographs (Nikon D300, 12.3 MP Camera). Image analysis was carried out using Image J (Image J 1.47i) and the percentage area of the resin retained on the retainer was calculated.

RESULTS

TENSILE PEEL TESTS

A total of 63 specimens were tested. The results of 2 specimens per group were excluded as it was known that the specimens had tilted during peel testing. Data analysis was carried out on the remaining 55 specimens. Raw data for tensile bond tests are shown in *Table 2* and summary statistics for each group are shown in *Table 3*.

The amount of force that was required to cause failure of the specimens increased as the amount of composite resin in the abutment increased to 50%. The lowest force required to produce failure was seen in the 100% enamel group.

Box plots revealed that variance was similar between the groups and Q-Q plots revealed that data was normally distributed in all groups.

One way ANOVA testing with a Tukey's HSD was used to determine if there were any statistically significant differences amongst the groups. Results are shown in *Table 4*.

Table 3: Summary statistics for each group; standard deviation in parentheses

	100% Enamel (n=13)	25% Composite (n=14)	50% Composite (n=15)	100% Composite (n=13)
Median (N)	36.22	41.44	56.92	48.41
Mean (N)	36.04 (7.65)	43.02 (7.65)	57.60 (13.69)	47.96 (9.80)

The results indicate that there are significant differences in load at failure between the following groups:

- 100% enamel and 50% Composite resin
- 100% enamel and 100% Composite resin
- 25% Composite resin and 50% Composite resin

MODE OF FAILURE

The majority of specimens exhibited mixed modes of failure, with some resin being present on the retainers. There was a trend for more resin to be left on the retainers as the percentage of composite resin in the abutments increased (*Table 5*). This represented a mix of adhesive failure at the cement-composite resin interface and cohesive failure within both the cement and the composite resin of the abutment. Two of the 100% composite resin specimens showed 100% resin coverage on the retainers.

100% enamel specimens showed more adhesive failure at the cement-metal interface, resulting in a lower percentage of resin coverage on the retainer.

DISCUSSION

BOND STRENGTH

In this study, the force at failure (N) recorded during the tensile peel tests for all-enamel specimens were similar to those reported by van Dalen *et al* 2005.[21]

The force required to produce failure of the specimens increased as the amount of composite resin on the bonding surface of the abutment increased. The force required to produce failure of the all-composite specimens was more than the all-enamel but less than the 50% enamel/composite resin hybrids.

The relatively higher bond strength of the specimens containing composite resin in comparison to the all-enamel specimens must be considered with caution as bovine enamel has been shown to have lower bond strengths to resin cement than human enamel.[22] However, within the limits of the experiment, the results do suggest that high bond strengths can be achieved when bonding base metal alloys to abutments restored with composite resin. In a clinical environment the results suggest that using teeth restored with composite resin to act as abutments for RBBs is a viable technique.

MODE OF FAILURE

The mode of failure was generally mixed but different trends were seen within the groups. In the 100% enamel (8x8 enamel) group there was a higher percentage of adhesive failure at the metal-resin interface. This is similar to that reported by van Dalen[21] and consistent with what is seen clinically. It also reflects positively on the strength of resin bonding to bovine enamel and its use in such studies.

In the groups with composite resin, a larger percentage of the retainers were covered in resin, suggesting cohesive failure within the resin cement or composite resin itself, or adhesive failure at the cement-composite interface. In a minority of the 50% composite resin/ enamel specimens (n=5), failure occurred as a result of fracture of the abutment, at the composite resin and enamel joint.

APPLICATION OF FORCE

Tensile peel testing was employed in the current study to represent the most clinically relevant method of simulating RBB failure. This experimental set up aims to reproduce the labio-lingual forces thought to result in the failure of anterior RBBs.[21]

Previous FEM of RBB abutments constructed of one material have identified that force is not distributed evenly over the abutment during tensile peel testing.[24-26] In this study, this is complicated further by the fact that two of the test groups were made up of a combination of enamel and composite resin components. There has been no work investigating how forces are distributed in this situation as they approach a complex interface between the two materials with different physical properties.

Within the scope of this study it is difficult to draw conclusions in this regard. It however can be seen from the images that a trend exists, as the amount of composite resin present in the abutment increases, more resin is left on the retainer. This may suggest that amount of strain generated in the retainer is less where abutments are made of composite resin, because the elastic modulus of this material is substantially less than that of enamel, and failure mode is therefore different. The reported Young's elastic modulus value for enamel is 84GPa.[27, 28] For composite resin, this is estimated at around 18GPa,[28, 29] with some variation, depending on the type of composite resin material used.

Table 4:

Contingency table showing results of one way ANOVA with Tukeys HSD, (significance level 0.05, df=3, F=11.249), * denotes results p<0.05

Group	25% Composite	50% Composite	100% Composite
100% enamel	0.291	0.000*	0.021*
25% Composite	-	0.002*	0.589
50% Composite	-	-	0.070

Table 5:

Mean area of retainer covered by resin (%) in each group following failure: standard deviation in parentheses.

Group	Mean Resin Coverage %
100% Enamel	39.69 (20.97)
25% Composite	42.34 (24.97)
50% Composite	61.02 (18.30)
100% Composite	91.87 (8.75)

LIMITATIONS OF THE EXPERIMENTAL METHOD

The specimen dimensions of 8mm by 8mm were chosen to represent the approximate surface area available for bonding on the palatal aspect of a maxillary central incisor tooth, a tooth frequently used as an abutment for the replacement of lateral incisors, one of most commonly developmentally missing teeth.

Sourcing human enamel to produce uniform specimens of this size would have been very difficult. The use of larger bovine teeth gave more scope for the preparation of flat enamel slabs from what is a naturally curved surface. Although the use of bovine enamel may have practical advantages, its bond strength to composite resin may be different to that of human enamel. Published results are somewhat equivocal with some studies reporting significantly lower bond strengths to permanent bovine enamel and others reporting no significant difference.[22] Lower bond strength to bovine enamel may account for the fact that the all-enamel specimens failed before the all-composite resin specimens. In this study, any discrepancy between bond strength to human and bovine enamel is not critical as it is the comparison amongst groups that is relevant.

The procedures used to construct the samples in this study were chosen to replicate the clinical environment as closely as possible. To reduce the risk of variation that may arise from roughening the abutment bonding surface with a diamond bur and the use of finger pressure in cementation all procedures were undertaken by one operator.

It has been established that in the oral environment composite resin materials undergo water sorption over time. The volumetric expansion and hydrolysis of methacrylate bonds has a deleterious effect on the mechanical properties of the material[9] and leaching of monomer[10] reduces the possibility of chemical bonding to new layers of composite resin material. Several methods of ageing composite resin have been described however there is no overall consensus as to which is the most clinically relevant.[17] In this study, all abutments were stored in water at 37˚C for 7 days before bonding of the retainer in. This was thought to be a reasonable representation of the time between impression taking and fitting of the bridge. This duration of ageing was not found to impact significantly on bond strength considering that the force to debond retainers from the abutments was higher for those containing composite than all enamel. Further work could investigate how extending this period of ageing affects bond strength to determine if there is a time window beyond which a strong bond to composite resin can no longer be achieved. This may lead to guidance as to the optimal period between impression taking and fit of the prosthesis, should the abutment contain a composite resin restoration.

CONCLUSIONS

The results of this study suggest that high bond strengths can be achieved when bonding base metal alloy retainers to composite resin-enamel abutments which have been aged for one week and roughened with diamond burs to create micro-mechanical retention.

Accepting the limitations of in vitro research, the findings can be related to the clinical environment in that they suggest that RBBs can be cemented to abutments containing composite resin restorations, provided that surface roughening is carried out and the restoration has been exposed to the oral environment for a minimal amount of time.

This supports the use of RBBs to replace missing teeth in hypodontia patients who have had diminutive abutment teeth built up with composite. This type of restoration may offer a minimally invasive solution in circumstances where treatment options are otherwise limited.

MANUFACTURER'S DETAILS

- Water cooled diamond discs, L.M. Van Moppes Diamond Tools Ltd, India
- Accutom-5 machine (Struers, Denmark)HP1074 Intensiv Diamond Discs, Intensiv SA, SwitzerlandSilicone Carbide Paper - WS flex 18 C, Hermes Schleifmittel GmbH & Co. KG, Germany
- Am-tech Digital Vernier Caliper P2600, DK Tools Ltd, Middlesex, UK
- Shade B3, Herculite XRV Ultra, Kerr Italia, Italy
- Super Etch, SDI Limited, Australia
- OptiBond SoloPlus, Kerr UK Ltd
- President Putty, Coltene Whaledent Ltd
- Heraenium Pw, Heraeus Kulzer GmbH, Germany
- Panavia F 2.0 (Tooth Coloured), Kuraray Europe GmbH, Germany
- FG Diamond Burs (Flat-end taper, 173-016C) MDT Micro Diamond Technologies Ltd, Israel
- Lloyd LR10K Plus Materials Testing Machine, Lloyd Materials Testing, Leicester, UK
- Loctite Super Glue Ultra Gel Control, Henkel, Ohio, USA
- SPSS Statistics v19, IBM Corporation, New York, United States
- Nikon Microscope, Nikon Corporation, Tokyo, Japan
- Nikon D300, 12.3 MP Camera, Nikon, Tokyo, Japan
- Motic Moticam 2300 3.0 MP Camera, Motic Images Plus Software
- Nikon D300, 12.3 MP Camera, Nikon, Tokyo, Japan
- Image J 1.47i, National Institutes for Health, USA

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