A laboratory investigation of three cements used for orthodontic banding of porcelain molars

Masters of Science Candidate: Tracy Herion, D.D.S.

A thesis submitted to the Department of Orthodontics, Oregon Health and Sciences University School of Dentistry in partial fulfillment of the requirements for the M. S. degree

Portland, Oregon 97239

March 2005

A Laboratory Investigation of Three Cements Used for Orthodontic Banding of Porcelain Molars

A thesis presented by Tracy Herion
In partial fulfillment for the degree of Master of Science in Orthodontics

March 2005

Approved: ______________________

Jack L. Ferracane, Ph.D.
Professor and Chairman
Department of Restorative Dentistry

Approved: ______________________

David L. May, D.M.D., Ph.D.
Assistant Professor
Department of Orthodontics

Approved: ______________________

Tsung-Ju Hsieh, D.D.S., M.S.D.
Assistant Professor
Department of Orthodontics

Acknowledgements

To Dr. Jack Ferracane, thesis advisor. Thank you for your guidance, suggestions, and expertise in materials testing.

To Dr. David May and Dr. Tsung-Ju (Frank) Hsieh, members of my thesis committee. Thank you for your interest in the project and help with editing drafts.

To Dr. David Covell, Chairman of the Orthodontic Department. Thank you for helping to organize the process of preparing the thesis and for reviewing drafts.

To Lucas Ferracane. Your knowledge of the Instron and the time you spent in the lab assisting me with the tests was so helpful.

To Drew Herion, my husband. Thank you for all the time spent discussing the project and for helping to prepare the samples. You have been a constant support throughout these last two and half years.

Abstract

Retention of bands cemented to porcelain crowns is an important consideration for some orthodontic patients. Objectives of this study were to: 1) compare the mean shear-peel bond strength of microetched orthodontic bands cemented to porcelain molar denture teeth with either a conventional glass ionomer (GIC; Ketac-Cem, 3M ESPE, St. Paul, MN), a resin modified glass ionomer (RMGIC; 3M Multi-Cure, 3M Unitek, Monrovia, CA), or a compomer (Transbond Plus, 3M Unitek, Monrovia, CA), 2) assess the amount of cement remaining on teeth following debanding, and 3) determine the survival time of cemented bands subjected to mechanical fatigue. Ninety porcelain denture teeth (Dentsply, York, PA) were secured to composite blocks, assigned to three groups, and 30 bands were cemented with each cement. Sixty banded teeth (20/cement group) were used to determine shear-peel bond strength and the remaining 30 (10/cement group) were used to determine survival time. Shear-peel bond strength was determined using an Instron machine (Model TT-B Universal Testing Instrument, Instron Engineering Corporation, Canton, MA) and groups were compared using one-way ANOVA. The amount of cement remaining on the teeth following band removal was scored visually and groups were compared with a chi-square test. Fatigue testing was simulated by placing the teeth with cemented bands in a vessel with water and ceramic pellets and rotating in a ball mill. A log-rank test was used to compare differences in survival times in the ball mill. The level of significance for all comparisons was set at $P<0.05$. No differences were found in mean shear-peel bond strength between the three cement groups. Shear-peel bond strength values determined for each group were: 0.63 MPa, Ketac-Cem; 0.59 MPa, 3M Multi-Cure; and 0.76 MPa, Transbond Plus. The amount of cement remaining on the teeth varied between the compomer and GIC groups ($P=0.011$) with more cement remaining on the teeth when compomer was used; no differences were found between other groups. The mean survival times of bands cemented with compomer (4.6 hours) or RMGIC (5.4) were longer than for bands cemented with GIC (2.3; $P<0.001$); no difference was found between compomer versus RMGIC. The findings show that on porcelain teeth the three band cements have comparable mean shear-peel bond strengths, but the survival times of RMGIC and compomer cements are superior to GIC when subjected to simulated mechanical fatigue.

Table of Contents

List of Figures

List of Tables

Literature Review

Orthodontic fixed appliances often include stainless steel bands around posterior teeth. Although direct bonding of posterior attachments by acid-etch composite technique is gaining in popularity, the use of bands on molars is still preferred by a majority of practitioners (Keim et al., 2002). To treat patients efficiently, it is necessary to retain the molar bands for the course of treatment, which may last two years or more. Bands are held securely in place by a combination of their close custom adaptation to teeth and an interposing layer of one of the many commercially available luting cements. Over the last forty years, the strength of the bond provided by orthodontic band cements to natural teeth has been thoroughly investigated in laboratory studies (Williams et al., 1965; Norris et al., 1986; Durning et al., 1994; Millett et al., 1995; Millett et al., 1998; Aggarwal et al., 2000; Millett et al., 2003a; Millett et al., 2003b; Clark et al., 2003). As discussed in these laboratory studies, the typical protocol used in laboratory investigations of cements is to determine force values required to remove bands cemented to teeth and to subject the cemented bands to some form of thermocycling and/or fatigue testing. The majority of cements that are now commercially available in orthodontics have been subjected to laboratory testing with bands cemented on natural teeth. When the cements are used according to manufacturer instructions, most have been shown to effectively retain orthodontic bands at clinically applicable force levels although force levels required to remove bands can vary between cements. A review of the literature by Millett and associates (1995) found that the clinical failure rate of bands cemented on natural teeth with the glass ionomer cement ranged from 6-26% over observation periods ranging from 12-24 months. Glass ionomer cement has also been used to effectively retain bands on stainless steel crowns when surfaces at the band/crown interface are first roughened with a diamond bur (Beemer et al., 1993). However, as a greater number of adults seek orthodontic treatment, and many of them having full coverage porcelain crowns, there is a need for information that can be used to make decisions regarding the placement of bands on porcelain molar crowns. A review of the literature showed that information is lacking with regard to how orthodontic band cements perform when used to place bands on molars with porcelain crowns. In a clinical setting a loose band on a porcelain tooth may be of less pathologic concern than one on a natural tooth because no coronal enamel decalcification and decay will occur on a porcelain surface under the loose band. However, loose bands in either case present a clinical inconvenience resulting in longer appointments and potentially longer treatment time. The variety of dental cements that are used for cementation of orthodontic bands are reviewed below.

Zinc Phosphate Cement

Zinc phosphate cement was commonly used throughout the last century. Zinc phosphate cement sets by a chemical reaction that occurs when a powder mix of zinc oxide containing additions of magnesium oxide and pigments is combined with a liquid solution of phosphoric acid in water buffered by aluminum and zinc ions. The reaction begins as the acidic (phosphoric acid) liquid dissolves the alkaline (zinc oxide) powder. The set cement is composed of a porous hydrated matrix of zinc phosphate surrounding residual zinc oxide particles (O'Brien, 2002; Craig et al., 2004). The cement is typically mixed on a cold glass slab to prolong working time by minimizing the temperature rise that results from the exothermic reaction. The setting reaction can also be slowed by adding only small increments of the powder to the mix over time intervals. The mixing of zinc phosphate is sensitive and time consuming but this deliberate method is necessary to reach the desired consistency and to provide adequate working time. Another drawback of zinc phosphate cement is a lack of strong band adhesion because the retention to the enamel surface and band is solely due to mechanical interlocking, as opposed to a combination of mechanical and chemical adhesion (O'Brien, 2002; Craig et al., 2004). Additionally, the cement has a low tensile but high compressive strength, resulting in brittleness, and it has a relatively high solubility in oral fluids (O'Brien, 2002; Craig et al., 2004). As a result, there is a high potential for micro-leakage resulting in demineralization of the tooth surface (Brown, 1989; Johnson, 2000; Craig et al., 2004). To limit demineralization some manufacturers add fluoride to the base cement, but this makes the cement more brittle (Brown, 1989).

More recently developed band cements that are less soluble in the oral cavity, are less brittle, and have greater retentive strength have largely replaced zinc phosphate and currently use of the latter is limited (Johnson, 2000; Craig et al., 2004). Zinc phosphate generally performs least effectively compared to other cements in debanding studies (Aggarwal et al., 2000; Durning et al., 1994). One of the earliest studies that examined band retention on crowns of natural teeth used zinc phosphate cement (Williams et al., 1965). This study is purportedly the first to examine cements on anatomic teeth rather than on a flat substrate (Williams et al., 1965). Bands cemented with zinc phosphate provided higher force values to achieve debanding then did bands cemented with zinc oxide eugenol (Williams et al., 1965). However, zinc oxide eugenol cements are no longer used in orthodontics, and more current studies of the strength required to deband natural teeth have compared zinc phosphate to glass ionomer and compomer cements. These studies have shown that bands cemented with zinc phosphate cement are removed at much lower force levels than more recently developed cements (Aggarwal et al., 2000; Durning et al., 1994).

Glass Ionomer Cement

Glass ionomer cements were developed over thirty years ago in Great Britain by Wilson and Kent (1972). Their glass ionomer cement was introduced under the name aluminosilicate polyacrylate (ASPA) cement. Glass ionomer cements are powder/liquid systems. The powder is composed of a melted fluoroaluminosilicate glass which is crushed and milled into fine particles. The essential ingredients of the glass are aluminum oxide and silicon dioxide, which form a three-dimensional tetrahedron structure of aluminosilicate glass. Metal oxides, metal fluorides, and metal phosphates are also contained in the glass. These provide metal ions that maintain the neutrality and decrease the molecular weight of the structure and provide increased reactivity with the liquid component. The fluoride and phosphate ions present in the glass are not included in the tetrahedron structure (Saito et al., 1999). A distinctive feature of fluoroaluminosilicate glass that makes it particularly useful in dentistry is that fluoride is released without detrimentally affecting the physical qualities of the cement (Saito et al., 1999). The fluoride is slowly released by diffusion and the cement can be recharged with fluoride when present in the oral environment (Forsten, 1991; Takahashi et al., 1993; Diaz-Arnold et al., 1995).

The second component of glass ionomer cement is an aqueous solution of polyacid. The polyacid is typically a 50% solution of polyacrylic-itaconic acid (or other polycarboxylic acid copolymer) in water. Tartaric acid is also incorporated in the liquid at the 5% level to increase working time and slow the setting reaction by forming complexes with the metal ions, thus interfering with their ability to cross-link the polyacid. The polyacid also may be freeze-dried and incorporated in the powder. When mixed with the liquid containing only water and dilute tartaric acid, the freeze-dried polyacid dissolves. The tartaric acid also may be incorporated into the powder so that the liquid component only contains water (Craig and Ward, 1997; O'Brien, 2002).

When the powder and liquid components of glass ionomer cements are mixed, they set by an acid-base reaction, with the glass acting as the base. In the presence of water, hydrogen ions in the polyacid attack the glass and release metal ions of calcium and aluminum. First the calcium ions, followed by the aluminum ions form ionic interactions with the carboxylic acid in the polyacid to form a salt gel matrix. The set cement is a composite structure. Within the matrix are glass particles surrounded by silica gel containing fluorite crystallites (Craig and Ward, 1997).

Glass ionomer cements have many advantages over more traditional cements, such as zinc phosphate, for use in cementation of orthodontic bands to natural teeth. Unlike zinc phosphate, glass ionomer cements can provide chemical adhesion to teeth and metal substrates (Hortz et al., 1977). A complete explanation of the mechanism providing chemical adhesion has not been formulated. One theory is that the adhesion is formed by ionic reaction of carboxyl groups in the acid with calcium ions in the tooth (Saito et al., 1999). Chemical adhesion is thought to reduce band failure (McComb, 1999). Glass ionomer also has improved tensile and compressive strength (decreasing brittleness) and lower oral solubility than zinc phosphate (McComb, 1999).

Demineralization under ill-fitting bands resulting in enamel white spots can be a rapid and destructive process occurring during orthodontic treatment (Øgaard et al., 1988). Resistance to demineralization provided by glass ionomer is likely a result of improved adhesion, fluoride release, and the antimicrobial nature of the cement (McComb, 1999). An *in vivo* comparison of lesions in a study where orthodontic bands were cemented with either glass ionomer or zinc phosphate cement showed that remineralization was more likely to occur over four weeks with glass ionomer cement (Rezk-lega et al., 1991). However, Eliades (1999) has criticized this study because it did not account for the initial pH differences between zinc phosphate and glass ionomer cement. The stronger initial acidity of zinc phosphate may have affected overall mineral loss (Eliades, 1999). The antimicrobial effect of glass ionomer is thought to be a result of bacterial sensitivity to fluoride, low initial pH, and the release of other ions (O'Brien, 2002; Eliades, 1999). *In vitro* comparison of glass ionomer and zinc phosphate for band cementation has shown that when bands are previously subjected to mechanical stress, the glass ionomer cements provide greater band retention (Durning et al., 1994).

Glass ionomer cements do have some drawbacks for use in orthodontic banding. The mixing and dispensing of glass ionomers, like zinc phosphate, is subject to inconsistency because the proportions of liquid and powder may vary slightly when dispensing and mixing are done by hand (Hamula et al., 1993). Some manufacturers have attempted to decrease this inconsistency by encapsulating the powder and liquid and mixing mechanically, but this adds considerable expense (Hamula et al., 1993). An initial set of cement is achieved in the mouth in about seven minutes, but the complete set of glass ionomer may take up to 24 hours. It is important to note that moisture contamination will impede the setting process, weakening the cement (Craig et al., 2004). Lastly, the site of failure of glass ionomer band cements has been investigated and found to occur primarily at the band/cement interface (Norris et al., 1986; Millett et al., 1998; Millett et al., 2003a).

In the case of unintended band failure, the failure site may provide additional protection against demineralization if the cement remains attached to the tooth, rather than the cement remaining on the band. When the cement remains on the tooth, food debris and plaque collected in the space under the band is not in direct contact with enamel (Norris et al., 1986). However, when bands are removed at the finish of treatment, excess cement remaining on the tooth makes clean up more difficult and time-consuming. The site of failure may be altered when micro etched bands are used. For example, i*n vitro* studies have shown that when micro etched bands are used, failure more often occurs at the enamel-cement interface, with more cement remaining on the band rather than on the tooth enamel after band removal (Millett et al., 1995; Millett et al., 2003b).

Resin Modified Glass Ionomer Cement

To overcome some of the shortcomings of glass ionomer cements additional orthodontic cements have been developed. Resin-modified glass ionomers and compomer cements are now also used for band cementation. Resin-modified glass ionomer cements (RMGIC), also known as hybrid ionomer cements, were designed with the intention of combining the best features of both resin composite and conventional glass ionomer. RMGIC is also composed of a powder and a liquid. Typically strontium glass containing fluoride is the main powder component. However, the polyacid and tartaric acid liquid of a conventional glass ionomer is modified by the addition of water-soluble resin monomers, 2-hydroxyethylmethacrylate (HEMA), and in some cases, pendant methacrylate groups grafted onto the polyacrylic acid copolymer. This composition change also provides a second curing mechanism, polymerization of the resin monomer, in addition to the acid-base glass ionomer reaction (Saito et al., 1999; Craig et al 2004). The initiation of polymerization of HEMA is dependent on cement composition and may be promoted either by an oxidation-reduction involving a peroxide and an amine or a photopolymerization involving a diketone and an amine (Saito et al., 1999). RMGIC is supplied in various forms for dispensing and mixing. The system may have separately packaged powder and liquid that are hand dispensed and mixed, or have the components encapsulated and ready for mechanical mixing, or be supplied as a two paste system packaged in a dispenser and hand mixed (Craig et al., 2004).

RMGIC shows improved qualities when compared to conventional glass ionomer and zinc phosphate cements, including increased fracture toughness and resilience, decreased sensitivity to moisture contamination, and lower solubility due to the presence of the resin component (McComb, 1999; Craig et al., 2004). Decreased moisture sensitivity is a result of a faster setting reaction because of the dual cure nature of the cement and its ability to undergo photopolymerization on command by use of a curing light. RMGIC also adheres chemically to tooth surface and metal (Aggarwal et al., 2000). Fluoride release and reuptake also occur in RMGIC in a range similar to that of conventional glass ionomer (Eliades, 1999; O'Brien, 2002). Adhesion and fluoride release give RMGIC the ability to provide protection from demineralization around the periphery of bands. *In vitro* comparison of teeth exposed to lactic acid-gelatin solution showed that the penetration of demineralization was less for teeth previously banded with RMGIC than for either non-banded control teeth or teeth previously banded with zinc phosphate cement (Foley et al., 2002).

Comparison of band cement strength in debond studies has shown that more force is required to remove bands cemented to natural teeth with RMGIC compared to zinc phosphate (Aggarwal et al., 2000). When RMGIC is compared to conventional glass ionomer in debond studies, the results of the two cements appear equivalent with regard to required debanding force, however bands cemented with RMGIC were shown to have superior fatigue properties (Millett et al., 2003a; Millett et al., 2003b).

Despite the ability of RMGIC to adhere to tooth structure, the site of band failure during debanding tests may occur more commonly at the cement/enamel interface, potentially facilitating clean-up following band removal (Millett et al., 1998; Millett et al., 2003a; Millett et al., 2003b). However, differences in the site of band failure have been found between various RMGICs supplied by different manufacturers (Millett et al., 2003a).

Compomer Cement

Compomers are also known as acid-modified composite resin (Johnson, 2000), modified composites (Millett et al., 2003b), or polyacid-modified composite resins (Aggarwal et al., 2000). Compomer cements are essentially resin composites that slowly release fluoride. Their physical properties are very similar to resin composite. The nomenclature and classification of RMGIC and compomers can be confusing. The main factors distinguishing the two is that compomers do not contain water, do not set by an acid-base reaction, and cannot chemically adhere to tooth structure (Saito et al., 1999). Compomers are a one-paste system. One main difference between compomers and composite is the filler material. Compomer filler contains glass powder that releases fluoride (Saito et al., 1999). No acid-base reaction occurs during the setting; rather setting occurs via free radical polymerization of methacrylate groups initiated by a photosensitizer (Johnson, 2000; Millett et al., 2003b). However, some manufacturers have proposed that a delayed acid-base does occur during setting as the resin of compomer contains acidic groups that may react with cations released from the fillers. Gillgrass et al. (1999) investigated fluoride release and antimicrobial activity of glass ionomer (Ketac-Cem, 3M ESPE, Seefeld, Oberbay, Germany) compared to compomer (Ultra Band Lok, Reliance Orthodontics, Itasca IL) and found both were much greater for glass ionomer. Interesting, however, they found that microleakage between the cement and tooth was equivalent for the two cements despite the lack of chemical bond between compomer and enamel. They postulated that although the compomer cement shrinks more during setting than conventional glass ionomer, compomers undergo significant hydroscopic expansion, which may offset microleakage. Investigation of compomers on natural tooth structure has shown that they lack any direct chemical adhesion (Moodley and Grobler, 2003). Compomers are more similar to composites than they are to glass ionomer cements in terms of their adhesion to teeth and therefore need to be bonded to tooth structure with a separate bonding agent. Since a bonding agent is omitted when compomer cements are used to place orthodontic bands, adherence of the bands must be solely mechanical.

Compomers are noted for their physical properties such as low solubility in oral fluids, high fracture toughness, and relatively higher compressive strength compared to zinc phosphate (Craig et al., 2004). Investigations of shear-peel band strength have shown mixed results. Aggarwal et al. (2000) showed that compomers perform equivalent to RMGIC and are superior to zinc phosphate. However, they noted that salivary contamination greatly reduced the retention of bands cemented with compomers. Millett et al. (2003a) also found compomers to have similar shear bond strengths to glass ionomer and RMGIC and noted that compomers tend to fail at the enamel/cement interface. In contrast, Millett et al. (2003b) found that bands cemented with compomers had lower retentive strength than those cemented with either RMGIC or glass ionomer. The latter paper did however show that compomers have greater fatigue properties than conventional glass ionomer. Lack of consistency with regard to testing of compomers may have to do with the various compositions of compomer available, making it difficult to draw the same conclusions about different brands of compomer cement (Aggarwal et al., 2000).

Surface Treatment of Orthodontic Bands

In addition to cement choice, the adhesion of an orthodontic band on a tooth has a considerable amount to do with band contour, fit, and surface texture. Investigations of orthodontic bands have shown that stainless steel bands may offer significantly greater retention if they are etched prior to cementation (Millett et al., 1995; Aggarwal et al., 2000). There are two methods of etching bands: factory micro etching and in-office sandblasting. Micro etching increases the surface area of the band. The resulting rough surface provides better chemical and mechanical bonding (Millett et al., 1995). Laboratory investigation has shown that micro-etched bands have improved bond strength over in-office sandblasted bands and this is likely due to greater metal roughness that results from factory micro-etching (Aggarwal et al., 2000). Clinical studies have also shown that sandblasted bands have reduced failure rates compared with untreated bands (Millett et al., 1995).

Bonding to Porcelain Surfaces

Dentistry has used porcelain as a restorative material for fabrication of denture teeth for over 200 years. However, improvements made during the 1960s to dental porcelain involving finer powders and vacuum firing greatly expanded the application of ceramics in dentistry (McLean, 2001). Porcelain is used today for the fabrication of denture teeth, porcelain-fused-to-metal (PFM) fixed crowns and bridges, all-ceramic crowns, and ceramic veneers (O'Brien, 2002). Traditional fine powdered dental porcelain is composed primarily from three ingredients: feldspar (K_2O-Al_2O_3-$6SiO_2$), silica (SiO_2), and alumina (Al_2O_3). The manufacturing process begins with heating the crystalline ingredients together with sodium carbonate or potassium carbonate fluxes. A glass forms that is not crystalline, but amorphous. The glass melts at a lower temperature than the initial ingredients. A crystalline material called leucite also forms in the glass under certain conditions and is embedded in the matrix of low-melting glass. Refiring with metal oxides adds color and fluorescence. The porcelain is crushed to a fine powder, which is the form used in the dental laboratory. Traditional porcelains are classified according to their fusing temperatures. Denture teeth are made with high-fusing porcelain, jacket crowns are fabricated with medium-fusing porcelain, and ceramic-metal restorations are made with low-fusing porcelain (Craig et al, 2004). High-fusing porcelain denture teeth are fired above 1300°C in a metal mold under vacuum. Low-fusing porcelain used with metal is applied in layers on a metal casting and fired in stages in a porcelain furnace, dried to remove residual water, and then fired from 870-1065°C under vacuum. For orthodontic purposes, adhesion to low or medium fusing porcelains is most applicable. Studies investigating bonding of orthodontic brackets have used uniform feldspathic discs to provide a homogenous substrate, from which to draw conclusions about adhesion to porcelain (Gillis and Redlich, 1998; Bourke and Rock, 1999; Jost-Brinkmann and Böhme, 1999; Kocadereli et al., 2001; Kitayama et al., 2003). This method saves considerable cost over bonding to fully fabricated PFM crowns.

Numerous studies have reported on bonding orthodontic brackets to porcelain teeth using a combination of resin composite or resin modified glass ionomer adhesive and some type of chemical conditioner and/or mechanical surface treatment (Gillis and Redlich, 1998; Bourke and Rock, 1999; Kocadereli et al., 2001; Kitayama et al., 2003; Pannes et al., 2003; Schmage et al., 2003). Multiple methods used alone or in combination, have been proposed for obtaining a direct bond of stainless steel brackets to porcelain. One suggestion is to remove the porcelain glaze and mechanically roughen with a diamond bur or sandblasting (Gillis and Redlich, 1998; Bourke and Rock, 1999; Kocadereli et al., 2001; Schmage et al., 2003). This method used alone is one of the least effective in achieving adequate bond strength (Gillis & Redlich, 1998; Schmage et al., 2003; Kocadereli et al., 2001) and does not offer any advantage over less damaging treatments (Bourke and Rock, 1999). A second method involves etching with hydrofluoric acid (Gillis and Redlich, 1998; Bourke and Rock, 1999; Kocadereli et al., 2001; Schmage et al., 2003). High bond strengths can be achieved with hydrofluoric acid (Gillis and Redlich, 1998; Schmage et al., 2003), but it may be less preferable than etching with phosphoric acid or complete omission of acid treatment because the etching process produces greater porcelain surface damage (Bourke and Rock, 1999). A third method involves etching with phosphoric acid followed by silane treatment (Bourke and Rock, 1999; Kitayama et al., 2003; Pannes et al., 2003). This is one of the least damaging and most effective means of achieving satisfactory bond strength (Bourke and Rock, 1999; Pannes et al., 2003). A fourth method involves priming porcelain with silane (Bourke and Rock, 1999; Kocadereli et al., 2001; Kitayama et al., 2003; Pannes et al., 2003). Silane treatment may be the single most important factor in determining satisfactory bond strength (Bourke and Rock, 1999). Several groups have found that the most effective combination treatment for achieving high bond strength is surface roughening or acid etching followed by silane treatment (Bourke and Rock, 1999; Kocadereli et al., 2001; Pannes et al., 2003; Schmage et al., 2003).

As previously mentioned, the drawbacks of these bonding methods can include damage to the porcelain surface by conditioning and during debonding (Gillis and Redlich, 1998; Kitayama et al., 2003; Schmage et al., 2003;). Additionally, they involve intraoral exposure to corrosive and potentially toxic agents (Bourke and Rock, 1999). The obvious and often preferable alternative to direct bonding, especially when posterior teeth are involved, is to attach a bracket by means of an orthodontic band (Ireland and Sherriff, 1995). The presence of orthodontic bands is known to make oral hygiene more difficult, causing increased plaque accumulation, gingival inflammation, and alterations in the bacterial composition around bands (Huser et al., 1990). However, these changes usually subside after appliance removal (Sallum et al., 2004). In contrast, damage to porcelain surfaces by surface conditioning techniques may require replacement of restorations and injury to oral tissues by accidental contact with strong acid. Despite the large body of literature regarding materials and techniques used for bonding to porcelain, there is no information to be found that describes the performance of cements used in banding of porcelain crowns when bands are placed using the same procedures that are used for cementing bands on natural molars, without surface treatment or conditioners, as is typically the case.

The aims of this study are:

1. to compare the shear-peel bond strengths of micro-etched orthodontic bands cemented to porcelain crowns with three orthodontic band cements: a conventional glass ionomer (Ketac-Cem, 3M ESPE, St. Paul, MN), a resin-modified glass ionomer (Multi-Cure, 3M Unitek, Monrovia, CA), and a compomer (Transbond Plus, 3M Unitek, Monrovia, CA),
2. to evaluate the predominate site of bond failure in the case of each cement type and to compare the amount of cement remaining on the tooth following debanding, and
3. to compare the survival time of bands cemented to the porcelain crowns with each cement type after simulating mechanical fatigue stress in a ball mill.

Materials and Methods

Sixty anatomic porcelain mandibular first molar denture teeth were obtained for the investigation of shear-peel bond strength (Trubyte bioform vacuum fired 33° posterior size 34M, Dentsply, York, PA). Literature supplied by the manufacturer listed feldspar, silicon dioxide, and aluminum oxide as the ingredients with the three highest weight percentage of the denture tooth composition. Each tooth was used only once for test purposes. The teeth were divided into three groups of twenty teeth. Each tooth was mounted in a 1.3 cm x 2.0 cm block of Triad Colorless TruTray Material (Dentsply, York, PA). Teeth were prepared for mounting by increasing the undercut of the diatoric hole with an inverted diamond cone bur in a high-speed dental hand piece. The glaze on the underside of the teeth was removed with 9.5% buffered hydrofluoric acid applied for 1 minute, rinsed with water and air-dried prior to applying silane with a brush (Ultradent Porcelain Etch and Silane, Ultradent Products, South Jordan, UT). A layer of Transbond XT Light Cure Adhesive Primer (3M Unitek, Monrovia, CA) was applied to the underside of the teeth and light-cured for 20 seconds (Hilux Dental Curing Light model 200, Benlioglu Dental Inc., Ankara, Turkey). The output of the light was measured at 450 mW/cm^2 (Cure Rite Visible Curing Light Meter, EFOS Inc, Williamsville, NY). Triad was pressed onto the underside of the tooth, the tooth was then pushed onto the top of an uncured block of Triad held in a clear plastic mold, lined with petroleum jelly, and the assembly light-cured in a Triad Visible Light Curing Unit (Dentsply, York, PA) for 2 minutes before removing the block from the mold. The denture teeth had a large undercut along the lingual-gingival that was embedded in the Triad material to prevent the undercut from acting as a mechanical lock for the cements. Teeth were embedded in the Triad material to an equal depth by making a scribe line on the lingual of each tooth occlusal to the bulk of the undercut using calipers adjusted to a set distance from the height of the mesiolingual and distolingual cusp tips and then highlighting the line with a permanent marker (Figures 1-5).

Stainless steel narrow contour first molar bands (size 35) with micro-etched fitting surfaces (3M Unitek, Monrovia, CA) were used. They were adapted with a band pusher to each tooth such that the band was seated on the lingual until it was flush with the top to the Triad block, leaving some band exposed above the occlusal surface of the denture tooth (Figure 6). The buccal of the band was seated until it was below the occlusal surface (Figure 7). Twenty bands were cemented with each of the three cements following the recommendation for sample size made by Fox et al. (1994) in their criticism of *in-vitro* orthodontic bond strength testing. Ketac-Cem (3M ESPE, St. Paul, MN), Unitek Multi-Cure (3M Unitek, Monrovia, CA), and Transbond Plus (3M Unitek, Monrovia, CA) were used for cementation. Table I compares characteristics of the three cements. Ketac-Cem is a hand-mixed power-liquid glass ionomer that cures chemically. Unitek Multi-Cure is a RMGIC supplied as separate powder and liquid components that are hand mixed. Multi-Cure sets by three mechanisms: acid-base reaction and resin polymerization that is produced by light curing and by self-curing. Transbond Plus is a compomer and is supplied as a single paste cement that is dispensed from a sealed tube and set only by light curing.

Manufacturer's instructions were followed with regard to mixing, handling, and curing of each cement. Ketac-Cem and Multi-Cure were stored and mixed at room temperature. Transbond Plus was stored in the refrigerator and dispensed at room temperature. Instructions for Ketac-Cem were to mix with a spatula two drops of liquid with one level spoonful of powder on a mixing pad within one minute. Instructions for Multi-Cure were to divide one large level spoonful of powder in half and completely mix the first half with a spatula into 3 drops of liquid on a mixing pad, then mix in the remaining half of the powder, not exceeding 45 seconds. One band was cemented with each mix of Ketac-Cem and two bands with each mix of Multi-Cure. Transbond Plus was dispensed directly onto the bands prior to placement. Following band placement, excess cement was removed with dry cotton rolls.

Bands cemented with Transbond Plus were light cured from the occlusal surface for 30 seconds. Bands cemented with Multi-Cure were light cured on the occlusal surface for 40 seconds (Hilux Dental Curing Light model 200, Benlioglu Dental Inc., Ankara, Turkey). The specimens were then transferred immediately to 100% humidity (achieved by lining sealed plastic containers with wet paper towels) and then placed in an oven maintained at 37°C for 24 hours prior to testing. Fox et al. (1994) reviewed 66 publications on bond strength testing of resin and glass ionomer adhesives and found that this approach was the most common and recommended method for storing teeth between bonding and testing. An Instron testing machine in tensile mode with a cross-head speed of 0.5 in/minute (Model TT-B Universal Testing Instrument, Instron Engineering Corporation, Canton, MA) was used to subject the specimens to a shear-peel debanding force. The specimens were placed in the Instron by securing the Triad block in the grips. Two 0.9 mm (0.036 inch) stainless steel wire loops engaged fully under the buccal tube and the lingual cleat of each band were placed in the opposing grips that were attached to the load cell with a universal joint (Figures 8-10). The universal joint allowed for movement in three planes of space during debanding. Testing proceeded until the band was removed completely from the tooth. The maximum force (lbs.) recorded on the force/time curve during shear-peel debanding was interpreted as the maximum debanding force or cement failure for each specimen (Millett, 1995). The maximum debanding force values were converted to shear-peel bond strength values (MPa) by dividing the force by the band surface area provided by the manufacturer (128.387 mm^2). To determine the surface area of the band in contact with the denture tooth, five samples were randomly chosen to measure the band area on the lingual that was exposed above the occlusal surface. This contact area was determined by removing all residual cement and the buccal and lingual attachments from the band. Total band weight was measured and the band was refit on the denture tooth. A diamond disc was used to cut away the band on the lingual that was above the occlusal surface and the band was weighed again. The difference in weight was used to determine the percentage of total band surface area that was not in contact with the tooth. An exact measurement of the total band surface area did not account for the micro-etched surface. The surface area measurement used was therefore an estimate as has been used in previous investigations (Millett, et al., 2003a).

All specimens were visually assessed to determine the predominant site of failure after band removal. The possible failure sites were the enamel-cement interface, the cement-band interface, or cohesive within the cement; combinations of these failure sites are also possible. In a clinical setting, failure site is significant with regard to removal of cement from the teeth following band removal. The failure site was classified using the Adhesive Remnant Index (ARI) originally proposed by Artun and Bergland (1984) for bonded brackets and adapted for cemented bands by Millett et al. (2003b). The scoring system is as follows: 0, no cement remains on the tooth surface; 1, less than half the tooth surface under the band is covered by cement; 2, more than half the tooth surface under the band is covered by cement; 3, all of the tooth surface under the band is covered by cement.

Thirty additional porcelain teeth were used to test fatigue survival time. These were not secured to Triad mounts. The teeth were divided into three groups of 10 and the groups were distinguished by the number of small dots (0, 1, or 2) drilled with a #2 round bur into the underside of each crown next to the diatoric hole. Bands were fit and cemented with each of the three cements until the top of the band was flush with the occlusal surface on the mesial and distal of the denture tooth. Since no special care was taken to avoid the large lingual-gingival undercut of the denture tooth, the entire inner band surface area was covered by cement and in contact with the denture tooth. The 30 banded teeth were stored for 24 hours at 37°C in 100% humidity prior to testing in the ball mill. The ball mill was used to assess cement failure and followed the protocol investigated and originally proposed by Abu Kasim et al. (1996). The test was conducted on a ball mill (Norton Plastics and Synthetics Division, Akron, OH) in two 140 mL capacity ceramic containers filled with 130 grams of 1.2 cm x 1.2 cm ceramic pellets and 70 mL of water at 37°C (Figure 11). The mill was opened every hour for 8 hours, the contents removed, and the teeth inspected for loose bands. Band tightness was determined by lightly attempting to dislodge the band with a hand scaler placed in the tube on the buccal attachment. Teeth with loose bands were recorded as failures during that time interval and were removed from the ball mill. All remaining teeth with intact bands were returned to the ball mill with another 70 mL of water at 37°C and testing resumed for another hour interval.

Mean shear-peel bond strengths of the three cements were compared using one-way analysis of variance (ANOVA). For comparison of ARI scores, a chi-square test was used. Kaplan-Meier estimates of the survivor functions and the log rank test were used to compare fatigue survival time distributions for the ball mill experiment. Statistical tests were conducted using SPSS (Statistical package for Social Sceinces for Windows) (SPSS Inc., Chicago, IL). All tests were made at the significance level of $\alpha \leq 0.05$

Table I. Cement characteristics

Trade name	*Cement type*	*Curing mechanism*	*Lot number*
Ketac-Cem	Conventional glass ionomer	Chemical cure (acid-base reaction)	180811 2007-04
Multi-Cure	Resin modified glass ionomer	Tri-cure (acid-base reaction, light cure, and self cure)	4DN/4EJ 2005-07
Transbond Plus	Compomer	Photopolymerization (light cure)	4CB 2006-02

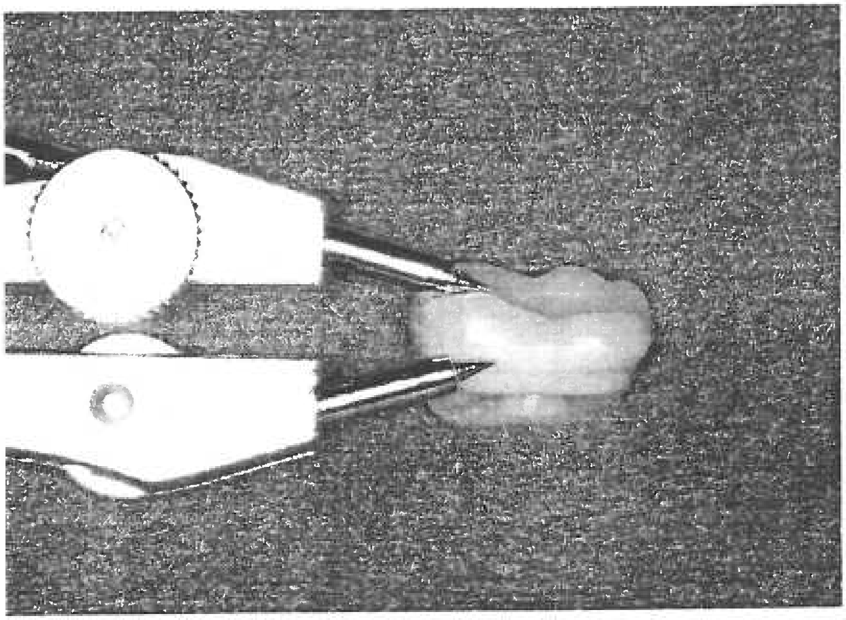

Figure 1. Using calipers to mark the set distance on the mesiolingual cusps for mounting denture tooth in the composite block.

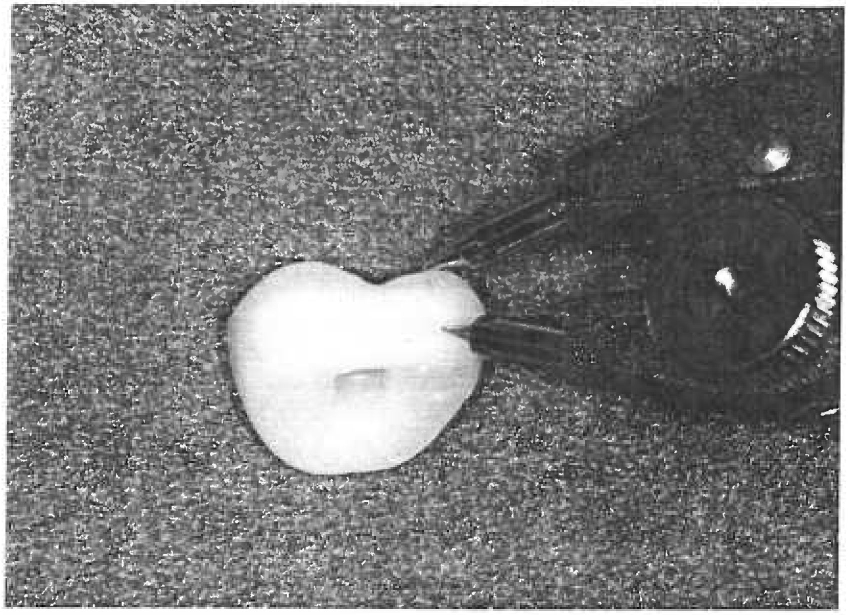

Figure 2. Using calipers to mark the set distance on the distolingual cusps for mounting denture tooth in the composite block.

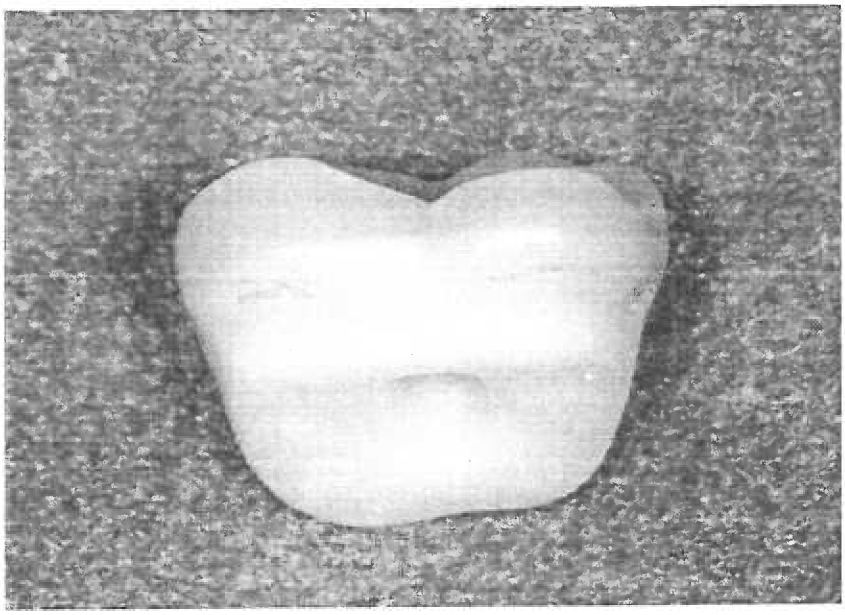

Figure 3. Scribe lines made with calipers on the lingual surface of the denture tooth.

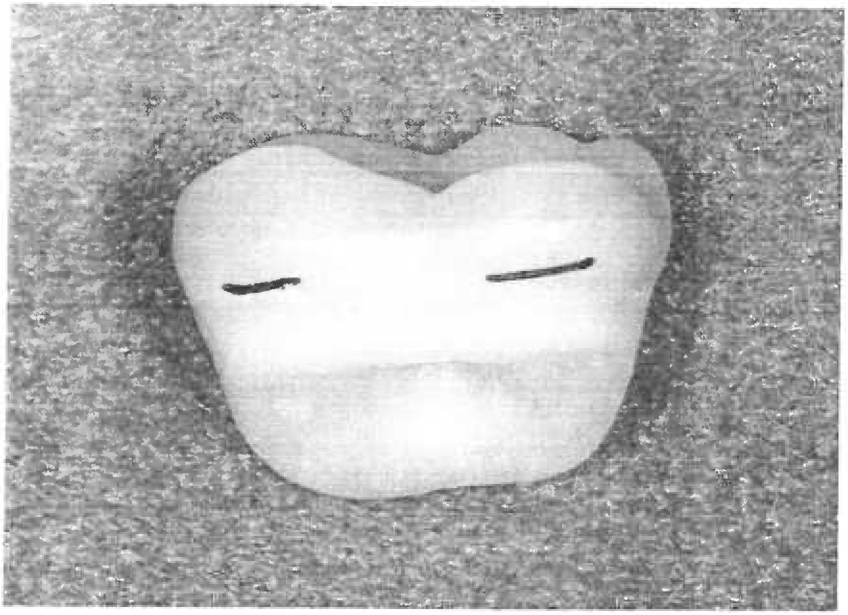

Figure 4. Scribe lines highlighted with permanent marker.

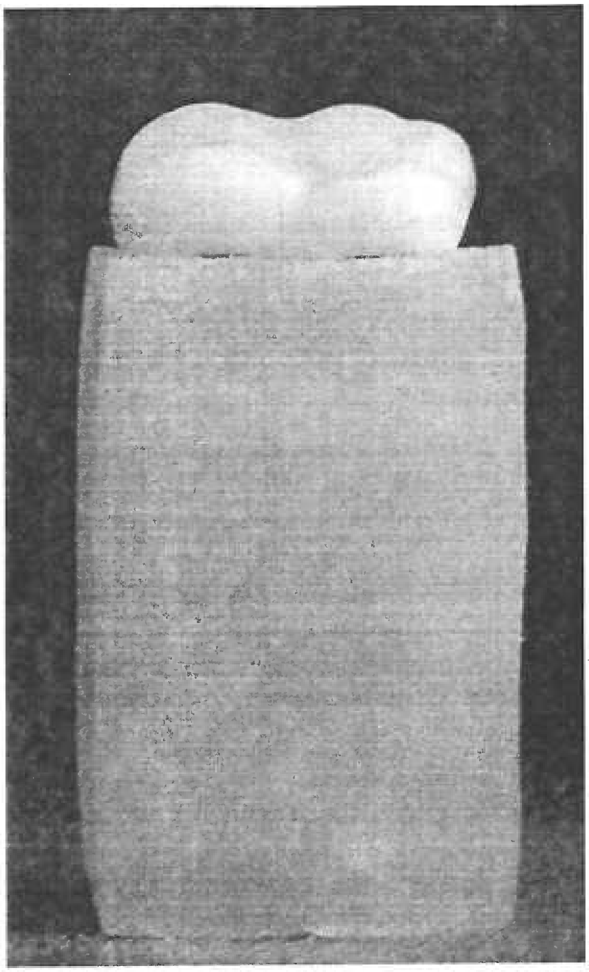

Figure 5. Lingual view of denture tooth mounted up to highlighted scribe lines in the composite block.

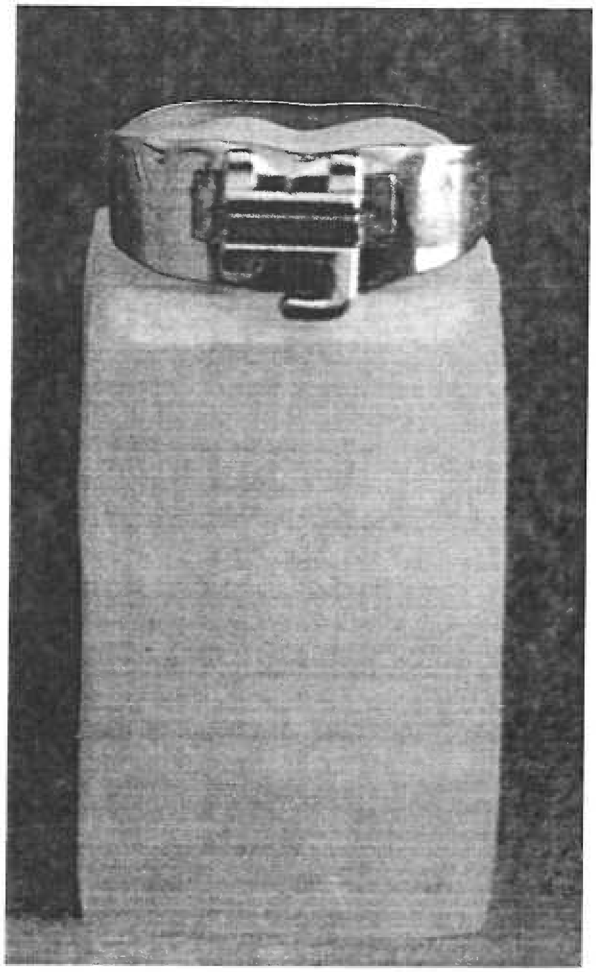

Figure 6. Buccal view shows full band seating leaves some band exposed above occlusal surface on the lingual.

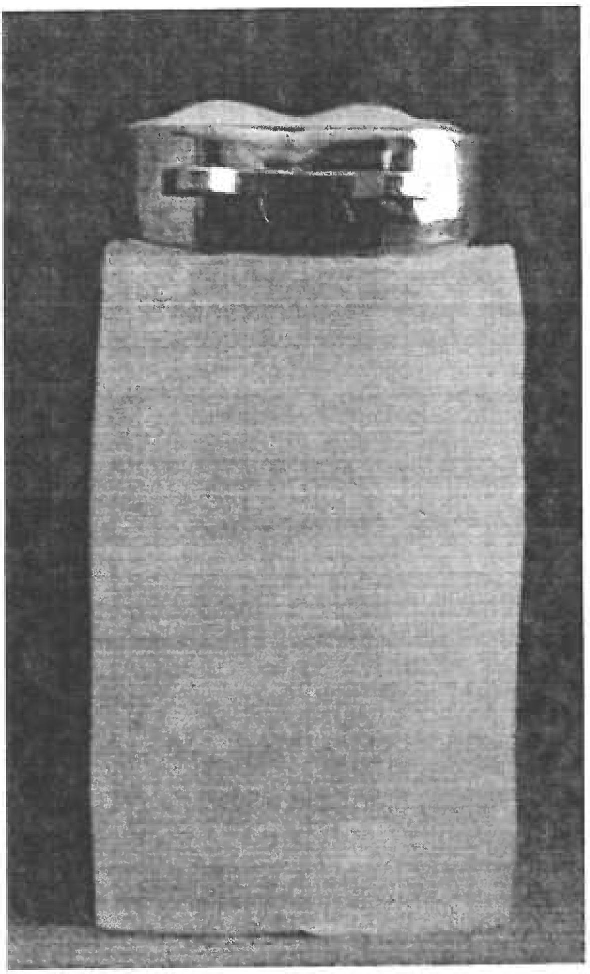

Figure 7. Lingual view shows full band seating places band below buccal occlusal surface.

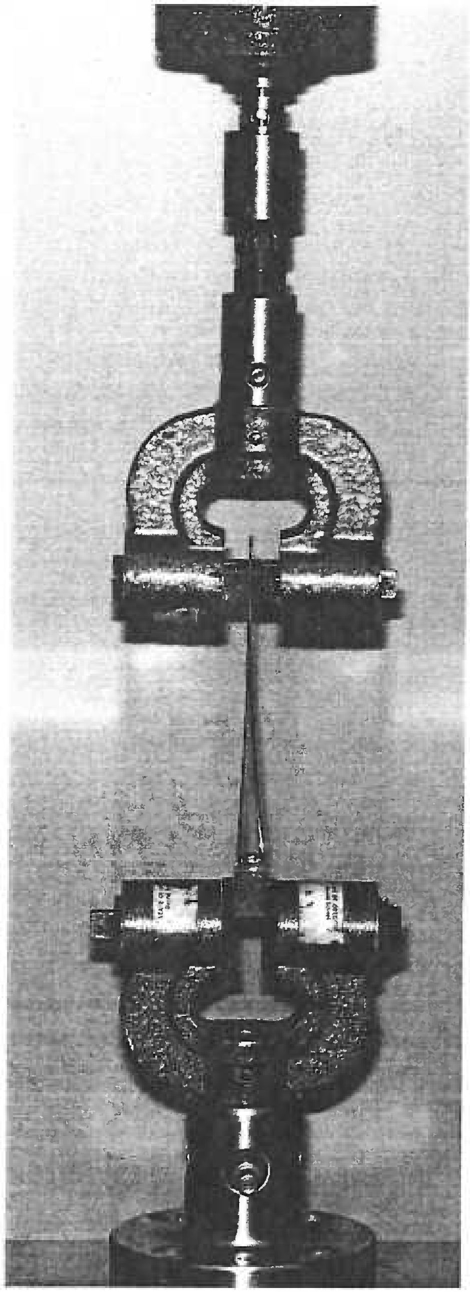

Figure 8. Securing sample in the Instron Testing Machine

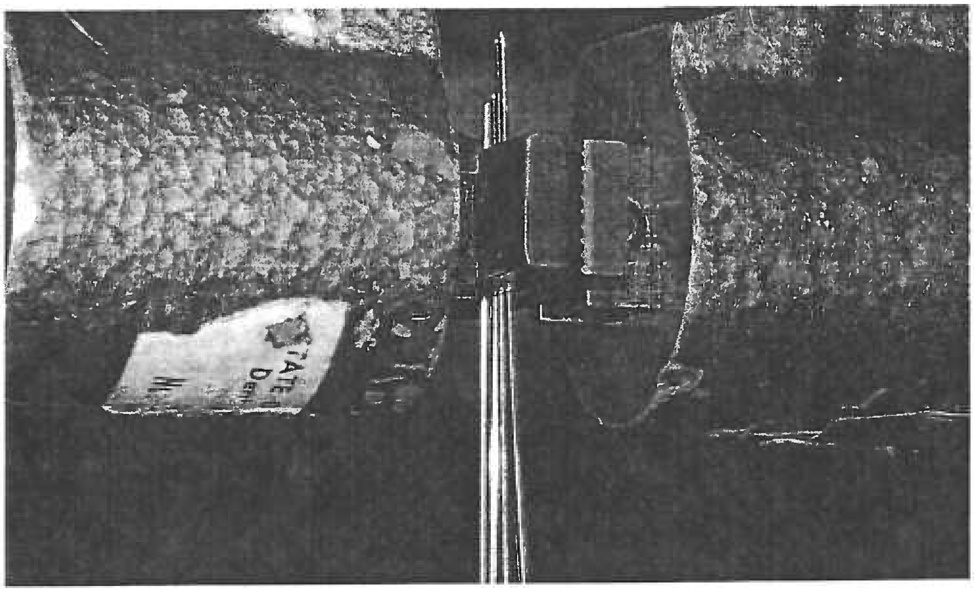

Figure 9. Stainless steel wire loops secured in the grips.

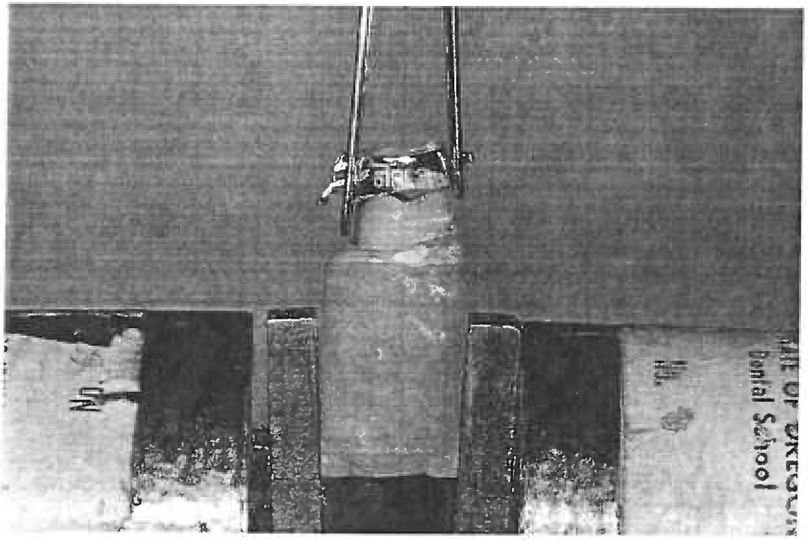

Figure 10. Stainless steel wire loops engaged under the buccal attachments and lingual cleat resulting in band removal during testing.

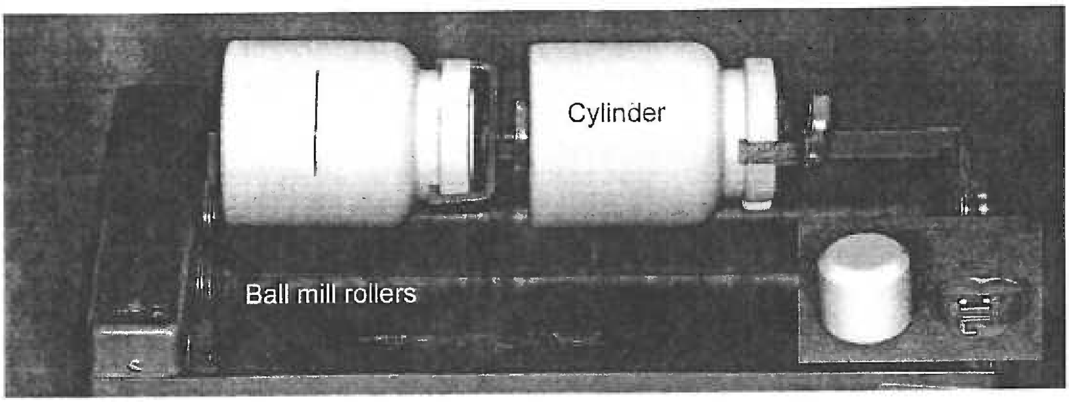

Figure 11. Two ceramic cylinders containing band cemented on denture teeth, water, and ceramic pellets rotating on the ball mill. Inset photo shows relative size of ceramic pellet to banded tooth.

Results

Shear-peel bond strength data for each cement group are given in Table II. There were no significant differences between the groups (P = 0.214). The area of the band in contact with the tooth, excluding band material above the occlusal surface on the lingual, was 85.5 ± 3.4% (n=5). Adjusted values for mean shear-peel bond strength, using the decreased overall surface area, are also shown in Table II. A representative force/time curve obtained for shear-peel bond strength testing is shown in Figure 12. The curve for all samples had an early transient flattening of the upward slope when all the slack was removed from the wire loops and they engaged fully under the band attachments. The highest force value recorded corresponded to complete band separation from the tooth, after which the force curve dropped to zero. Data were not gathered for all 60 samples. In each group some teeth pulled out of the mounting before the band was removed and a peak force value corresponding to complete band removal was not obtained. Three samples failed in this fashion in the Ketac-Cem group, two in the Multi-Cure group, and two in the Transbond Plus group, leaving sample sizes of 17, 18, and 18, respectively.

The most common site of cement failure for all three groups was at the porcelain/cement interface (ARI scores of 0 or 1). The distribution of adhesive remnant scores for each cement is shown in Table III. A significant difference in the distribution of ARI scores was found between Ketac-Cem and Transbond Plus (P = .011). More cement remained on the teeth after band removal on Transbond Plus samples than on Ketac-Cem samples. Ketac-Cem samples failed exclusively at the porcelain/cement interface with no residual cement remaining on any teeth (ARI score of 0). However, even Multi-Cure and Transbond Plus samples receiving an ARI score of 1 had considerably less than 50% of the crown surface covered by cement. Figure 13 shows a representative Transbond Plus sample that received an ARI score of 1. No significant differences in ARI scores were found between Ketac-Cem vs. Multi-Cure or Multi-Cure vs. Transbond Plus.

The fatigue survival time distribution for bands cemented with each cement is shown in Figure 14. The mean survival time of bands cemented with Transbond Plus (4.6 hours) and Multi-Cure (5.4 hours) was significantly longer than for those cemented with Ketac-Cem (2.3 hours) ($P<0.001$). There was no significant difference in mean survival time between bands cemented with Transbond Plus or Multi-Cure. It is not possible to determine the location of cement failure resulting from the fatigue test because the cement becomes dislocated from the teeth and bands as the specimens continue to tumble over the course of the hour.

Table II. Sheer-peel bond strength values for mandibular molar bands cemented with Ketac-Cem, Multi-Cure, or Transbond Plus

Cement	*N*	*Mean force value (kg)*	*Mean bond strength (MPa)*	*Range*	*Standard deviation*	*Mean bond strength (MPa) using 85.5% of band area*	*Standard deviation using 85.5% of band area*
Ketac-Cem	17	8.25	0.63	0.21-1.21	0.32	0.74	0.37
Multi-Cure	18	7.73	0.59	0.17-1.09	0.30	0.69	0.36
Transbond Plus	18	9.94	0.76	0.24-1.21	0.26	0.89	0.31

Table III. Distribution of adhesive remnant scores for bands cemented with each cement

ARI score	*Ketac-Cem**	*Multi-Cure*	*Transbond Plus**
0 (no cement on tooth)	17 (100%)	16 (89%)	13 (72%)
1	0	2 (11%)	5 (28%)
2	0	0	0
3 (no cement on band)	0	0	0

* difference significant, p=0.011

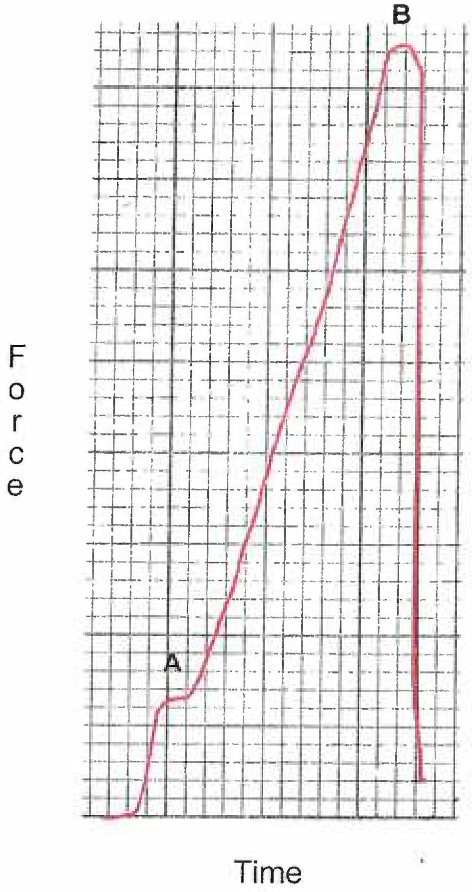

Figure 12. Representative force/time curve used to determine shear-peel bond strengh. Region A corresponds to all of the slack being removed from the mounting. Region B is the highest force valued achieved, just prior to complete band removal.

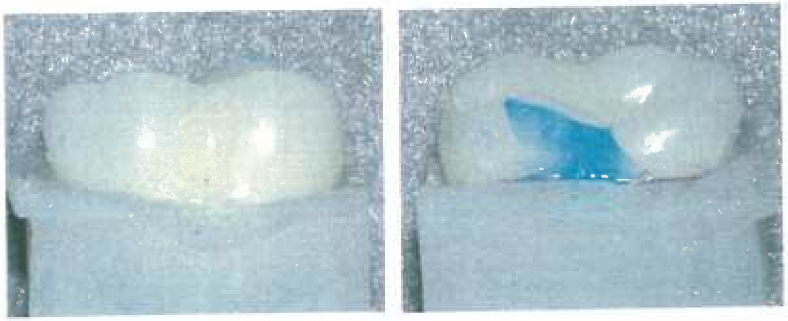

Figure 13. Buccal and lingual views of one representative Transbond Plus sample that received an ARI score of 1 (less than half of the tooth surface that was under the band is covered by residual cement). Sample shows that minimal cement remained on the tooth but a score of 1 was still appropriate.

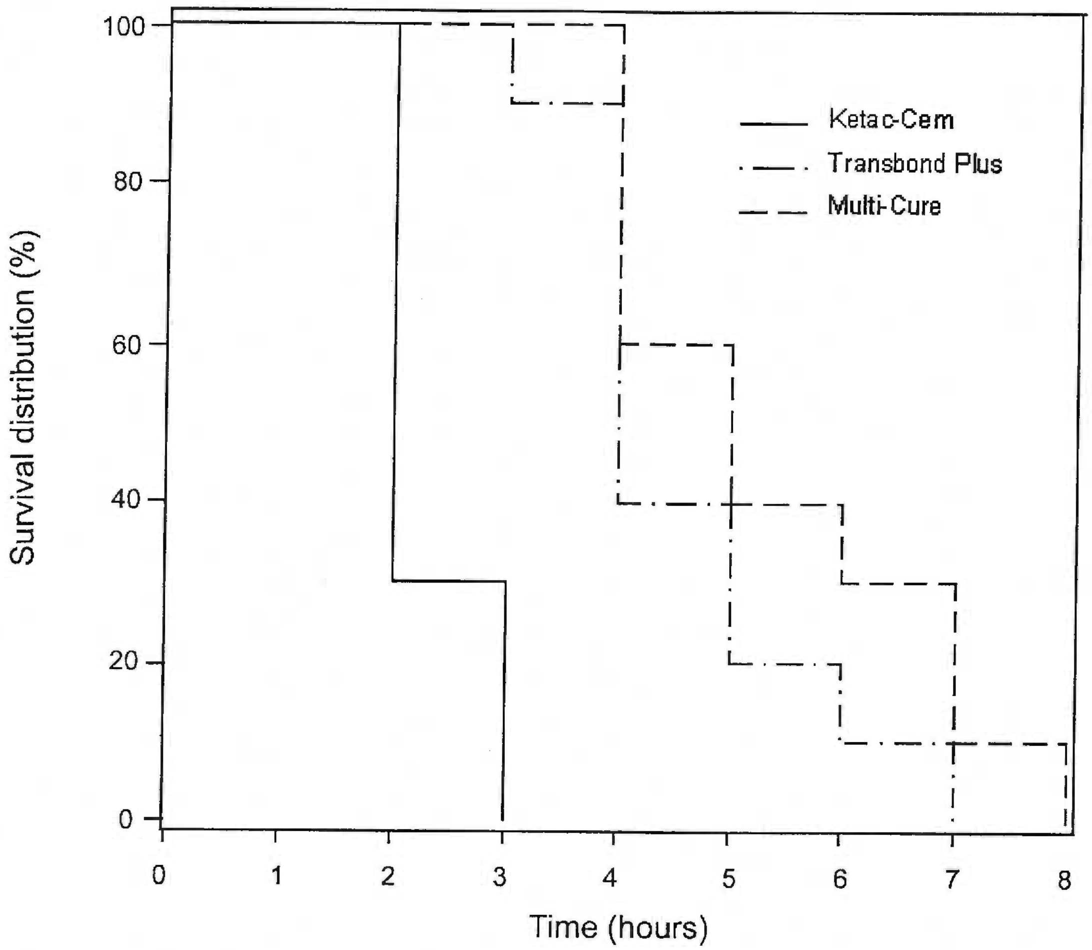

Figure 14. Survival time distribution for 10 mandibular molar bands cemented with each cement.

Discussion

The shear-peel bond strengths of orthodontic bands cemented to porcelain teeth with Ketac-Cem, Multi-Cure, and Transbond Plus were investigated using the maximum force recorded on the force/time curve. This method, first proposed by Millett et al. (1995) and used subsequently by other investigators (Millett et al., 1998; 2003a; 2003b), provides a value that has been shown to be reproducible and has eliminated confusion about what particular point on the curve represents cement failure. Using a similar protocol for shear-peel bond strength testing, Millett et al. (2003b) noted that a mix of shear, compressive, and tensile force, as opposed to pure shear testing, is actually achieved when using a force that is vertical to the long axis of a tooth to pull off an orthodontic band. The combination of forces results from the convexity of the crown and the inexact adaptation of the band.

Following initial sample size recommendations made by Fox et al. (1994) for investigations of orthodontic bracket bond strength studies, 20 bands and teeth were used in each cement group. The recommendations for sample size in bracket testing have been applied to band testing by previous investigators (Millett et al., 2003a). However, in the present study, results of shear-peel bond strength were not obtained for all samples due to failure of the mounting of the denture teeth in the composite block. Denture teeth do not have root forms to help lock the tooth in the composite and resist dislodgement during testing. To strengthen the lock of the denture tooth in the composite block, the porcelain embedded in the block was undercut with a bur, hydrofluoric acid etched, and treated with silane and resin bonding agent. This combination of treatment was found in pilot investigations to greatly enhance the retention of the teeth in the composite block. However, during testing some samples still failed by the tooth dislodging from the block prior to the band being removed. Therefore, 17 to 18 samples were successfully measured to determine mean shear-peel bond strengths. No samples included in the results appeared to fail through a combination of band removal and failure of the mounting.

In their laboratory investigation of debanding, Aggarwal et al. (2000) proposed removing orthodontic bands with a band removal device similar to hand instruments used clinically to gain a purchase point under the gingival edge of the band on the buccal surface for lower molars. They proposed that this method of removal better simulates the clinical environment than does pulling from both the buccal and lingual surfaces beneath attachments welded to the center of the bands. However, the method of band removal proposed by Aggarwal et al. (2000) is unique to their investigation and limits the ability to make comparisons with other investigations that almost exclusively use the buccal-lingual method of pulling off the band. For this reason, the more commonly used approach of pulling from both sides of the band was chosen for the present study.

In the present study, the mean shear-peel bond strength did not differ significantly between cement groups. Although no other studies have been found that investigate these cements on porcelain teeth, they have been investigated on natural teeth. Millett et al. (2003a) also found no significant differences between shear-peel bond strength of bands cemented with RMGIC (Multi-Cure) or GIC (Ketac-Cem), confirming the findings of the present study. Aggarwal et al. (2000) also investigated Multi-Cure cement, but rather than comparing it to traditional GIC, they determined that bands cemented with the RMGIC had a greater mean shear-peel bond strength than those cemented with Zinc Phosphate cement. Other investigations of Transbond Plus on natural teeth have produced different results than the present study. Millett et al. (2003b) found that bands cemented with Transbond Plus had a significantly lower mean shear-peel bond strength compared to Ketac-Cem. In contrast, bands cemented with Transbond Plus have shown significantly greater mean shear-peel bond strength than those cemented with Zinc Phosphate (Aggarwal et al., 2000). Aggarwal et al. (2000) compared bands cemented on natural teeth with Multi-Cure to Transbond Plus and they also found no difference in mean shear-peel bond strength between the cements.

The force per unit area values (MPa) (calculated for 85.5% of the original band area in contact with the porcelain denture tooth) for all three cements in this study were generally lower than the values obtained in other investigations on natural teeth that used similar methods to the present study (Millett et al., 1998; 2003a; 2003b). Values for Ketac-Cem on natural teeth have been determined in three studies and ranged from 1.27 (SD 0.31) to 1.65 MPa (SD 0.37) (Millett et al., 1998; 2003a; 2003b), approximately two times greater than the value found in the present study (0.74 MPa, SD 0.37). Millett et al. (2003a) determined the shear-peel bond strength of bands cemented with Multi-Cure to be 1.63 MPa (SD 0.41), over two times greater than the value found in the present study (0.69 MPa, SD 0.36). In contrast, Millett et al (2003b) found a lower value for Transbond Plus (0.415 MPa, SD 0.264) on natural teeth compared to the present study (0.89 MPa, SD 0.31). The above means also show the wide variability of shear-peel bond strength values found in tests using methodology similar to the present study. Previous studies have reported standard deviations ranging from 20-50% of the mean shear-peel bond strength value (Millett et al., 1998; 2003a; 2003b). The variability in the present study is also within this wide range.

There are probably multiple factors contributing to the lower mean shear-peel bond strength values determined in the present study on porcelain teeth compared to values found on natural teeth. One of the most likely factors may be the shape of the denture teeth. The area of the denture tooth that was banded had virtually no convexity, providing no undercuts for mechanical locking. Additionally, the lingual wall of the denture tooth is much shorter than in natural teeth with similar mesio-distal width. It may also be that less force is needed to remove bands from the porcelain teeth as compared to natural teeth because of surface characteristics of porcelain such as greater smoothness and lower surface tension.

Chemical bonding between enamel and cement may also play a role in the adhesion of bands cemented with GIC and RMGIC when band cements are investigated on natural teeth. When porcelain teeth are used, the bands are retained solely by limited mechanical means. This may also be why no differences were found between any cements in contrast to some other investigations on natural teeth which showed bands cemented with the compomer Transbond Plus to provide inferior mean shear-peel bond strength when compared to RMGIC and GIC. However, Millett et al. (2003a) compared the compomer cement Ultra Band Lok (Reliance Orthodontic Products Inc., Itasca, IL) to both Ketac-Cem and Multi-Cure and found no significant differences in mean shear-peel bond strengths of cemented bands on natural teeth. Variations in composition between brands of compomer cements may lead to differences in shear-peel bond strength. The present study shows that for band cementation on porcelain teeth, conventional GIC provides comparable shear-peel bond strength to the newer RMGIC and compomer cements. It is typical in dentistry to enhance adhesion of composite based cements, such as compomers, to porcelain with hydrofluoric acid etching and resin bonding, but this is not typically done by orthodontists during banding due to the possibility of damage to the porcelain surface. Further clinical testing is necessary to determine if these cements provide adequate band retention on untreated porcelain surfaces in the mouth. Further investigation of non-damaging porcelain surface treatments may also be necessary to determine methods for improving band adhesion on porcelain.

Visual assessment of the teeth following band removal showed that minimal amounts of cement were retained on the polished porcelain surface of the teeth. The micro-etched surface of the band was more retentive than the porcelain tooth surface in all cases. In studies on natural teeth, the site of failure for both Multi-Cure and Ketac-Cem varied from the present study. Millet et al. (2003a) found that the predominate site of cement failure for Multi-Cure was the cement/band interface. Millett et al. (1998) found the Ketac-Cem had a mixed site of failure at both the enamel/cement and cement/band interface, with the cement/band interface predominating. However, neither investigation used bands with a micro-etched inner surface. Subsequent investigations of Ketac-Cem using micro-etched bands have shown the enamel/cement interface to be the predominate site of failure on natural teeth (Millett et al., 2003a; 2003b). It is likely that Ketac-Cem and Multi-Cure failed almost exclusively at the porcelain/cement interface in the present study, as opposed to the cement/band interface as has been found on natural teeth, because: 1) micro-etched bands were used, 2) there is no chemical adhesion by these cements to porcelain, and 3) the highly polished surface of the porcelain tooth provides very little mechanical adhesion

In the present study, the bands were cemented on dry teeth and then transferred into a humid environment. Investigations of band cements have shown that moisture contamination by saliva can affect adhesion and failure site. Millett et al. (2003a) speculated that in a clinical situation, unintentional moisture contamination during banding may alter cement properties. Aggarwal et al. (2000) studied the shear-peel bond strength of bands cemented with Transbond Plus in the presence and absence of saliva contamination during cementation and found that saliva presence was detrimental to band retention. Their results suggest that a dry field is important for compomer adhesion just as it is for use of resin composites. In contrast, they suggested that some salivary moisture enhances RMGIC and GIC adhesion. Further investigation of these cements on porcelain surfaces in the presence of moisture contamination is needed.

Use of fatigue survival time testing in conjunction with shear-peel bond strength testing provides further information on how cemented bands hold up to externally applied mechanical stress (Durning et al., 1994; Millett et al., 1995; Abu Kasim et al., 1996; Millett et al., 1998; 2003a; 2003b). Thermocycling has also been used to model stress that may be encountered clinically (Norris et al., 1986; Aggarwal et al., 2000). Norris et al. (1986) found glass ionomer cements had greater mean repetitive strength after 60 days of thermocycling compared to one and seven days. Aggarwal et al. (2000) did not test for changes in shear-peel bond strength due to varying lengths of thermocycling but did subject all samples to 30 days of thermocycling prior to testing and were only able to speculate regarding its affects. No other investigation has provided evidence that thermocycling affects bond strength of band cements. Fox et al. (1994) suggested in their criticism of bond strength studies to standardize storage methods between bonding and testing to storage in water at 37°C for 24 hours.

As an alternative to thermocycling, the method of using a ball mill to fatigue test has been shown to provide reproducible results in a short period of time that are consistent with clinical performance of cements, even with the use a relatively small sample size of ten (Abu Kasim et al., 1996; Millett et al., 1995). One disadvantage of the ball mill is that the precise mechanisms causing cement failure have only been hypothesized and fatigue failure may not be the only mechanism at work. The most likely process resulting in failure is fatigue by the slow development of a crack through the prechipped cement and ongoing destabilization resulting from the mechanical action of the pellets (Abu Kasim et al., 1996). One potential shortcoming of the method used in this study and previous studies is that the failed samples were removed from the mill after each hour. This potentially results in less applied fatigue events as the test proceeds, but the effects are probably negligible. Although ceramic pellet size, shape, and the RPM setting of the ball mill varied in the present study from other investigations using the ball mill on cemented bands, generalized comparisons can be made regarding survival time.

In the present study, bands cemented with both Multi-Cure and Transbond Plus had a greater survival time (5.4 and 4.6 hours, respectively) than those cemented with Ketac-Cem (2.3 hours). Three other investigators have compared various compomer cements and RMGIC to Ketac-Cem and consistently found that bands cemented with Ketac-Cem had the shortest survival time (Millett et al., 1998; 2003a; 2003b). Similar to the present study, Millett et al. (2003a) found that the survival time of Multi-Cure (8.8 hours) was approximately 2.5 times greater than for Ketac-Cem (3.4 hours). Another study comparing Transbond Plus to Ketac-Cem found no statistically significant difference in survival times of 11.1 hours for Transbond Plus and 9.9 hours for Ketac-Cem (Millett et al., 2003b). However, a survival time of 9.9 hours for Ketac-Cem is approximately three times longer than found in this study or previous investigations (Millett et al., 2003a; 1998). The survival time for Transbond Plus is more consistent across investigations. The compomer cement, Ultra Band Lok, has been compared to Ketac-Cem and it had a significantly greater survival time of 10.8 hours compared to 3.4 hours for Ketac-Cem (Millett et al., 2003a). The results of the present investigation on survival time indicate that Multi-Cure and Transbond Plus can be expected to have lower clinical failure rates for band cementation than Ketac-Cem. Interestingly, the results of the two experiments (shear-peel bond strength testing and survival time) for Ketac-Cem are in disagreement. Ketac-Cem performed the same as the other two cements for shear-peel bond strength testing, but had a significantly shorter survival time. The discord in results of shear-peel bond strength testing and fatigue testing for GIC has been noted by other investigators as well (Durning et al., 1994; Millett et al., 2003a) and may be due to the lower fatigue resistance compared to shear strength of GIC when it is tested 24 hours after mixing rather than after a greater length of time when further setting may result in the two being more closely related (Lohbauer et al., 2003).

Conclusions:

- No significant difference was found between the mean shear-peel bond strengths of bands cemented on porcelain teeth with glass ionomer (Ketac-Cem), resin modified glass ionomer (Multi-Cure), or compomer (Transbond Plus).
- The amount of cement remaining on porcelain teeth following debanding differed significantly between bands cemented with Transbond Plus and Ketac-Cem but did not differ significantly between bands cemented with Transbond Plus or Multi-Cure, and Multi-Cure or Ketac-Cem.
- The mean survival time of bands cemented on porcelain teeth with either Multi-Cure or Transbond Plus were significantly longer than for bands cemented with Ketac-Cem. No significant difference was found between mean survival times of band cemented with Multi-Cure or Transbond Plus.
- The results of the present study relative to previous studies using natural teeth, suggest that in a clinical setting cements used on porcelain teeth are likely to provide less retention of orthodontic bands

than what can be expected on natural teeth. Fatigue testing results indicate that Ketac-Cem may provide less predictable band retention on porcelain in clinical use than Multi-Cure and Transbond Plus.

References

Aggarwal M, Foley TF, Rix D. A comparison of shear-peel band strengths of 5 orthodontic cements. Angle Orthod 2000;70:308-316.

Abu Kasim NH, Millett DT, McCabe JF. The ball mill as a means of investigating the mechanical failure of dental materials. J Dent 1996;24:117-124.

Artun J. and Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod 1984;85:333-340.

Beemer RL, Ferracane JL, Howard HE. Orthodontic band retention on primary molar stainless steel crowns. Pedia Dent 1993;15:408-413.

Bourke BM and Rock WP. Factors affecting the shear bond strength of orthodontic brackets to porcelain. Br J Orthod 1999;26:285-290.

Brown D. Orthodontic materials update - orthodontic band cements. Br J Orthod 1989;16:127-131.

Clark JR, Ireland AJ, Sherriff M. An in vivo and ex vivo study to evaluate the use of a glass polyphosphonate cement in orthodontic banding. Euro J Orthod 2003;25:319-323.

Craig RG, Powers JM, Wataha JC. Dental materials properties and manipulation (8th ed.). St. Louis: Mosby 2004.

Craig RG, Ward ML (Eds.). Restorative dental materials (10th ed.) St. Louis: Mosby 1997.

Diaz-Arnold AM, Holmes DC, Wistrom DW, Swift EJ. Short-term fluoride release/uptake of glass ionomer restoratives. Dent Mat 1995;11:96-101.

Durning P, McCabe JF, Gordon PH. A laboratory investigation into cements used to retain orthodontic bands. Br J Orthod 1994;21:27-32.

Eliades G. Chemical and biological properties of glass-ionomer cements. In Davidson CL & Mjor IA (Eds.), Advances in glass-ionomer cements (pp 85-101). Carol Stream, IL: Qunitessence 1999.

Foley T, Aggarwal M, Hatibovic-Kofman S. A comparison of in vitro enamel demineralization potential of 3 orthodontic cements. Am J Orthod Dentofacial Orthop 2002;121:526-530.

Forsten L. Fluoride release and uptake by glass ionomers. Scand J Dent Res 1991;99:241-245.

Fox NA, McCabe JF, Buckley JG. A critique of bond strength testing in orthodontics. Br J Orthod 1994;21:33-43.

Gillgrass TJ, Millett DT, Creanor SL, MacKenzie D, Bagg J, Gilmour WH, Foye RH. Fluoride release, microbial inhibition and microleakage pattern of two orthodontic band cements. J Dent 1999;27:455-461.

Gillis I, Redlich M. The effect of different porcelain conditioning techniques on shear bond strength of stainless steel brackets. Am J Orthod Dentofacial Orthop 1998;114:387-92.

Hamula W, Hamula DW, Brower K. Glass ionomer update. J Clin Orthod 1993;27:420-425.

Hotz P, McLean JW, Sced I, Wilson AD. The bonding of glass ionomer cements to metal and tooth substrates. Br Dent J 1977;142:41-47.

Huser MC, Baehni PC, Lang R. Effects of orthodontic bands on microbiological and clinical parameters. Am J Orthod Dentofacial Orthop 1990;97:213-218.

Johnson N. Current products and practice - orthodontic banding cements. J Orthod 2000;27:283-4.

Ireland AJ, Sherriff M. Orthodontic materials and biomechanics. In Lloyd CH, Scrimgeour SN (Eds.), Dental materials: 1993 literature review (pp 84-86), J of Dent 1995;23:67-93.

Jost-Brinkmann P, Böhme A. Shear bond strengths attained in vitro with light-cured glass ionomers vs composite adhesives in bonding ceramic brackets to metal or porcelain. J Adhesive Dent 1999;1:243-253.

Keim RG, Gottlieb EL, Nelson AH, Vogels DS. 2002 JCO study of orthodontic diagnosis and treatment Procedures, Part 1 results and trends. J Clin Ortho 2002;36:553-568.

Kitayama Y, Komori A, Nakahara R. Tensile and shear bond strength of resin-reinforced glass ionomer cement to glazed porcelain. Angle Orthod 2003;73:451-456.

Kocadereli I, Canay S, Akça K. Tensile bond strength of ceramic orthodontic brackets bonded to porcelain surfaces. Am J Orthod Dentofacial Orthop 2001;119:617-620.

Lohbauer U, Frankenberger R, Kramer N, Petschelt A. Time-dependent strength and fatigue resistance of dental direct restorative materials. J Materials Sci Materials Med. 2003;14:1047-1053.

McComb D. Luting in orthodontic practice. In Davidson CL & Mjor IA (Eds.), Advances in glass-ionomer cements (pp 171-182). Carol Stream, IL: Quintessence 1999.

McLean JW. Evolution of dental ceramics in the twentieth century. J Pros Dent 2001;85:61-6.

Millettt DT, McCabe JF, Bennett TG, Carter NE, Gordon PH. The effect of sandblasting on the retention of first molar orthodontic bands cemented with glass ionomer cement. Br J Orthod 1995;22:161-169.

Millett D, McCabe JF, Gordon PH. The role of sandblasting on the retention of metallic brackets applied with glass ionomer cement. Br J Orthod 1993;20:117-122.

Millett DT, Kamahli K, McColl J. Comparative laboratory investigation of dual-cured vs. conventional glass ionomer cements for band cementation. Angle Orthod 1998;68:345-350.

Millett DT, Cummings A, Letters S, Roger E, Love J. Resin-modified glass ionomer, modified composite or conventional glass ionomer for band cementation? – an in vitro evaluation. Euro J Orthod 2003;25:609-614.

Millett DT, Duff S, Morrison L, Cummings A, Gilmour WH. In vitro comparison of orthodontic band cements. Am J Orthod Dentofacial Orthop 2003;123:15-20.

Moodley D, Grobler SR. Compomers: adhesion and setting reactions. S African Dent J 2003;58:24-28.

Norris DS, McInnes-Ledoux P, Schwaninger B, Weinberg R. Retention of orthodontic bands with new fluoride-releasing cements. Am J Orthod 1986;89:206-211.

O'Brien WJ (Ed.). Dental materials and their selection (3rd ed.). Carol Stream, IL: Quintessence Publishing 2002.

Øgaard B, Rølla G, Arends J. Orthodontic appliances and enamel demineralization - part 1 lesion development. Am J Orthod Dentofacial Orthop 1988;94:68-73.

Pannes DD, Bailey DK, Thompson JY, Pietz DM. Orthodontic bonding to porcelain: a comparison of bonding systems. J Pros Dent 2003;89:66-69.

Rezk-Lega F, Øgaard B, Arends J. An in vivo study of the merits of two glass-ionomers for the cementation of orthodontic bands. Am J Orthod Dentofacial Orthop 1991;99:162-167.

Saito S, Tosaki S, Hirota K. Characteristics of glass-ionomer cements. In Davidson CL & Mjor IA, (Eds.), Advances in glass-ionomer cements (pp 15-50). Carol Stream, IL: Quintessence 1999.

Sallum EJ, Nouer DF, Klein MI, Gonçalves RB, Machion L, Sallum AW, et al. Clinical and microbiologic changes after removal of orthodontic appliances. Am J Orthod Dentofacial Orthop 1994;126:363-366.

Schmage P, Nergiz I, Herrmann W, Özcan M. Influence of various surface-conditioning methods on the bond strength of metal brackets to ceramic surfaces. Am J Orthod Dentofacial Orthop 2003;123:540-546.

Takahashi K, Emilson CG, Birkhed D. Fluoride release in vitro from various glass ionomer cements and resin composites after exposure to NaF solutions. Dent Mat 1993;9:350-354.

Williams JD, Swartz ML, Phillips RW. Retention of orthodontic bands as influenced by the cementing media. Angle Orthod 1965;35:278-85.

Wilson AD, Kent BE. A new translucent cement for dentistry. Br Dent J 1972;132:133-135.

Appendix A. Data from shear-peel bond strength testing and ARI scores.

Table IVa. Instron debond force values and ARI scores

Italics = values adjusted for 14.5% of band area on lingual not in contact with tooth

* Sample numbers out of sequence as a result of the previous sample(s) failing

Sample #	Group #	LBS	KG	SA mm2	MPa	*SA mm2*	*MPa*	ARI
Ketac-Cem								
1	1	31.5	14.32	128.387	1.093673	*109.7709*	*1.27915*	0
2	1	20.25	9.20	128.387	0.703076	*109.7709*	*0.822311*	0
3	1	10.75	4.89	128.387	0.373238	*109.7709*	*0.436535*	0
* 5	1	27	12.27	128.387	0.937434	*109.7709*	*1.096414*	0
6	1	12	5.45	128.387	0.416637	*109.7709*	*0.487295*	0
7	1	15	6.82	128.387	0.520797	*109.7709*	*0.609119*	0
8	1	7.5	3.41	128.387	0.260398	*109.7709*	*0.304559*	0
9	1	23.25	10.57	128.387	0.807235	*109.7709*	*0.944134*	0
10	1	21.5	9.77	128.387	0.746475	*109.7709*	*0.87307*	0
*13	1	6.25	2.84	128.387	0.216999	*109.7709*	*0.2538*	0
14	1	15.5	7.05	128.387	0.538157	*109.7709*	*0.629423*	0
15	1	7.5	3.41	128.387	0.260398	*109.7709*	*0.304559*	0
16	1	35	15.91	128.387	1.215192	*109.7709*	*1.421277*	0
17	1	28.75	13.07	128.387	0.998194	*109.7709*	*1.167478*	0
18	1	24.75	11.25	128.387	0.859315	*109.7709*	*1.005046*	0
19	1	8.25	3.75	128.387	0.286438	*109.7709*	*0.335015*	0
20	1	14	6.36	128.387	0.486077	*109.7709*	*0.568511*	0
Mean		**18.16176**	**8.255348**		**0.630572**		***0.737512***	
Standard Deviation					**0.316698**		***0.370407***	
Transbond Plus								
*22	2	21.25	9.66	128.387	0.737795	*109.7709*	*0.863*	0
23	2	9.25	4.20	128.387	0.321158	*109.7709*	*0.375623*	0
24	2	7	3.18	128.387	0.243038	*109.7709*	*0.284255*	0
25	2	24	10.91	128.387	0.833275	*109.7709*	*0.97459*	1
26	2	11.25	5.11	128.387	0.390598	*109.7709*	*0.456839*	1
27	2	28.25	12.84	128.387	0.980834	*109.7709*	*1.147174*	0
*29	2	24	10.91	128.387	0.833275	*109.7709*	*0.97459*	0
30	2	28.25	12.84	128.387	0.980834	*109.7709*	*1.147174*	0
31	2	18.5	8.41	128.387	0.642316	*109.7709*	*0.751247*	0
32	2	22.75	10.34	128.387	0.789875	*109.7709*	*0.92383*	0
33	2	23.25	10.57	128.387	0.807235	*109.7709*	*0.944134*	0
34	2	29	13.18	128.387	1.006874	*109.7709*	*1.17763*	1
35	2	23.25	10.57	128.387	0.807235	*109.7709*	*0.944134*	0
36	2	27.25	12.39	128.387	0.946114	*109.7709*	*1.106566*	0
37	2	20.75	9.43	128.387	0.720435	*109.7709*	*0.842615*	0
38	2	35	15.91	128.387	1.215192	*109.7709*	*1.421277*	1
39	2	28.5	12.95	128.387	0.989514	*109.7709*	*1.157326*	0
40	2	12	5.45	128.387	0.416637	*109.7709*	*0.487295*	1
Mean		**21.86111**	**9.936919**		**0.759013**		***0.887739***	
Standard Deviation					**0.265592**		***0.310634***	
Multi-Cure								
41	3	24.5	11.14	128.387	0.850635	*109.7709*	*0.994894*	0
42	3	5	2.27	128.387	0.173599	*109.7709*	*0.20304*	0

43	3	9.5	4.32	128.387	0.329838	*109.7709*	*0.385775*	0
44	3	8.25	3.75	128.387	0.286438	*109.7709*	*0.335015*	0
45	3	11.5	5.23	128.387	0.399277	*109.7709*	*0.466991*	0
46	3	15.5	7.05	128.387	0.538157	*109.7709*	*0.629423*	0
47	3	7.5	3.41	128.387	0.260398	*109.7709*	*0.304559*	0
48	3	7	3.18	128.387	0.243038	*109.7709*	*0.284255*	0
49	3	17.5	7.95	128.387	0.607596	*109.7709*	*0.710639*	1
50	3	30.75	13.98	128.387	1.067633	*109.7709*	*1.248694*	0
51	3	23.5	10.68	128.387	0.815915	*109.7709*	*0.954286*	1
52	3	12.5	5.68	128.387	0.433997	*109.7709*	*0.507599*	0
53	3	19.5	8.86	128.387	0.677036	*109.7709*	*0.791855*	0
54	3	31.5	14.32	128.387	1.093673	*109.7709*	*1.27915*	0
55	3	28.5	12.95	128.387	0.989514	*109.7709*	*1.157326*	0
*57	3	7.75	3.52	128.387	0.269078	*109.7709*	*0.314711*	0
*58	3	24	10.91	128.387	0.833275	*109.7709*	*0.97459*	0
60	3	21.75	9.89	128.387	0.755155	*109.7709*	*0.883222*	0
Mean		**17**	**7.727273**		**0.590236**		***0.690335***	
Standard Deviation					**0.305188**		***0.356945***	
GI	Mean				0.630572			
	Standard Deviation				0.316698			
Compomer	Mean				0.759013			
	Standard Deviation				0.265592			
RMGI	Mean				0.590236			
	Standard Deviation				0.305188			

Table IVb. Data used to determine the percentage of original band surface area contacting the denture tooth

Sample	*Original band weight without buccal and lingual attachments (grams)*	*Cut band weight without attachments (grams)*	*Percent of original band area contacting tooth*
1	0.158	0.135	85.4
2	0.159	0.130	81.8
3	0.155	0.140	90.3
4	0.157	0.130	82.8
5	0.154	0.134	87.0
			Mean 85.5% Std. Dev. 3.4%

Appendix B. Instron data distributions

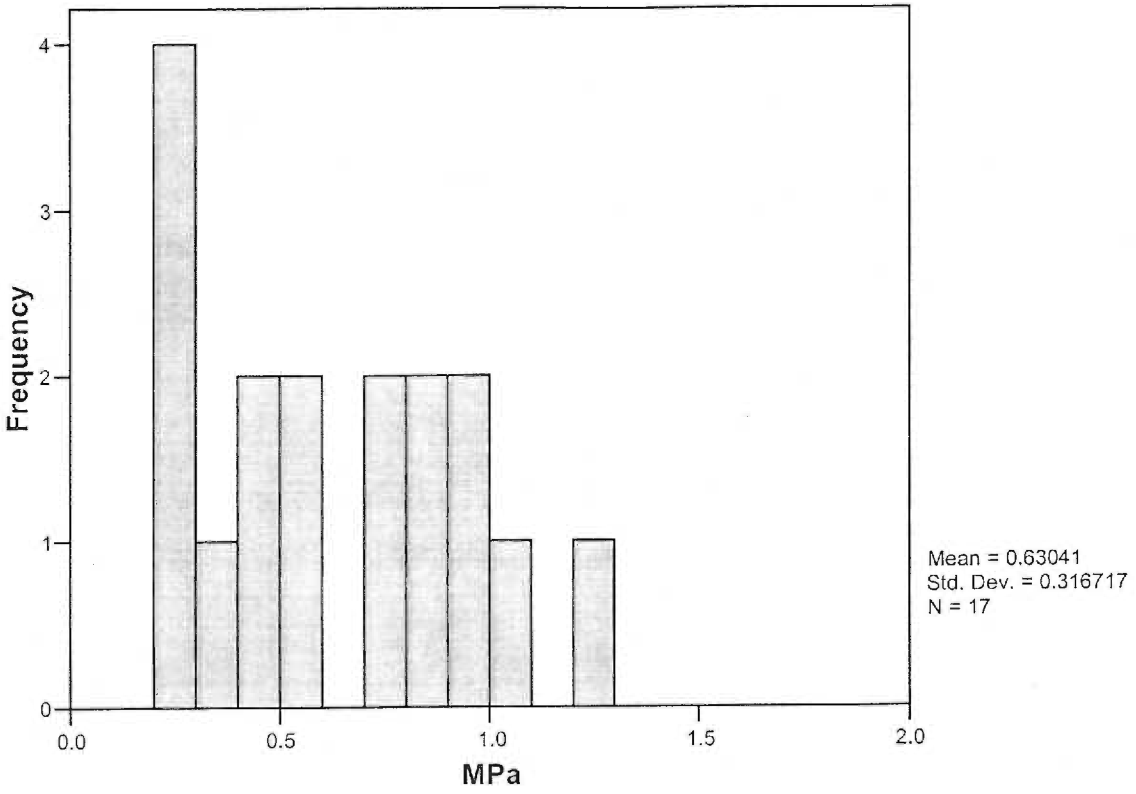

Figure 13. Ketac-Cem shear-peel debond values distribution

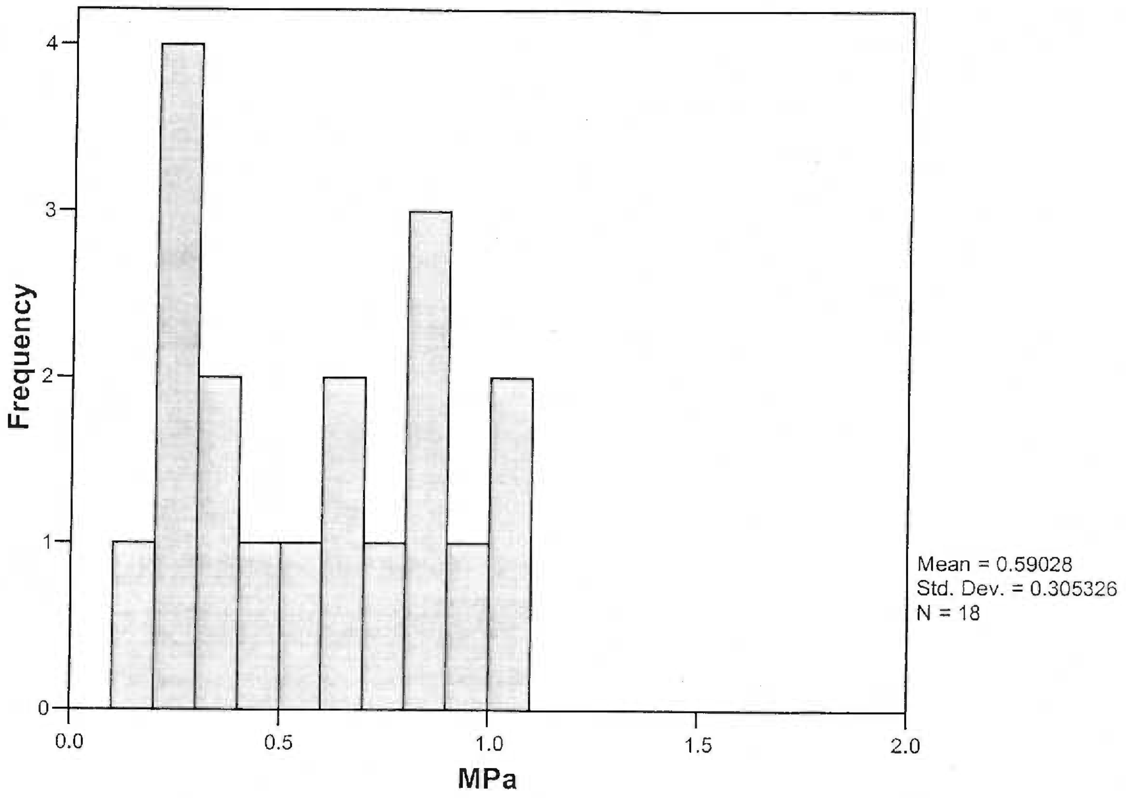

Figure 14. Multi-Cure shear-peel debond values distribution

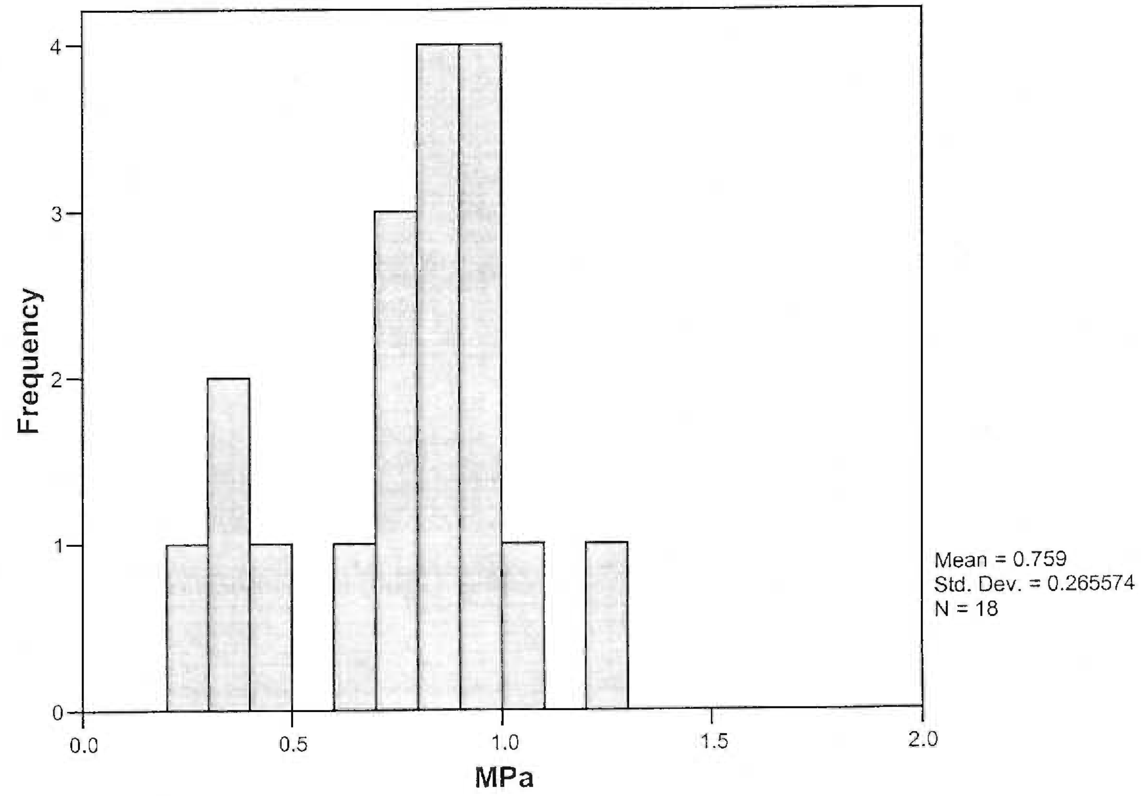

Figure 15. Transbond Plus shear-peel debond values distribution

Appendix C. ANOVA of mean shear-peel bond strength values

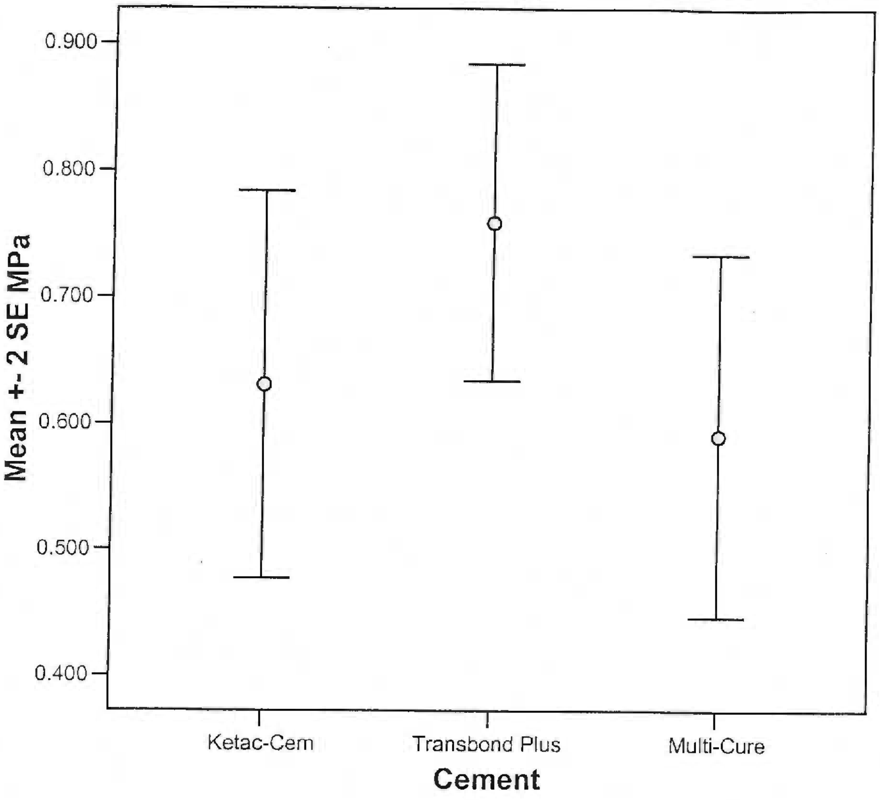

Figure 16. Mean shear-peel bond strength values (MPa)

Table V. Descriptives of mean shear-peel bond strength values (MPa)

MPa

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Glass ionomer	17	.63041	.316717	.076815	.46757	.79325	.217	1.215
Compomer	18	.75900	.265574	.062596	.62693	.89107	.243	1.215
Resin modified glass ionomer	18	.59028	.305326	.071966	.43844	.74211	.174	1.094
Total	53	.66045	.299601	.041153	.57787	.74303	.174	1.215

Table VI. Test of homogeneity of variances

MPa

Levene Statistic	df1	df2	Sig.
1.095	2	50	.342

Table VII. ANOVA of mean shear-peel bond strength values (MPa)

MPa

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.279	2	.139	1.588	.214
Within Groups	4.389	50	.088		
Total	4.668	52			

Appendix D. Chi-squared analysis of ARI scores

Table VIII. Summary of ARI data for all 3 cement groups

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
ARI * Group	53	96.4%	2	3.6%	55	100.0%

Table IX. ARI group crosstabulation

Count

		Group			
		Glass ionomer	Compomer	Resin modified glass ionomer	Total
ARI	0	17	12	16	45
	1	0	6	2	8
Total		17	18	18	53

Table X. Chi-squared test of 3 cement groups

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.917[a]	2	.019
Likelihood Ratio	9.508	2	.009
Linear-by-Linear Association	.748	1	.387
N of Valid Cases	53		

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 2.57.

Chi-squared analysis of glass ionomer and compomer

Table XI. Summary of glass ionomer and compomer

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
ARI * Group	35	63.6%	20	36.4%	55	100.0%

Table XII. ARI group crosstabulation of glass ionomer and compomer

Count

		Group		Total
		Glass ionomer	Compomer	
ARI	0	17	12	29
	1	0	6	6
Total		17	18	35

Table XIII. Chi-squared test of glass ionomer and compomer cements

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	6.839[b]	1	.009		
Continuity Correction[a]	4.694	1	.030		
Likelihood Ratio	9.156	1	.002		
Fisher's Exact Test				.019	.011
Linear-by-Linear Association	6.644	1	.010		
N of Valid Cases	35				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.91.

Chi-squared analysis of glass ionomer and RMGIC

Table XIV. Summary of GI and RMGIC

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
ARI * Group	35	63.6%	20	36.4%	55	100.0%

Table XV. ARI group cross tabulation of GI and RMGIC

Count

		Group		
		Glass ionomer	Resin modified glass ionomer	Total
ARI	0	17	16	33
	1	0	2	2
Total		17	18	35

Table XVI. Chi-squared test of GI and RMGIC

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.003[b]	1	.157		
Continuity Correction[a]	.472	1	.492		
Likelihood Ratio	2.774	1	.096		
Fisher's Exact Test				.486	.257
Linear-by-Linear Association	1.946	1	.163		
N of Valid Cases	35				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is .97.

Chi-squared analysis of compomer and RMGIC

Table XVII. Summary of compomer and RMGIC

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
ARI * Group	36	65.5%	19	34.5%	55	100.0%

Table XVIII. ARI group cross tabulation of compomer and RMGIC

Count

		Group		Total
		Compomer	Resin modified glass ionomer	
ARI	0	12	16	28
	1	6	2	8
Total		18	18	36

Table XIX. Chi-squared test of compomer and RMGIC

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.571[b]	1	.109		
Continuity Correction[a]	1.446	1	.229		
Likelihood Ratio	2.666	1	.102		
Fisher's Exact Test				.228	.114
Linear-by-Linear Association	2.500	1	.114		
N of Valid Cases	36				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 4.00.

Appendix E. Survival analysis and log rank statistic

```
Survival Analysis for hours

Factor cement = Ketac-Cem
 Time          Status      Cumulative       Standard      Cumulative       Number
                            Survival         Error          Events        Remaining

    2.00        1.0                                           1               9
    2.00        1.0                                           2               8
    2.00        1.0                                           3               7
    2.00        1.0                                           4               6
    2.00        1.0                                           5               5
    2.00        1.0                                           6               4
    2.00        1.0          .3000           .1449            7               3
    3.00        1.0                                           8               2
    3.00        1.0                                           9               1
    3.00        1.0          .0000           .0000           10               0

Number of Cases:   10          Censored:    0        (    .00%)    Events:  10


          Survival Time      Standard Error    95% Confidence Interval

Mean:          2.30                   .15       (      2.00,        2.60 )
Median:        2.00                   .         (       .  ,         .   )
```

```
Survival Analysis for hours

Factor cement = Transbond Plus
 Time         Status     Cumulative      Standard      Cumulative      Number
                          Survival        Error          Events       Remaining

   3.00        1.0         .9000           .0949              1             9
   4.00        1.0                                            2             8
   4.00        1.0                                            3             7
   4.00        1.0                                            4             6
   4.00        1.0                                            5             5
   4.00        1.0         .4000           .1549              6             4
   5.00        1.0                                            7             3
   5.00        1.0         .2000           .1265              8             2
   6.00        1.0         .1000           .0949              9             1
   7.00        1.0         .0000           .0000             10             0

Number of Cases:   10         Censored:    0        (    .00%)    Events: 10


         Survival Time     Standard Error    95% Confidence Interval

Mean:         4.60                   .37      (      3.87,        5.33 )
Median:       4.00                   .31      (      3.39,        4.61 )
```

```
Survival Analysis for hours

Factor cement = Multi-Cure
  Time       Status     Cumulative      Standard      Cumulative      Number
                          Survival        Error          Events      Remaining

    4.00       1.0                                         1              9
    4.00       1.0                                         2              8
    4.00       1.0                                         3              7
    4.00       1.0          .6000          .1549           4              6
    5.00       1.0                                         5              5
    5.00       1.0          .4000          .1549           6              4
    6.00       1.0          .3000          .1449           7              3
    7.00       1.0                                         8              2
    7.00       1.0          .1000          .0949           9              1
    8.00       1.0          .0000          .0000          10              0

Number of Cases:   10          Censored:    0         (    .00%)    Events: 10


         Survival Time      Standard Error     95% Confidence Interval

Mean:          5.40                 .48        (      4.47,       6.33 )
Median:        5.00                 .77        (      3.48,       6.52 )
```

```
Log Rank Statistic and (Significance)

Factor          GIC     Compomer

 Compomer      17.98
             ( .0000)

   RMGIC       20.55      1.84
             ( .0000) ( .1750)
```

Introduction

Orthodontic fixed appliances often include stainless steel bands around posterior teeth (Keim et al., 2002). To treat patients efficiently, it is necessary to retain the molar bands for the course of treatment, which may last two years or more. Bands are held securely in place by a combination of their close custom adaptation to teeth and an interposing layer of one of the many commercially available luting cements. Over the last forty years, the strength of the bond provided by orthodontic band cements to natural teeth has been thoroughly investigated in laboratory studies (Williams et al., 1965; Norris et al., 1986; Durning et al, 1994; Millett et al., 1995; Millett et al., 1998; Aggarwal et al., 2000; Millett et al., 2003b; Millett et al., 2003a; Clark et al., 2003). As discussed in these laboratory studies, the typical protocol used in laboratory investigations of cements is to determine force values required to remove bands cemented to teeth and to subject the cemented bands to some form of thermocycling and/or fatigue testing. The majority of cements that are now commercially available in orthodontics have been subjected to laboratory testing with bands cemented on natural teeth. A review of the literature by Millett and associates (1995) found that the clinical failure rate of bands cemented on natural teeth with the glass ionomer cement ranged from 6-26% over observation periods ranging from 12-24 months. However, with a greater number of adults seeking orthodontic treatment, and many of these having full coverage porcelain crowns, there is a need for information that can be used to make decisions regarding the placement of bands on porcelain molar crowns. A review of the literature did not locate any information with regard to how orthodontic band cements perform when used to secure bands on molars with porcelain crowns.

Numerous cements have been used to retain orthodontic bands. Zinc phosphate cement was commonly used throughout the last century, however more recently developed band cements have largely replaced zinc phosphate (Johnson, 2000; Craig et al., 2004). Glass ionomer cements (GIC) were developed over thirty years ago (Wilson & Kent, 1972). A distinctive feature of GIC that makes it particularly useful in dentistry is fluoride release (Saito et al., 1999). GIC has higher tensile and compressive strength (decreasing brittleness) and lower oral solubility than zinc phosphate (McComb, 1999). Resin-modified glass ionomer cements (RMGIC) and compomer cements are now also used for band cementation. Fluoride release and reuptake also occur in RMGIC in a range similar to that of conventional glass ionomer (O'Brien, 2002; Eliades, 1999). Compomers are also known as acid-modified composite resin (Johnson, 2000), modified composites (Millett et al., 2003b), or polyacid-modified composite resins (Aggarwal et al., 2000). Compomer cements are essentially resin composites that slowly release fluoride. Their physical properties are very similar to resin composite (Craig et al., 2004).

Laboratory investigations of force values required to remove cemented bands from natural teeth have shown that RMGIC and GIC appear equivalent with regard to required debanding force, however bands cemented with RMGIC were shown to have superior fatigue properties (Millett et al., 2003a; Millett et al., 2003b). Investigations of compomer cements have shown mixed results, with some studies finding compomers performing equivalent to GIC and RMGIC and superior to zinc phosphate (Aggarwal et al., 2000; Millett et al., 2003a) and another finding that bands cemented with compomers have lower retentive strength than those cemented with either RMGIC or GIC (Millett et al., 2003b). In addition to the cement selected, the adhesion of an orthodontic band to a tooth has a considerable amount to do with band contour, fit, and surface texture. Investigations of orthodontic bands have shown that stainless steel bands may offer significantly greater retention if they are etched prior to cementation (Aggarwal et al., 2000; Millett et al., 1995). The site of failure of GIC occurs primarily at the band/cement interface (Millett et al., 2003a; Millett et al., 1998; Norris et al., 1986). In contrast, band failure occurs more commonly at the cement/enamel interface when RMGIC (Millett et al., 2003a; Millett et al., 2003b; Millett et al., 1998) and compomers (Millett et al., 2003a) are used.

Laboratory studies comparing types of cement under simulated mechanical stress should be used as a first step in determining possible clinical performance. However, no studies have been published that evaluate GIC, RMGIC, or compomer cements in relation to the retention of orthodontic bands on porcelain teeth. The aims of this study are:

1. to compare the shear-peel bond strengths of micro-etched orthodontic bands cemented to porcelain crowns with three orthodontic band cements: a conventional glass ionomer (Ketac-Cem, 3M ESPE, St. Paul, MN), a resin-modified glass ionomer (Multi-Cure, 3M Unitek, Monrovia, CA), and a compomer (Transbond Plus, 3M Unitek, Monrovia, CA),
2. to evaluate the predominate site of bond failure in the case of each cement type and to compare the amount of cement remaining on the tooth following debanding, and

3. to compare the survival time of bands cemented to the porcelain crowns with each cement type after simulating mechanical fatigue stress in a ball mill.