Tensile Peel Failure of Resin-Bonded Ni/Cr Beams: An Experimental Study

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ABSTRACT

Objectives: To measure the tensile peel strength of different types of luting cements and studies their effect on the adhesive bond quality of resin-bonded bridges.

Methods: Six cements were investigated; two chemically adhesive resin cements (Super-Bond C&B and Panavia 21), one compomer cement (Dyract Cem), two resin-modified glass ionomer cements (Fuji Plus and RelyX Luting), and one conventional glass ionomer cement (Ketac Cem). The tensile peel strength was investigated by bonding grit-blasted Ni/Cr alloy beams to a block of the same alloy using the different types of luting cements (n = 20 for each cement), leaving half the length of the beam free. Beams were pulled off the block with a peeling action by applying a tensile load to the free end of the beam and load at which failure occurs was recorded. All the fractured surfaces of the tested samples were examined under a stereo zoom microscope**.**

Results: Data were analyzed using one-way analysis of variance (ANOVA), which showed significant differences between the mean tensile peel strength of the cements ($P < 0.05$). Tukey's pairwise comparisons showed that the mean tensile peel strength (in Newton) of Super-Bond (7.7) was significantly greater than Panavia 21 (6.1) as well as all other luting cements. Ketac Cem gave the lowest value of TPS (2.4). The mode of failure for all the tested cements was cohesive in nature.

Conclusion: Adhesive resin cements have the highest tensile peel strength which may explain their good clinical performance in resin-bonded bridges compared to other luting cements.

Key words: Luting cement, Resin-bonded bridge, Tensile peel strength.

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Introduction

The resin-bonded bridge (RBB) is a conservative alternative to conventional fixed bridge for the replacement of one or two lost teeth with a minimal preparation of the abutments.[1,2] It provides good aesthetic results and has low cost. The primary disadvantage of RBB is that the longevity of the prosthesis is less than that for conventional prosthesis.[2,3] Improvements in the prosthesis design, preparation design and adhesive bond strength enhance the survival rates of RBB but there are still an unacceptable number of clinical failures mostly because of debonding.[4,5]

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Assessment of bonding for RBB is usually studied by measuring tensile or shear bond strength. The general view is that the higher the tensile bond strength, the higher would be the adhesive bond quality. Degrange *et al.*[6] found higher values of tensile bond strengths with Panavia Ex material bonded to Ni/Cr alloy compared to Super-Bond C&B (70.7 MPa and 28.5 MPa respectively). With retainers having a surface area of 10mm², the tensile force required to cause debonding would have to be about 280 N - 700 N, and such high loads are unlikely to occur clinically, nevertheless, debonding of the RBB is a common mode of failure.[4,5] Another surprising observation is that the RBB most frequently fails at the resin-metal interface leaving a layer of resin on the enamel.[4,5] This contrasts with the observation that the tensile bond strength of resin-metal is generally higher than that of resin-enamel.[4]

The tensile peel strength (TPS) test as a means of assessment of bonding of RBB was explored by Northeast *et al.*[7] They proposed that the failures of RBB occur due to tensile peel stresses in the adhesive layer. The loading conditions result in a peeling action at the adhesive interface and this may provide a more probable explanation for failure of RBB than measurement of tensile or shear bond strengths.[7]

The purpose of this study was to measure the TPS of different types of luting cements bonded to Ni/Cr alloy and study the effect on the adhesive bond quality.

Methods

Six cements were investigated (Table I); two chemically adhesive resin cements (Super-Bond C&B and Panavia 21), one compomer cement (Dyract Cem), two resin-modified glass ionomer cements (Fuji Plus and RelyX Luting), and one conventional glass ionomer cement (Ketac Cem).

Twenty Ni/Cr alloy beams (Talladium-V, Talladium, Bucks, UK) 22mm long, 5 mm wide and 0.5 mm thick were used. A 1mm diameter central hole was drilled 1.5mm from one end of each beam. A 15 mm brass block (20 blocks) with a Ni/Cr alloy base bonded to one of its surfaces was also used in this study (Fig. 1). Ni /Cr beams and blocks were blasted with fresh 50µm alumina grit, washed in distilled water in an ultrasonic cleaner for 5 minutes and then air-dried before bonding with the luting cements.

Manufacturers' specifications as to proper mixing time, paste-to-paste and powder-to-liquid ratios were carefully followed during mixing of luting cement. After mixing the luting cement, it was applied to the fitting surface of the beam. The beam was aligned perpendicular to the centre of the free edge of the Ni-Cr block such that a 10 mm length of the beam was bonded to the block with the aid of an alignment jig.

A compressive load of 40 N was applied vertically to the beam (at about the middle of the 10 mm bonded to the block) during setting of the cement using a Lloyd universal testing machine to produce consistent cementation procedure. Excess cement was removed. 20 samples were made for each type of the tested cements. The samples were stored in the dry air at room temperature and tested after 24 hours.

The prepared samples were mounted in a Lloyd tensile machine (Lloyds Instruments. UK) with the free end of the beam perpendicular to, and in line with, the load cell (100N). Each beam was pulled off the block by a small hook that engaged the hole on the free end of the beam (Fig. 2) at a crosshead speed of 1mm/min and the force at failure was recorded.

Results

The mean TPS values and the standard deviations (in Newton) are as follows: Super-Bond C & B 7.7 +/- 1.4, Panavia 6.1 +/- 1.3, GC Fuji plus 5.1 +/- 0.7, Rely X Luting 4.5 +/- 0.8, Dyract Cem 4.2 +/- 1.3, Ketac Cem 2.4 +/- 0.4.

Fractured surfaces were examined at 40 X magnifications under stereo zoom microscope. The mode of failure of all the tested cements was similar in the first 2mm and was cohesive in nature. The crack initiation took place close to the adhesive-substrate where there are high tensile peel stresses. The fracture then travelled close to the beam-adhesive interface (Fig. 3) leaving most of the luting cements on the block surface (Fig. 4).

There was no exposure of the grit-blasted beam surfaces that were cemented with Super-Bond C&B and Panavia for the whole bonded area of the beam. The beams that were cemented with other luting cements were covered with the

Table I: Product and manufacturer information of luting cements that were tested

Luting Cement	Type	Setting Reaction	Manufacturer
Super-Bond C&B*	4-META +PMMA Adhesive resin	Polymerization	Sun Medical Co., Moriyama, Shiga, Japan.
Panavia 21	MDP/ Bis-GMA Adhesive resin	Polymerization	Kuraray Co, LTD, Osaka, Japan.
Dyract Cem Plus	Polyacid-modified composite resin.	Polymerisation.	Dentsply DeTrey, Konstanz, Germany.
RelyX Luting	Resin Modified Glass Ionomer	Polymerisation and Acid-Base reaction.	3M ESPE, St Paul, MN, USA.
GC Fuji Plus	Resin Modified Glass Ionomer	Polymerisation and Acid-Base reaction.	GC America, Chicago, III
Ketac Cem Aplicap	Conventional Glass Ionomer	Acid-Base reaction.	3M ESPE, St Paul, MN, USA.

* This cement is also marketed by Parkell products (Farmington, NY, Japan) under the trade name C&B Metabond.

Table II: One-way analysis of variance for tensile peel strength of all tested cements

Source	DF	SS	MS	F	P-value
Resin	5	319.90	63.98	55.96	0.000
Error	114	130.34	1.14		
Total	119	450.25			

cement in the first 2mm of bonded surface. For the remaining length of beam surfaces, some areas were covered with the cement while other areas showed exposed grit-blasted metal.

Data were analyzed using one-way analysis of variance (ANOVA), which showed significant differences between the mean TPS of the cements ($P < 0.05$) (Table II). Tukey's pairwise comparisons (Fig. 5) showed that the mean TPS of Super-Bond was significantly greater than Panavia as well as all other luting cements. The mean TPS of Dyract Cem, Fuji Plus and RelyX Luting were not significantly different. The mean TPS of Ketac Cem was significantly the lowest.

Discussion

The RBB requires reliable bonding between the tooth substrate and the cast metal framework. Assessment of bonding for RBB is usually studied by measuring tensile or shear bond strength of resin-metal bond and resin-enamel bond. The reported bond strengths of resin to enamel are generally less than that of the resin to metal.[8] This would indicate that resin- enamel bond is the weakest in this system and failure at this interface should be most common. A surprising observation is that the RBB most frequently fails at the resin-metal interface leaving a layer of resin on the enamel.[4,5]

The concept of a TPS as a means of comparing the adhesive capabilities of luting cements of RBB was explored by Northeast *et al*.[7] They proposed that the loading conditions, resulting in a peeling action at the adhesive interface, may provide a more probable explanation for failure of RBB than measurement of tensile or shear bond strengths.[7]

The TPS of different luting cements were measured in this study. The experimental apparatus used was similar to that used by Northeast *et al*.[7] The design of the TPS experimental apparatus is somewhat similar to the design of the RBB if we assume that the Ni-Cr beam acts as the retainer of RBB, the block as the tooth structure and the pull out load as the load responsible for failure of RBB. The TPS experimental apparatus is structural dependent as it depends on the beam thickness; the thicker the beam the higher the TPS value obtained.[7] With thicker retainer the level of stress within the luting cement was reduced, showing that the stress the luting cement has to withstand is an important contributory factor to the clinical outcome and is governed by enhancing the mechanical properties of the luting cements. That means the values of TPS for the luting cements used in this study will change if we change the thickness of the beams. However, the 0.5 mm beam thickness is similar to the recommended retainer thickness used clinically.

The TPS of the adhesive resin cements (Super-Bond and Panavia) were significantly higher than all other cements. Adhesive resin cements form chemical bonds with clean sand blasted base

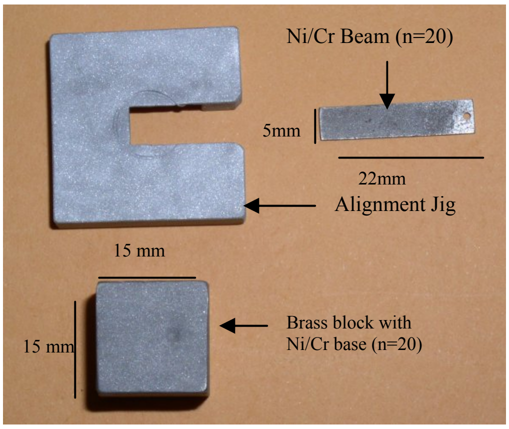

Fig. 1: Materials used in the tensile peel strength test

Fig. 2: The sample mounted in the Lloyd tensile machine during the pull out test.

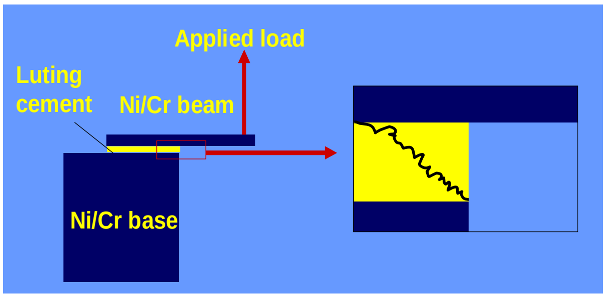

Fig. 3: Diagram illustrating the mode of failure of the luting cements

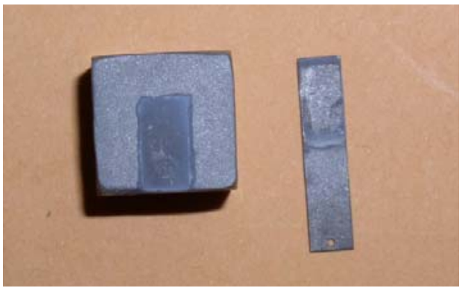

Fig. 4: The surface of Ni/Cr beam and base after fracture. Note that only the first bonded area on the beam was covered with the cement while most of the cement was left on the surface of the base

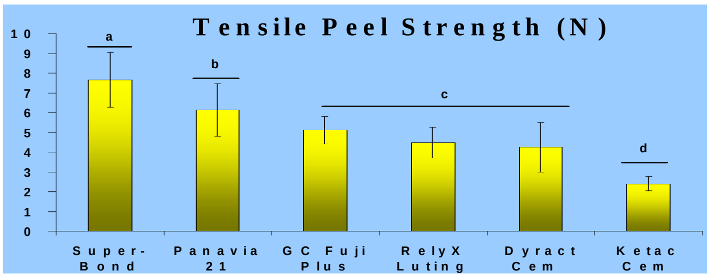

Fig. 5: Tukey's pair wise comparisons for the mean tensile peel strength. Groups that are labeled with the same letter are not significantly different from one another

metal surfaces.(9,10) The chemical bonding of those resins to metal surface is facilitated by the high affinity of carboxylic monomer (found in Super-Bond) and phosphate monomer (found in Panavia) to the oxide film found on chromium containing non-precious alloys.(9,10) The TPS of Super-Bond is significantly greater than that of Panavia. This may be due to differences in the chemical composition of those materials; Panavia 21 is Bis-GMA-based resin cement that contains high volume fraction of

inorganic fillers. While Super-Bond is an unfilled poly methyl methacrylate (PMMA) based resin cement that contains long flexible chains of high molecular weight. Plastic deformation of the long flexible chains delays the onset of brittle fracture, resulting in higher fracture toughness value(11,12) and also higher TPS value.

The TPS of compomer and resin-modified glass ionomer lie between that of composite and glass ionomer. This is expected as those materials have composition which lies somewhere on the continuum between resin cements and glass ionomer cements. There was no significant difference between the TPS of Dyract cem, Fuji Plus and RelyX Luting. This is due to the relatively close chemical composition of those materials. The presence of resinous components

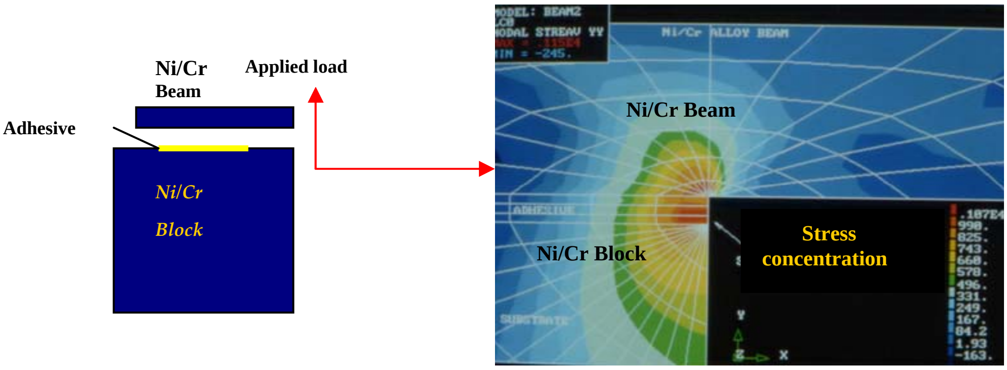

Fig. 6: The finite element analysis of the stress distribution pattern for tensile peel stresses[7] showed that the bulk stress is generated just within the first 2 mm of attachment to the block

in compomer and resin-modified glass ionomer cements has been shown to increase their fracture toughness.[12,13,14] This could be responsible for the greater TPS than that of conventional glass ionomer cements. The lower TPS of Dyract Cem (compomer) compared to Fuji Plus capsules (resin-modified glass ionomer cements), although its not significantly different, may be due to high voids incorporated during mixing of this powder/ liquid cement that cause stress concentration and lead to easier fracture. Another factor may be the presence of urethane dimethacrylate (UDMA) in the contents of Fuji Plus, which have been shown to increase the toughness of composite materials.[15]

The TPS of Ketac Cem, conventional glass ionomer cement, is significantly lower than all the other luting cements. Glass ionomer cement is susceptible to dehydration and crazing during the initial setting reaction.[12,13,15] The resultant microcracks would act to initiate and facilitate crack propagation within the cement matrix.[12,13,15] Clinically it may be advisable to protect the margins of the prostheses cemented with glass ionomer with a protecting agent to avoid the dehydration and crazing.

The TPS values obtained in this study are generally lower than those obtained from tensile bond strength test, this agrees with Northeast study.[7] Therefore, the load required for bond failure to occur due to tensile peel stresses within the adhesive interface is potentially more clinically relevant than measurement of tensile or shear bond strengths, which would predict higher failure loads that are unlikely to be encountered clinically. The reason for the high differences between tensile bond strength and TPS values becomes clear when one considers how the load is distributed in the adhesive layer for these different test arrangements. In the case of the tensile bond strength test, consisting of two rods bonded together with the cement, the stress distribution in the cement layer is relatively uniform.[16,17] This is not the case in the tensile peel strength test where a large stress concentration is generated within the first 2mm in the cement layer close to the free surface such that the bulk of the cement layer is not being stressed and the rest of the retainer makes virtually no contribution to its retention (Fig. 6).[7]

The standard deviation of the TPS test is lower than that of the tensile bond strength tests which generally give high standard deviations with coefficients of variations of more than 30%.[16,17] In both tests the adhesive layer has a large range of defects but in the tensile bond strength test the failure is dictated due to defects in the total volume of the adhesive because the adhesive is stressed everywhere. While in the tensile peel strength test, the failure starts within a specific area of the adhesive layer such that the distribution of defects within the rest of adhesive layer is ignored.

Generally, when the specimens bonded with the cement were subjected to forces, the fracture initiated at the weaker location in the specimen. In this study the mode of failure of all the studied cements was virtually identical; this was cohesive in nature leaving most of the cement on the substrate (Fig. 4). This is similar to the clinical failure where most of the cement is left on the tooth surface after debonding.[4,5] Since the fracture started from within the cement itself and not at the beam-cement interface, this means it is the ability of the cement to resist crack propagation or the fracture toughness of the cement itself that may be responsible for the higher TPS of adhesive resin cements compared to other luting cements. The TPS test is somewhat similar to the fracture toughness test principle in that both of them measure the ability of the material to resist crack propagation. That's why it is not surprising to find relationship between the fracture toughness and the TPS, such that the material with higher fracture toughness has higher TPS.[18] The high fracture toughness and TPS of the adhesive resin cements may explain their good clinical performance in RBB. On the other hand, glass ionomer cement showed unacceptable rate of debonding although it adheres well to tooth structure and metals.[19,20] This could be due to their low fracture toughness and TPS which may contraindicate their use in RBB. Studies indicated that the problem with the glass ionomer cements is a lack of strength of the material itself, not of the adhesive bond to the substrate.[19,20]

But this does not mean that the fracture toughness of the luting cement is the only property that is needed to enhance the outcome of the RBB. Other mechanical properties of the luting cement are still important. We still need a material with a high diametral tensile and compressive strength in order to resist stresses within the adhesive layer and tolerate the masticatory forces.[21,22] Elastic modulus is also important, it has been suggested that luting cement with an elastic modulus in the intermediate range between that of tooth structure and the indirect restorative material is desirable because this can reduce interfacial stress concentrations without causing excessive strains.[21,22]

The tests used to assess the adhesive resin cements of RBB give contradictory results. The tensile bond strength test showed higher values for Panavia compared to Super-Bond.[6,22,23] On the other hand TPS values obtained in this study showed higher values for Super-Bond compared to Panavia. The wedge test showed higher fracture energy of Super-Bond compared to Panavia.[6,22,23] The fatigue tests showed that Super-Bond C&B resin cement had an inferior fatigue bond strength compared to Panavia and Comspan (Bis-GMA resin cement) bonded to different types of alloy.[24-26] There is a need to establish which test is more appropriate in order to determine which type of adhesive will give better clinical performance.

Especially for RBB, the TPS and the fracture toughness data may provide better information than standard tensile bond strength data upon the behaviour of adhesive joints under clinical conditions. In the oral cavity, however, it is considered that factors such as saliva, cyclic occlusal loading, and thermal stresses during function will affect the luting cement and bonding interface over time. So further studies under extensive and prolonged laboratory aging conditions that better simulate clinical situation are needed before judging the higher performance of one material over other materials.

Conclusion

Within the limitations of this study it is concluded that:

- Adhesive resin cements have the highest TPS which may explain their good clinical performance in RBB compared to other luting cements. Among the adhesive resin cements, Super-Bond had higher TPS than Panavia 21.
- TPS data for cements may provide a more probable explanation for failure of RBB compared to tensile bond strength data which would predict higher failure loads that are unlikely to be encountered clinically.

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