THE UNIVERSITY OF ADELAIDE

THE INFLUENCE OF COMPRESSIVE CYCLIC LOADING ON THE RETENTION OF CAST CROWN COPINGS CEMENTED TO IMPLANT ABUTMENTS

A thesis submitted in partial fulfillment for the Degree of Doctor of Clinical Dentistry (Prosthodontics)

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LAYOUT OF THIS THESIS

This thesis is presented in two sections:

Section 1: Thesis as detailed in Contents

Section 2: Article submitted and accepted for publication in the Australian Dental Journal 2008; 53(4)

SECTION 1

CONTENTS

STATEMENT

This thesis is submitted in partial fulfillment for the requirements for the Degree of Doctor of Clinical Dentistry (Prosthodontics) at the University of Adelaide. This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution, and to the best of my knowledge and belief contains no material previously published or written by another person, except where due reference is made in the text of the report.

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Summary

Background

The cementation of crowns to dental implant abutments is an accepted form of crown retention that requires consideration of the properties of available cements within the applied clinical context. Most current dental cements were developed primarily for use with natural tooth crowns, but must act in a different manner with implant components. Cements are exposed to a number of stressors that may reduce crown retention in vivo, not the least of which is occlusal loading. This study investigated the influence of compressive cyclic loading on the physical retention of cast crown copings cemented to implant abutments.

Method

Cast crown copings were cemented to Straumann synOcta titanium implant abutments with three different readily used and available cements. Specimens were placed in a humidifier, thermocycled and subjected to one of four quantities of compressive cyclic loading. The uniaxial tensile force required to remove the cast crown copings was then recorded. Data analysis was conducted using two-way ANOVA and paired post tests.

Results

Statistical analysis arising from post tests following two-way ANOVA testing revealed the mean retention values for crown copings cemented with Panavia-F cement (5.103, 2.681, 3.178, 2.986MPa) were statistically significantly greater than both KetacCem (0.646, 0.701, 1.083, 0.914MPa) and TempBond non–eugenol (0.074, 0.181, 0.190, 0.303MPa) cements at each compressive cyclic loading quantity. KetacCem and TempBond non–eugenol cements produced relatively low mean retention values that were not statistically significantly different at each quantity of compressive cyclic loading. Compressive cyclic loading had a statistically significant effect on Panavia-F specimens alone, but increased loading quantities produced no further statistically significant difference in mean retention. Compressive cyclic loading had no overriding statistically significant effect on the retention of all specimens as a population.

Conclusions

Within the limitations of the current in vitro conditions employed in this study, the retention of cast crown copings cemented to Straumann synOcta implant abutments with Panavia-F, KetacCem, and TempBond non-eugenol was significantly affected by cement type but not compressive cyclic loading. Panavia-F is the cement of choice for the definitive non-retrievable cementation of cast crown copings to Straumann synOcta implant abutments out of the three cements tested. The implications of these results relate to the choice of cement to provide the desired crown coping retention.

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Abbreviations

Ave – average

CAD-CAM – computer-aided design / computer-aided manufacture

CTE – coefficient of thermal expansion

Hz - Hertz

IRM – Intermediate restorative material

ISO – International Organization for Standardization

kg – kilogram

MDP - 10-methacryloyloxydecyl dihydrogen phosphate

mm - millimetre

MPa – MegaPascals

N – Newtons

no. – number

SA – surface area

SD – standard deviation

SEM – Scanning Electron Microscopy

TempBond NE – TempBond non-eugenol

VBATDT - 6-[N-(4-vinylbenzyl)propylamino]-1,3,5-triazine 2,4-dithione

Chapter 1

1.1 Introduction

Dental implants are an effective and popular option for replacing the single missing tooth and form an important part of mainstream dental practice today. Their use often represents a better alternative over traditional options of tooth replacement. Crowns may be retained to implant abutments in a number of ways. The selection of the method of crown retention presents the clinician with a treatment planning challenge that involves recognition of the drivers of the desired treatment outcome. Amid other factors, aspects of retrievability versus aesthetics have largely been considered in deciding whether crowns should be screw-retained or cement-retained.

The option to cement crowns to implant abutments may be elected, or contrastingly forced upon the clinician due to implant positioning. The choice of cement must subsequently be considered. The majority of cements used in implant dentistry at present have been designed for use with crowns luted to natural teeth. Cements used with implant components are required to act in a different manner than with natural teeth. In cementing crowns to implant abutments, luting agents are required to oppose two metallic surfaces whereas with natural teeth one surface normally consists of enamel, dentine or restorative material.

In implant dentistry, careful consideration of the choice of cement should include reference to the abutment and crown specifications, opposing surface characteristics, desired retention, individual properties of the preferred cement and ease of excess cement removal. Different types of cements provide different levels of crown retention (Clayton et al, 1997; Carter et al, 1997; Alfaro et al, 2004). The degree of crown retrievability has been linked to the use of temporary and permanent cements (Mansour et al, 2002; Akca et al, 2002; Pan and Lin, 2005; Squier et al, 2001), although variations exist in the quantity of retention provided by the same types of cements used with different implant systems and under different in vitro conditions (Kent et al, 1997; Mansour et al, 2002; Pan and Lin, 2005; Ongthiemsak et al, 2005; Kaar et al, 2006; Akca et al, 2002; Ramp et al, 1999; Clayton et al, 1997).

A multitude of factors in the oral environment affect the properties and retention of dental cements. In vitro tests can not accurately reproduce all oral factors such as temperature changes, occlusal forces, salivary pH, salivary buffering capacity and saliva flow rate. However, in vitro conditions can be used to simulate some influential aspects of the oral environment in order to obtain evidence of the potential performance of cements in vivo. Compressive cyclic loading is one such condition that may be employed to simulate occlusal stresses encountered in the oral environment and may affect the retentive properties of dental cements.

Resin, glass-ionomer and zinc oxide cements are some of the more readily available and widely used products for traditional crown and bridge procedures. These types of cements are now employed clinically in cementing crowns to implant abutments. Subsequently, research into their properties and performance when used with implant systems is required to provide recommendations on their use.

1.2 Aims of the study

The aims of the study were to determine:

- The effect of compressive cyclic loading on the retention of cast crown copings cemented to Straumann synOcta abutments with:
    - Panavia-F
    - KetacCem
    - TempBond NE
- The comparative retention provided by Panavia-F, KetacCem, and TempBond NE when used to cement cast crown copings to Straumann synOcta abutments

The study design comprised cementation of cast crown copings to Straumann synOcta abutments with three different cements. All specimens were placed in a humidifier, thermocycled and subjected to one of four quantities of compressive cyclic loading. The uniaxial tensile force required to remove the cast crown copings was then recorded. Eight rounds of testing were performed over a nine week period.

The null hypotheses for this study were:

- $H_0 1$: There is no influence of compressive cyclic loading on the physical retention of cast crown copings cemented to Straumann synOcta implant abutments with Panavia-F, KetacCem, and TempBond NE

- $H_0 2$: There is no difference in the retention provided by Panavia-F, KetacCem, and TempBond NE for cast crown copings cemented to Straumann synOcta implant abutments

The research questions were:

- Does compressive cyclic loading influence the physical retention of cast crown copings cemented to Straumann synOcta implant abutments with Panavia-F, KetacCem, and TempBond NE?

- Do Panavia-F, KetacCem, and TempBond NE provide different retention when used to cement cast crown copings to Straumann synOcta implant abutments?

Chapter 2 Literature Review

2.1 Dental implants

Implant-retained prostheses have become a well-established option for treatment of the partially or fully edentulous patient and often represent an improvement over traditional alternatives. Improved support, a more stable occlusion, preservation of bone, improved patient acceptance, and emergence profiles are some reasons an implant-retained prosthesis may be considered (Zarb and Schmitt, 1996).

2.1.1 History

In 1952, Professor Per-Ingvar Brånemark (a physician) discovered, by a fortunate accident, that it was impossible to recover any of the bone anchored titanium microscopes he was using in his research; the titanium had apparently bonded irreversibly to living bone tissue (Brånemark and Zarb, 1989). Professor Brånemark then demonstrated that, under controlled conditions, titanium could be structurally integrated into living bone with high predictability, a phenomenon later termed osseointegration (Brånemark and Zarb, 1989). The first practical application of this phenomenon was the implantation of titanium roots in an edentulous patient in 1965, although the initial results were unacceptably poor with five year success rates around 50% (Albrektsson and Wennerberg, 2005). What followed over subsequent years and decades, amid initial controversy, was the development of implant systems with greater success.

Today, a plethora of different implant systems exist, each with their proposed advantages. Currently, survival rates of endosseous root-form dental implants range from 85% for multiple unit fixed prosthodontics, to 95% and higher for single implants and removable prostheses (el Askary et al, 1999; Engquist et al, 1995; Andersson et al, 1998). Although in quantifying this, the literature is somewhat unclear as to the criteria used to delineate success or failure of implants.

In the future, bioactive and altered surface properties of implants that stimulate bone growth may be further developed (Albrektsson and Wennerberg, 2005). Perhaps with the increased knowledge of human genetics and possibility of in vivo growth of new teeth, implants may one day be rendered obsolete (Albrektsson and Wennerberg, 2005).

2.1.2 Implant types

In 2005, a Cochrane database review of 31 different randomized controlled trials identified more than 1300 types of dental implants in different materials, shapes, sizes, lengths and with different surface characteristics or coatings (Esposito et al, 2005). The review found there was insufficient evidence from trials to demonstrate any particular type of implant was superior (Esposito et al, 2005). Fortunately, in modern day practice, implant systems are becoming more streamlined and coordinated for the clinician, with a minority of major brands dominating the market.

2.1.3 Abutment types

Complementing the vast array of implants is an even wider array of abutments catering for almost any clinical circumstance. As well as standard abutments for both anterior and posterior regions, recent developments have been made with zirconium oxide ceramic customized abutments, more specifically for the aesthetic zone (Sorensen, 2006).

2.1.4 Clinical use

Implants have a multitude of uses ranging from the support of single unit crowns, multiple unit bridges, full arch fixed and removable prostheses, and even extraorally such as prosthetic ears. Mini-implants can now be used to provide orthodontic anchorage (Kanomi, 1997).

2.2 Cement versus screw-retained crowns

The implant abutment-retained crown is now a well accepted and highly successful option for replacing a single missing tooth. Opinions remain divided regarding cement-retained versus screw-retained implant abutment-retained crowns, and to a large extent the debate continues over aspects of retrievability versus aesthetics.

Recently, a combination cement and screw-retained restoration was described by Rajan and Gunaseelan (2004) that utilized characteristics of both techniques which in theory allowed retrieval of the cemented crown in a simpler and safer way. Taylor et al (2000) and Vigolo et al (2004) both suggested the choice of cement or screw-retained crowns was most likely not based on clinical results, rather the clinician’s preference. Vigolo et al (2004) found no evidence of different behaviour of peri-implant marginal bone or soft tissue when cement or screw-retained techniques were used with single tooth implant restorations.

2.2.1 Cement-retained crowns

As it is often difficult to achieve a passive fit coping for screw-retained implant abutment-retained crowns, cement-retained implant prostheses have become increasingly popular (Pan and Lin, 2005). The cement space that exists between the crown and abutment can help compensate for discrepancies in the fit of the crown (Guichet et al, 2000; Pauletto et al, 1999; Michalakis et al, 2000). The absence of a screw to draw sometimes inadequately fitting components together with a clamping force would be likely to eliminate strain on the crown / abutment / implant assembly (Vigolo et al, 2004). However, Andersson et al (1992) reported that in early trials of the CeraOne implant abutment system, 2 out of 32 patients required restorations to be remade as they failed to seat completely during cementation.

Although generally more simple to deliver than screw-retained crowns, the issue of expressing potentially irretrievable excess cement on seating crowns is also an influential factor, and complications have been highlighted in papers by Agar et al (1997) and Pauletto et al (1999). In most instances, surgery was required to remove excess cement. In a study of cement removal from restorations luted to titanium abutments with simulated subgingival margins, resin cement was proven to be the most difficult to remove when excess was expelled subgingivally (Agar et al, 1997).The use of temporary cements has been promoted as excess extruded cement may dissolve within a short period of time, however, not all temporary cements may dissolve rapidly particularly when located subgingivally (Armellini et al, 2006). Armellini et al (2006) also postulated that crowns cemented under normal forces may not overcome peri-implant mucosal resistance and potentially result in poor seating.

Cement-retained crowns may be preferred in the aesthetic zone where the locations of the screw access hole would otherwise detract from the final aesthetic result. Cement-retained crowns are not necessarily irretrievable, however the risk of damage to the abutment, crown and potentially implant during removal is higher than screw-retained crowns. A crown cemented to an implant abutment may be difficult, if not impossible, to retrieve without sectioning it, thus destroying the restoration and adding cost and time to renewal (Bernal et al, 2003). Cement-retained crowns also potentially allow more occlusal contacts as there is no tendency to avoid occlusion on the restoration used to seal abutment screw access channels (Bernal et al, 2003). Cement-retained crowns are more easily fabricated as traditional laboratory techniques are followed. Increasing confidence in the stability of the implant abutment screw connection, and the high survival rates of osseointegrated implants have expanded the popularity of permanent cementation (Zarb and Schmitt, 1990; Carter et al, 1997; Binon, 1996).

2.2.2 Screw-retained crowns

Screw-retained crowns have primarily been developed and promoted in response to the need for retrievability, for example when removal of the crown is required for hygiene, repairs or if abutment screw loosening has resulted. The incidence of abutment screw loosening has been reported in 2-45% of cases in a review of 17 studies by Goodacre et al (1999), with the highest incidence reported with single crowns in the premolar and molar areas (Becker and Becker, 1995). A possible cause for such high failure rates in the early implant systems was the use of titanium abutment screws that resulted in a high coefficient of friction between the abutment and screw (McGlumpy et al, 1998). With the introduction of gold alloy abutment screws and components that necessitate infrequent abutment screw tightening, the reported incidence of screw loosening has decreased (Bernal et al, 2003; Eckert and Wollen, 1998; Henry et al, 1996; Vigolo et al, 2000).

Screws may be aligned parallel to the long axis of the abutment, or custom made to engage the abutment obliquely or perpendicular. For optimal location of the screw access hole, screw-retained crowns demand precise placement of the implant. A screw access hole may occupy 50-66% of the intercuspal occlusal table, often involving the central fossa, and may weaken the porcelain around the access hole and at the cusp tips (Vigolo et al, 2004). Screw-retained crowns add further cost of additional components to an already generally accepted expensive treatment option, and require additional training of dental technicians. Complications have been reported more commonly in screw-retained implant crowns than cemented crowns, and more frequently with single unit than multiple unit crowns (Parein et al, 1997). As the complexity of the restoration and number of units increases, screw-retained methods of retention may be favoured to permit the easier retrieval of such prostheses at reduced patient expense compared with the more invasive and irreversible techniques required to retrieve cement-retained prostheses (Chee and Jivraj, 2006).

The pros and cons of screw versus cement-retained crowns will continue to be discussed. Nonetheless, clinicians may be forced or choose to retain their implant abutment-retained crowns by means of cement in some circumstances. It is important to be aware of the properties of the chosen cement, and recognize the differences that may apply to cementing crowns to implant abutments and natural teeth.

2.3 Dental cements

Dental luting cement provides the retentive interface and seal between the natural tooth or implant abutment surface and crown, and allows for minor seating discrepancies. In opting for a cement-retained implant abutment crown, the choice of cement, amongst other factors, must be carefully considered. Each type of cement has individual properties, different mechanisms of action and various strengths and weaknesses.

Current cements tend to be promoted with a focus on micro-mechanical and chemical adhesion to tooth and / or crown surfaces, and have predominantly been developed for cementing indirect restorations to natural teeth, rather than specifically for dental implant systems. Chemical bond characteristics of cements to natural teeth are less applicable to implant abutments and crowns as two metallic surfaces are opposed with implant components. Dental cements, as they apply to implant abutment-retained crowns, rely on mechanical interlocking in surface irregularities to achieve retention (Carter et al, 1997). The type of cement used is known to affect the retention characteristics of the restoration (Pan and Lin, 2005). In considering implant abutment-retained crowns, the ideal cement should be strong enough to retain the crown indefinitely, yet weak enough to allow the clinician to retrieve it if necessary (Breeding et al, 1992). However, it is difficult to quantify retention values that provide this ideal.

It should be borne in mind that variables such as preparation taper, cervico-occlusal wall height, surface finish of the preparation and casting have an important influential effect on crown retention. In addition, the type of cement used, cement film thickness, mixing ratios and techniques, cement volume, cement viscosity and seating pressure effect cement properties and performance and hence crown retention.

2.3.1 Cement film thickness

The thickness of cement spacer needs to be balanced to allow for minor seating discrepancies, but also provide sufficient accuracy of fit and retention. In an early study, Dixon et al (1992) investigated cement spacing of 0µm, 25µm, 50µm, and 75µm using platinum foil with noble metal castings cemented to premanufactured titanium implant abutments using Core paste, Resiment and zinc phosphate cements. These authors found the use of cement spacing increased retention and increasing thicknesses of cement spacing provided reduced seating discrepancies. Spacing did not reduce the retention values for any of the cements (Dixon et al, 1992). In order to exhibit a seating discrepancy value below 25µm, CorePaste required cement spacing of 75µm whereas Resiment and zinc phosphate required only 25µm of spacer under in vitro conditions (Dixon et al, 1992). This may suggest seating discrepancies are cement type and cement spacing dependant, rather than purely cement spacing dependant. It should be noted that within this in vitro experiment, uniform luting space over entire casting / abutment interface was provided by the platinum foil, unlike traditional natural tooth crowns where marginal areas are generally not spaced.

Wu and Wilson (1994), in their study of seating discrepancy using brass crowns and stainless steel dies, concluded 30µm of die spacing was required for resin luting cements. Cement spacing by means of a paint-on die spacing material has been generally used but may be product specific. The ideal thickness of die spacer has not been scientifically established, however the commonly accepted range has traditionally been set at approximately 20-40μm (Luthra, 2005; Eames et al, 1978; Fusayama et al, 1964).

Vermilyea et al (1983) found die relief agents resulted in a 32% reduction in the forces required to dislodge castings cemented to tooth preparations with zinc phosphate. Luthra (2005) agreed with Vermilyea et al (1983) and reported that the use of a commercial standard die spacer resulted in 28.3% reduction in force required to remove castings cemented to freshly extracted molar teeth with zinc phosphate cement.

Contrastingly, Passon et al (1992) in their study of the retention of full cast crowns cemented using zinc phosphate cement, found that die spacer did not significantly affect the retention up to the application of 16 coats (151μm). Two points are worthy of further note in the Passon et al (1992) study that may have relevance in explaining their conflicting results. Firstly, die-spacer was applied to within 1mm of the preparation margin and did not completely cover the axial walls, which may allow tooth-crown contact in this area. Secondly, plastic teeth were used which demonstrate different physical properties to natural tooth structure.

Carter and Wilson (1996) found an increase in retention from 250N with no spacer to 375N with eight coats of spacer using zinc phosphate to cement crowns to standardized prepared natural molar teeth. The conflicting results reported suggest the effect of die-spacing on crown retention remains incompletely determined, and standardized in vitro testing protocols are required for further comparison (Carter and Wilson, 1996). The ideal cement film thickness appears to vary with different cements and may further vary when crowns are cemented to implant abutments as compared to natural teeth.

2.3.2 Marginal leakage

Gorodovsky et al (1992), in their study of the retention of full crowns on prepared extracted human molars, found by scanning electron microscope analysis that the margins of zinc phosphate and resin cement were almost intact, however glass ionomer cement had substantially dissolved from the margins after storage for 1 hour at 37ºC and 100% humidity. This certainly has implications in ensuring that, on cementation with glass ionomer cement, crowns are fully seated and have minimal exposed cement at the margin to minimize cement dissolution.

Singer and Serfaty (1996), in their follow-up study of 92 implant-retained fixed partial dentures that had been cement-retained between 6 months and 3 years, reported a 9.8% washout of provisional cement (TempBond or IRM) within the first year. This therefore has repercussions for the choice of cement to retain implant abutment crowns.

2.3.3 Cement failure

Carter et al (1997), in a retrospective analysis of 36 selected implant-retained single crowns, observed more frequent cement failure in the same abutments in the posterior region compared with the anterior region. This may be more closely associated with greater occlusal loads placed on posterior regions.

It is important to highlight that implant overloading can occur more easily, with fewer symptoms, and with more permanent damage than overloading of teeth because implants do not have a surrounding supportive ligament that can provide proprioception, better distribution of forces, sharp pain perception, or adaptations to overloading, such as thickening of the periodontal ligament (Ulrich et al, 1993). Therefore, dental cements retaining implant abutment-retained crowns may be inadvertently placed under greater loads than natural teeth.

Alfaro et al (2004), in their study of the retention of metal copings to implant abutments using 11 different cements, commented that the retentive failure was adhesive and occurred consistently at the abutment-cement interface with the cement residue attached to the casting. This was one of the few papers that mentioned the type of cement failure. The same workers also highlighted the finding of Lepe et al (1999) that compressive strength and retentive properties of cements can be altered by modifying the powder: liquid ratio or by the addition of modifiers. This may be an important consideration in producing consistent cement where the mixture of two components is required over repeated rounds of testing.

2.4 Filling abutment screw access channels

Implant abutment screw access channels may be completely filled, partially filled or left open prior to cementing the final crown. The choice may influence the retention characteristics of the cemented crown.

Koka et al (1995), in their study regarding the retention of CeraOne gold cylinders with zinc phosphate and TempBond non-eugenol, concluded filling the access channels to the gold abutment screw provided significantly higher cement failure loads compared to not filling the access openings. In this study, TempBond non-eugenol used with a filled access opening produced greater retention than zinc phosphate with an unfilled access opening. Whether this was due to added micromechanical retention, chemical bond or the inability of cement to escape into the internal abutment cavity thus creating a greater force of cement between the internal coping surface and the abutment was unclear. This therefore suggests that filling the access channel in the CeraOne system is more important in terms of retention than the choice of cement (Pan and Lin, 2005).

In the study by Pan and Lin (2005), Fermit-N, a light-cured temporary urethane-based composite resin with silicone dioxide fillers, was used to fill the access screw channel before cementation. Ongthiemsak et al (2005) filled the access channels of their 10 abutment samples with polyvinylsiloxane impression material. In the study by Bresciano et al (2005) into the retention of four cements on Procera abutments of different heights and convergence angles, the access channel was sealed with gutta percha and composite resin.

Kent et al (1997) left half of the abutment access channels unfilled, and filled half with Duralay, an autopolymerising resin, due to the findings of Koka et al (1995). Kent et al (1997) found no statistically significant effect of filling the access opening on crown retention using zinc phosphate, TempBond non-eugenol and TempBond eugenol. Kent et al (1997) commented that the red coloured Duralay was highly visible should the crown ever need to be removed, but materials such as gutta percha, polyvinylsiloxane, or cotton pellets could also serve the same purpose.

In a separate study examining the effect of screw hole filling on retention of implant crowns, Chu et al (2005) filled 15º Esthetic abutment (Brånemark System) screw access channels either completely with polyvinylsiloxane impression material, partially with polyvinylsiloxane impression material, or had the lower portion filled with polyvinylsiloxane impression material and the remainder with composite resin. These workers found the force required to remove restorations was significantly greater with the partially filled polyvinylsiloxane impression material and composite resin placed over polyvinylsiloxane impression material compared with the channel completely filled with polyvinylsiloxane impression material. The authors concluded that the method selected to fill the screw access channel of an implant abutment could be a significant factor affecting retention of a cemented restoration.

The majority of studies did not comment on whether their screw access channels were filled. Presumably, they were not filled, as filling the screw holes should constitute a significant and mentionable aspect of the methodology, and as has been shown contributes to the results of implant abutment crown retention. It appears no consensus exists as to whether to fill, partially fill or leave open the abutment screw access channels, and with what type of material. This choice may have a potential effect on the retention of cemented implant abutment-retained crown copings.

2.5 In vitro conditions

In vitro conditions attempt to artificially simulate those conditions that exist in the natural oral environment, but generally do not entirely reflect all variables encountered in vivo. Most in vitro conditions are difficult to validate as accurately simulating the in vivo environment. Therefore, simulations of the oral environment are derived from assumptions. Similarly, very few assumptions have been validated as reproducing observed clinical behaviour.

ISO (International Organization for Standardization) standards have been developed in an attempt to standardize the testing of materials in general, and should be used as the benchmark for in vitro testing. Standardized testing protocols permit meaningful and accurate comparison of different experiments. ISO standard ISO / TR 11405:1994(E) outlines the conditions for standardized treatment of dental material specimens in order to simulate in vivo conditions. However, as can be seen in the ensuing paragraphs of this section, many variations in the elements comprising in vitro testing conditions exist.

2.5.1 Crown seating pressure

The force required to cement crowns onto natural teeth or implant abutments is critical in expressing any excess cement around the margins and ensuring the crown is fully seated preventing marginal gaps. Also of importance during cementation is the volume of cement loaded into the crown. The expression of potentially irretrievable excess cement has far greater consequences in vivo than in vitro.

Ongthiemsak et al (2005) cemented castings under a 6kg load for 10 minutes, in reference to a study by Breeding et al (1992) that compared the retentive strengths of castings cemented to machined titanium implant abutments and to a human premolar with TempBond, IRM and Life.

Pan and Lin (2005) used a 2kg weight to seat crowns onto abutments, and stored the abutment / crown complex with the attached weight at 37ºC in an oven with 100% humidity for one hour. Kaar et al (2006) used a 1kg dead weight for 10 minutes to cement gold cylinders to CeraOne abutments, and then stored their samples in a 37ºC incubator with 100% humidity for 84 hours. Mansour et al (2002) loaded castings cemented onto ITI solid abutments with a 5kg load for 10 minutes. Pan et al (2006) used a 19.6N (2kg) load for one hour in 100% humidity and 37ºC to cement castings to SteriOss abutment analog assemblies, then placed specimens in a humidifier for a further 23 hours without a load. Ramp et al (1999) used a 6kg load for 10 minutes with minimal disturbance for a further 10 minutes.

Bresciano et al (2005) used a constant load of 10kg for 10 minutes to cement copings to Procera abutments of different height and convergence angle. Bernal et al (2003) cemented crowns to abutments using a 10kg load for an unspecified time. Kent et al (1997) seated their abutments quickly with finger pressure before a controlled axial load of 5kg was applied for 10 minutes. Alfaro et al (2004) applied luting agents to the internal walls of castings, then seated the castings on abutments with finger pressure for five seconds followed by a 5kg constant load for 10 minutes with a load gauge. The cemented specimens were then allowed to remain at room temperature for an additional 20 minutes before testing.

Piemjai (2001), in an investigation into the effect of seating force, margin design, and cement on marginal seal and retention of complete metal crowns, found greater seating forces (300N (30.6kg) as compared with 100N (10.2kg) and 25N (2.6kg)) produced better crown seating but had no significant effect on crown retention. It was also established that shoulder and shoulder with bevel finish lines provided better crown retention than a chamfer. Kent et al (1996) found the amount of cement used (0.01ml or 0.02ml of zinc phosphate, TempBond eugenol, and TempBond non-eugenol) did not affect retention when used with the CeraOne implant system.

These investigations demonstrate the technique to cement crowns for in vitro testing varies between studies, and to date no consensus appears to stand. No known ISO standard has been developed for cementing dental crowns to either natural teeth or implant abutments.

2.5.2 Humidifier

Storage of samples in a humidifier is an in vitro simulation of the thermal stresses encountered in the oral environment. Although the humidifier is modelled on an in vivo simulation, it does not completely equate to clinical conditions. In accordance with ISO standard ISO / TR 11405:1994(E), specimens should be placed in a humidifier at 100% humidity and 37ºC for 24 hours prior to thermocycling.

Ongthiemsak et al (2005) stored samples at 37ºC in an atmosphere of 100% humidity for 24 hours before testing. Ongthiemsak et al (2005) found the retentive force of zinc oxide / eugenol cement was reduced in 100% humidity because of its high solubility in direct contact with water (Millstein et al, 1991; Markowitz et al, 1992).

After cementation, Pan and Lin (2005) stored each abutment / crown with a 2kg attached weight at 37ºC in an oven in 100% humidity for one hour. After one hour the weight was removed and the abutment / crown complex stored in the oven at 37ºC in 100% humidity for a further 23 hours.

Bresciano et al (2005) stored their samples in a humidor for 24 hours prior to experimental testing. Bernal et al (2003) placed their samples in a humidor at 37ºC for one hour before testing. Kent et al (1997) stored their samples in 100% humidity for 24 hours prior to testing. Squier et al (2001) placed samples in a humidor at room temperature prior to thermocycling for 24 hours before testing. GaRey at al (1994) stored all test samples in 100% humidity in addition to combinations of thermocycling, compression loading, and blood contamination. In a unique in vitro condition, Kaar et al (2006) stored their samples in a 37ºC incubator with 100% humidity for 84 hours.

Standard times within a humidifier were predominantly used prior to testing samples. In the research described, most samples were placed in a humidifier for either one hour or 24 hours. Additional time within the humidifier may not necessarily equate to additional simulated thermal stress on the sample. Different materials may have different sensitivities to the humidifier. It was apparent the humidifier had at least some affect on samples and should be used during in vitro studies to attempt to simulate the conditions of the oral environment.

2.5.3 Thermocycling

Thermocycling samples through hot and cold water baths is a further in vitro simulation of the thermal stresses encountered in the oral environment. Although thermocycling is modelled on an in vivo setting, it has not been validated as accurately and completely equating to clinical conditions.

The recommendation from ISO standard ISO / TR 11405:1994(E) for testing dental materials involves placement of specimens in a humidifier at 100% humidity and 37ºC for 24 hours, then subsequent thermocycling for 500 cycles between 5ºC (±2ºC) and 55ºC (±2ºC) with a 20 second dwell time in each water bath, and 5-10 second interlude between water baths, where one cycle constitutes a combined hot and cold water bath immersion. As can be seen in the ensuing paragraphs, variations exist in the application of thermocycling and conditions of thermocycling with various studies.

In ranking the retentive ability of 11 cements, Alfaro et al (2004) stored half of their samples in saline solution at 37ºC for 72 hours after crown cementation, and half in dry conditions at 22ºC. These researchers found storage in saline affected different cements in different ways, but the retention values of most cements differed between the two test conditions.

Pan and Lin (2005) subjected their abutment / analog assemblies and cast superstructures to 1000 cycles on a thermocycling machine, cycling between 5ºC and 55ºC for 30 seconds in each bath.

GaRey et al (1994) placed a group of cemented abutment samples in a thermocycling machine cycled between 8ºC and 60ºC for 400 cycles (2.5 minutes per cycle) and compared the retentive strength to non-thermocycled groups. The choice of 400 cycles was selected in reference to a study by Crim and Franklin (1987) that investigated the effect of storage and cycling duration on the microleakage of crowns luted with resin cement. In this study, the researchers found no difference in marginal dye penetration through cement when samples were thermocycled either 100 or 1500 cycles (Crim and Franklin, 1987). Ga Rey et al (1994) found a slight, but not statistically significant, reduction in retentive strength in the thermocycled group compared with the control group. The authors explained that as the coefficients of thermal expansion for the implants and posts were similar to that of the cements, minimal dimensional change would have occurred during the thermal shock tests (GaRey et al, 1994).

Nakamura et al (1989) contrasted resin and conventional cements for luting inlays to natural teeth and exposed their samples to 1000 cycles between 4ºC and 60ºC. Nakamura et al (1989) found a similar percentage reduction in retention as in the study by GaRey et al (1994), indicating that an elevation in the number of thermocycles may not further significantly weaken cements.

In other studies involving thermocycling, Kerby et al (1992) reported slightly smaller retention values for cemented posts in Steri-Oss implants when thermocyled 1000 times. Uchiyama (1986) demonstrated a 1% to 5% reduction in retention of shear bond to failure values when discs were cemented to teeth with resin cements and thermocycled 300 times. When the same samples were exposed to compressive cyclic loading alone, a 2% to 10% reduction in retention values was observed. Diaz-Arnold (1989) reported no significant difference in retentive strengths of nickel-chromium-beryllium alloy discs cemented with three resin cements and thermocycled 300 times.

Matsumura et al (1990) suggested thermocycling was a technique that accelerated water aging deterioration. In their study of adhesive bonding of titanium with a titanate coupler, no significant difference in retention was demonstrated between 20,000 and 50,000 thermocycled specimens. This, and previous findings from studies involving thermocycling, may possibly be explained by looking at the thermocycling process and / or the material being tested. Thermocycling may simulate some oral thermal stresses but in a different manner to those actually encountered in vivo. The materials tested may be affected by a small quantity of thermocycling up to a point, after which further thermocycling had a minimal measurable effect. The importance of considering the coefficients of thermal expansion of the materials being tested has been previously mentioned. It has not yet been possible to equate quantities of thermocycles with equivalent in vivo time. Nevertheless, it was apparent thermocycling had at least some affect on in vitro samples, albeit sometimes statistically insignificantly, and should be used during in vitro studies to simulate the oral environment.

2.5.4 Development of in vitro tooth wear simulations

The purpose of the tooth wear machine is to simulate human masticatory function, however variations between individuals exist and estimations of the quantity, magnitude and direction of masticatory forces are required. The development of in vitro tooth wear simulation can be traced to initial studies that investigated the wear characteristics of the first dental resins where one abrasive surface was rolled over another surface of interest (Smith and McCabe, 1987; Tillitson et al, 1971; Lugassy et al, 1972). Early results varied considerably depending on the load applied and the abrasive agent. Subsequently, human enamel was used to slide and impact against composite materials, but laboratory results did not equate to clinical observations (Dickson, 1979; Lutz et al, 1984). Harrison and Lewis (1975) then developed an in vitro device that simulated the masticatory cycle controlled for contact time, sliding time and stroke speed, but the correlation to clinical results was inversely related.

Roulet (1987) appeared one of the first to use a metal stylus to deliver a controlled force to the tooth and / or composite surface. This researcher found a strong correlation between microstructural degradation in vitro and clinically stressed restorations. Unfortunately, there was no simulation of wear rates associated with posterior composite resins (Roulet, 1987). De Gee et al (1986) used a different system that applied a load via a rotating drum through an intermediate slurry of poppy seeds and water which served as a food bolus. This in vitro simulation was found to recreate occlusal microstructural degradation and generated wear that corresponded with clinical results (Leinfelder et al, 1989). Both De Gee et al (1986) and Roulet (1987) were able to relate in vitro to in vivo results, but were not able to predict clinical performance.

Leinfelder et al (1989) subsequently developed an in vitro simulation that was able to predict clinical results, particularly in relation to composite resins. Leinfelder et al (1989) applied a 55N (5.6kg) load with a descending stainless steel stylus that slid across the occlusal surface while producing a constant force. A slurry of polymethacrylate particles was used to create masticatory stress on the surface. One stroke was applied every 0.6 seconds for 50,000 cycles, followed by thermocycling between 0ºC and 65ºC for 20 minutes. Leinfelder et al (1989) concluded their apparatus was able to reproduce marginal defects, marginal degradation and microstructural defects in composite resins seen clinically, but was still not able to simulate more generalized wear.

It should be recognized that in testing composite materials, dental cements, and indeed most other dental materials, that they are used in combination and are subjected to complex stresses and environments (Kelly, 2006). For example, composite resins are used with dentine bonding agents. It is therefore difficult to fully assess a single material from information about the material alone. Furthermore, factors specific to the oral environmental influence the properties of materials (eg. moisture contamination), therefore limiting the value of specific material properties unless studied clinically or within a validated laboratory simulation (Kelly, 2006).

In considering the retention of implant abutment cemented crowns, many variables influence their behaviour that may preclude the formation of precise clinical guidelines. In most in vitro studies, ideal simulated preparations, ideal abutment heights and taper, and ideal cementing techniques are used that may not be possible in vivo. Therefore, the results of in vitro studies should be considered carefully before applying them to clinical situations. Nevertheless, it is generally considered that the fatigue strength of materials tends to be reduced to a greater extent in the severe conditions of the oral environment compared with that of in vitro studies (Craig and Powers, 2002).

2.5.5 Specific in vitro tooth wear conditions

In their study on the effect of compressive cyclic loading on the retention of a temporary cement used with implants, Ongthiemsak et al (2005) applied a two cycles per second sinusoidal-type compressive loading to castings between 20N (2kg) and 130N (13.3kg) for 500 000, 1 000 000, and 5 000 000 cycles thought to simulate approximately six months, one year and five years of human mastication. This estimation was based on historical in vivo masticatory load testing by Graf (1969), Anderson (1956), Anderson and Picton (1958) and Helkimo (1978).

In a study on the effect of seven different luting agents on the retention of dental implant-retained crowns, Pan and Lin (2005) subjected implant abutment / analog assemblies and cast superstructures to 100,000 cycles at 1.2 Hz on a chewing machine under a force of 75N (7.7kg) which was estimated to represent a three year in vivo chewing cycle. The specimens were then subjected to 1000 cycles on a thermocycling machine (5-55ºC), with 30 seconds in each water bath. The estimation of three years of in vivo chewing function was based on a study by Suzuki et al (1999) that compared in vitro wear of posterior composite resins, and subjected samples to a load of 75N (7.7kg) with a stainless steel stylus for 100,000 cycles at 1.2 Hz, in reference to aforementioned work of Leinfelder et al (1989).

Matthews et al (1991), in an early investigation into the effect of connector design on cement retention in an implant and natural tooth-retained fixed partial denture, subjected their samples to 200,000 cycles at 85 Hz with a 4kg load to simulate one year of function in reference to a previous study by Outhwaite et al (1982).

GaRey et al (1994) compared the effects of thermocycling, load-cycling, and human blood contamination on the retentive strength of five different cements used for cementing abutments to root form implants. In addition to thermocycling and storage in a humidifier, these workers subjected selected samples to a 4.6kg vertical compressive load at 35.5ºC in 100% humidity for 55,000 cycles over eight hours. This was the first study of its kind to include the effects of blood contamination on resin cements.

Graf (1975) reported normal masticatory forces were mostly vertical and varied with age, gender, muscle mass, skeletal form, and the position in the arch. Occlusal contact time averaged approximately 17 minutes a day, eight of which occurred during mastication (Graf, 1969). Most normal masticatory forces were vertical along the long axis of the dentition and averaged less than 70N (7.1kg) with a typical Western diet (Graf et al, 1974). Non-axial masticatory forces varied with the chewing stroke and location in the mouth but were generally less than 50N (5.1kg) in the bucco-lingual direction and 20N (2.2kg) in the anterior-posterior direction (Graf et al, 1974).

Kaidonis et al (1998) in their investigation into wear of human enamel, and in using the same tooth wear machine as the current study, proposed weighted cyclic compressive loading of between 2kg and 10kg represented average human masticatory force. No significant difference in wear rates existed between running specimens at 80 or 160 cycles per minute, where one functional wear cycle constituted a uni-directional movement where a moving upper specimen was rubbed against a fixed lower specimen in one direction for a specified duration with a specified weight (Kaidonis et al, 1998). Additionally, with the number of cycles kept constant, no statistical significant difference in average wear rates was found when using forces of 3.2kg or 9.95kg. Specimens were cycled for 89,000 cycles before quantification of wear rate.

Additionally, it was observed that using the heat produced at the surface when rubbing two enamel surfaces together was 32ºC to 35ºC, closely approximating that of the oral environment (Kaidonis et al, 1998). This additional in vitro condition was thought to add to the accuracy of in vivo simulation. Contrastingly, Kaar et al (2006) opposed this in their study of fatigue damage to cemented CeraOne gold cylinders, and immersed their specimens in (presumably room temperature) water to create a wet environment and reduce any heat that might be generated during the experiment.

In a separate study, Shabanian and Richards (2002) investigated the wear characteristics of a composite resin, a glass ionomer cement and a resin-modified glass ionomer cement. In using the same tooth wear machine as the current study, a range of loads between 0 and 9.95 kg was applied to samples that received 80,000 cycles at 80 cycles per minute. A relationship of increased wear rate with increased load was identified.

Correlation of the number of in vitro tooth wear machine cycles with equivalent in vivo wear is subjective and open to estimation. No known study has validated this due to apparent difficulties in ethics and measurement.

2.6 Findings from natural tooth / crown retention studies

The retention of crowns to natural teeth, and indeed implant abutments, is influenced by the interplay of tooth preparation taper, cervico-occlusal wall height, surface finish of the preparation and casting, cement film thickness and type of cement. Retention may also be affected by cement mixing ratios and techniques, cement volume, cement viscosity and seating pressure. The focus of many natural tooth / crown retention studies has to date related to convergence angles, crown height and cement bonding mechanisms.

Traditional convergence angles for full coverage crown preparations have been set between 4º and 10º, however some believe absolute parallelism produces the highest retention (Wilson and Chan, 1994). Jorgensen (1955) proved that a 6º taper for natural tooth crown preparations was ideal. This study showed that a 15º taper provided 33% of the retention of the ideal 6º taper, and a 25º taper reduced retention by 75% (Jorgensen, 1955). It was proposed that the retention of implant abutment-retained crowns would be approximately three times greater than the retention of natural tooth-retained crowns, since most practitioners prepared tooth abutments to 15º to 25º of taper (Eames et al, 1978).

Wilson and Chan (1994) found that convergence angles between 6º and 12° were optimal for full crown preparations when using zinc phosphate to cement cast metal crowns onto machined brass dies, and concluded convergence angles of less than 6º were not desirable even if they could be clinically achieved. Wilson and Chan (1994) also commented that a relationship existed between the convergence angle and the critical cement thickness that was necessary to realize the maximum strength properties of zinc phosphate cement.

Chan et al (2005), in a similar later study concerning the retention and seating discrepancy of complete cast metal crowns cemented onto metal dies with convergence angles ranging from 0º to 70º, agreed that crown retention (and marginal discrepancy) was influenced by the preparation convergence design. Many further studies have demonstrated an increase in retention is related to a decrease in taper and an increase in occluso-cervical height (Kaufman, 1961; Gilboe and Teteruck, 1974; Leempoel et al, 1987).

Gorodovsky et al (1992) performed a study on the retention of complete cast crowns on extracted human molars using five different cements (zinc phosphate, glass ionomer (KetacCem), composite resin, composite resin with a dentinal bonding agent, and adhesive resin cements). After standardized crown preparations to 4º taper and 4.5mm crown height, they found the retention provided by the adhesive resin cement was double that of the zinc phosphate and glass ionomer cement. The retention of the adhesive resin cement was 65%

greater than the composite resin and composite resin with a dentine bonding agent cements. Interestingly, under scanning electron microscope analysis of the margins, the resin cement was almost intact, zinc phosphate had undergone limited disintegration, and glass ionomer cement displayed the poorest marginal integrity.

Kakigawa et al (1989) exposed crowns cemented to prepared teeth with Panavia cement to 86,400 cyclic loads of 7.5kg. These workers reported a 36% reduction in the tensile strength compared with baseline samples. Further experimental details were unfortunately unavailable.

Breeding et al (1992) compared the retentive strengths of castings cemented to machined 9º taper titanium implant abutments and to a human premolar with TempBond, IRM and Life (calcium hydroxide cavity liner). These workers found no significant differences in the retention between the cemented castings on the titanium abutments and the natural tooth, and concluded that superstructures provisionally cemented with Temp Bond, Life or IRM may be removed from implant abutments with minimal abutment or fixture disturbance. It should be noted that the context of this study applied to the period in which abutments were cemented to titanium fixtures.

Crown height appears intimately related to crown surface area. In a historical study of the retention of gold castings to aluminium alloy dies using zinc phosphate cement, Kaufman et al (1961) found that with tooth preparations of identical taper, each unit area of the crown surface demonstrated comparable retentive ability, regardless of the other dimensions of the preparation. Kaufman et al (1961) also reported a linear increase in retention as the preparation increased in diameter. Thus, maximizing the surface area would maximize retention. As implant abutments usually possess greater occluso-cervical height due to their subgingival placement, greater retention would be expected compared with natural teeth.

Tooth surface texture has also been suggested as an additional influential factor affecting crown retention. In an extensive study of 105 extracted human teeth standardly prepared using diamond, tungsten carbide, and tungsten carbide finishing burs, Ayad et al (1996) found statistically significant differences in the surface topography as analyzed with a surface profilometer and scanning electron microscope. In this study, the authors referred to “ideal roughness” of the tooth surface to permit optimal wetting, but not excessive roughness so that air may be trapped between cement and dentine. The optimal roughness may be an important component of natural tooth crown retention that is absent in cemented implant-abutment retained crowns.

Further to their initial work, Ayad et al (1997) standardly prepared 90 extracted human teeth with diamond, tungsten carbide finishing and cross-cut carbide burs to produce different surface finishes. The type of rotary instrument used for tooth preparation provided no significant difference on the retentive strength of castings when used with either glass-ionomer (KetacCem) or adhesive resin (Panavia-EX) cements, and cross-cut carbide burs improved retention of cast crowns cemented with zinc phosphate cement by 46% and 55% compared with diamond stones or finishing burs. However, one particular type of bur did not produce significantly different retention values with all cements, rather the results were more strongly related to the type of cement used. Panavia-EX provided more retention than both KetacCem and zinc phosphate (Ayad et al, 1997).

The behaviour of dental cements may be different on implant abutments than natural teeth. To date, it has been necessary to predominantly depend on studies that report on cement retention performance on natural teeth (Alfaro et al, 2004).

2.7 Findings from implant abutment / crown retention studies

Previous studies in the area of implant abutment cement-retained crowns focus on the use of temporary cements such as TempBond (zinc oxide / eugenol or zinc oxide / non-eugenol) to permanently cement crowns in order to improve the chance of retrieval if needed. In these studies, castings were cemented to implant abutments, subjected to various in vitro simulations and the load to failure measured using a tensometer.

2.7.1 Ranking order studies

A number of in vitro studies described the tensile force required to remove crowns or crown copings cemented to implant abutments or implant abutment replicas with various cements.

Akashia et al (2002) provided a ranking order of four temporary cements used to cement gold cylinders to stainless steel replicas of CeraOne abutments. Although all cements provided similar retention, calcium hydroxide cavity liner (Dycal) provided the greatest retention, followed by acrylic / urethane-based provisional cement (ImProv), non-eugenol temporary cement (TempBond) and eugenol temporary cement (TempBond NE).

Maeyama et al (2005) ranked a total of five different permanent and temporary luting cements according to the retention of gold-platinum-palladium alloy copings on prefabricated abutments. They discovered composite resin and resin-reinforced glass ionomer cements provided more than 3.5 times retention as glass ionomer cement, three times as much as zinc phosphate, and 8.5 times as much as zinc oxide / non-eugenol cement. Maeyama et al (2005) concluded that the retentive strength of metal copings was different to that of conventional cemented restorations on natural teeth, and these differences may be influenced by differences in surface roughness and abutment height.

In further similar studies, Kent et al (1997) and Koka et al (1995) agreed with previous findings that zinc phosphate provided significantly greater retention than TempBond and TempBond non-eugenol cements for gold cylinders cemented to CeraOne 5mm abutments.

Clayton et al (1997) found zinc phosphate provided a 164% stronger mean retentive bond than glass ionomer cement and a 49% stronger mean bond than resin cement using the CeraOne gold cylinder cemented to the 3.7mm tall CeraOne abutment. Subsequently, zinc phosphate was recommended as the cement of preference, however its use posed difficulties in terms of retrievability. Clayton et al (1997) also found zinc phosphate cement produced the largest mean marginal gap opening of 62µm compared with composite resin and glass ionomer cement, but was not of clinical significance and was still within clinical acceptable limits.

In an early retrospective clinical analysis, Carter et al (1997) found implant-retained single crowns cemented with TempBond were more likely to be associated with cement failure than those cemented with zinc phosphate, and subsequently altered their protocol to use permanent cements. They commented that as TempBond took a longer time to achieve an initial and final set than zinc phosphate, it was possible that movement of the crown during function or oral exploration with opposing teeth or the tongue during this critical initial setting period could cause disruption of the cement or a potential mechanical lock.

These workers concluded that although the removal of a cemented crown was infrequently necessary, it was more difficult because fracture of the cement bond could involve destruction of the crown.

Within their study, Carter et al (1997) noted that the internal surfaces of copings had different surface textures depending on whether the crown was cast or milled. This observation was partly reasoned for why some crowns cemented with TempBond repeatedly decemented. Two patients with 13 decementations in total, presumably from smoother surface textures and TempBond cement, were excluded from the study to reduce the lack of independence between events. It has been previously proven that increasing the coping surface roughness tended to increase the retentive ability of zinc phosphate or polycarboxylate cements (Oilo and Jorgensen, 1978; Jorgensen, 1955).

2.7.2 Abutment design variation studies

Other studies have investigated and commented on the effect of various abutment designs on crown retention.

Bresciano et al (2005) examined the retention of four cements (zinc phosphate, zinc oxide / eugenol, polyurethane resin with and without Vaseline) on Procera abutments of 5, 7 and 9mm height, and 0º, 4º and 8º of convergence angles. As well as providing a ranking order for the cements (zinc phosphate followed by polyurethane resin without Vaseline, polyurethane with Vaseline, then zinc oxide

/ eugenol), these researchers found an increase in height and decrease in taper of CAD-CAM implant abutments was related to an increase in retention of metal castings. This same relationship reported earlier for natural tooth abutments by Jorgensen (1955); Kaufman (1961); Gilboe and Teteruck (1974); Leempoel et al (1987) had now also been found by Bresciano et al (2005) to apply to titanium implant abutments.

Bresciano et al (2005) also commented that the addition of petroleum jelly (Vaseline) to Improv as per the manufacturer's instructions to allow for retrievability not only reduced retention but created a wide standard deviation compared with the other groups. This may imply that the addition of Vaseline was difficult to standardize and may have caused unpredictable behaviour (Bresciano et al, 2005).

Bresciano et al (2005) were one of the few studies to offer clinical advice stemming from their in vitro study, and suggested clinicians should carefully evaluate the height and taper of the abutment in choosing their cement with regard to its retention value. Additionally, in the presence of short tapered abutments, zinc oxide / eugenol should be avoided, and when short abutments were employed, a reduced convergence angle would be required in order to achieve adequate retention. Finally, long, perfectly parallel abutments should be avoided, presumably due to the difficulties in crown retrievability (Bresciano et al, 2005).

Bernal et al (2003) investigated the effect of 20º and 30º convergence angles, 4mm and 8mm occluso-cervical dimensions and zinc phosphate, TempBond, TempBond with Vaseline and Improv cements on the retention of gold crowns cemented to machined titanium alloy cylinders. Bernal et al (2003) concurred with Bresciano et al (2005), that abutment preparations with greater occluso-cervical dimension and less occlusal convergence exhibited higher tensile resistance to dislodgement. The greatest retention values were achieved in abutments with a 20º taper and 8mm axial wall height. Bernal et al (2003) again confirmed zinc phosphate provided greater resistance to removal than TempBond.

In an earlier study, Kent et al (1996) investigated the effect of “chimney height” (3.7mm and 5mm) on the retention of gold alloy cylinders cemented to CeraOne abutments with zinc phosphate, TempBond and TempBond NE. These researchers also reported greater chimney height provided greater retention. The greatest retention was provided by the 5mm abutment with zinc phosphate cement. Furthermore, the amount of cement used did not affect retention. They used 0.01ml and 0.02 ml of luting agent that resulted in comparable retention values, but concluded 0.01ml was recommended to minimize expression of excess cement (Kent et al, 1996).

Mansour et al (2002) studied the retention of cast copings on ITI solid abutments using Panavia 21, zinc polycarboxylate, resin reinforced glass ionomer, zinc phosphate, zinc oxide eugenol and TempBond NE cements. These workers reported Panavia-21 provided a mean retention value of 11.5 times that of TempBond NE, and more than three times that of zinc phosphate cement. Mansour et al (2002) commented that their ranking was different to that obtained when the same cements were used on natural teeth. Cement retention values obtained from similar studies using extracted natural teeth as abutments may be misleading when used for cement-retained implant abutment supported crowns (Mansour et al, 2002). Different heights, tapers, surface areas and surfaces between natural teeth and implant abutments need to be considered in assessing crown retention.

In a clinical follow-up study of 225 implants that had been cement retained for six months to three years, Singer and Serfaty (1996) reported crowns cemented with TempBond or IRM lost the greatest amount of retention within the first year in function. Interestingly, all of the observed failures involved short abutments of 3-4mm in height and TempBond or IRM.

In their research exploring the retention of CeraOne gold cylinders cemented with zinc phosphate and TempBond to three different diameters of CeraOne titanium abutments, Covey et al (2000) concluded the increase in surface area of wide abutments did not result in an improvement in retention over that of a standard abutment. Interestingly, this opposes the findings from the early study by Kaufman et al (1961) who reported a linear increase in retention as the preparation on natural teeth increased in diameter and recommended a maximal surface area to maximize retention. In fact, in the study by Covey et al (2000), the retention strength per unit area of the wide abutments was found to be lower than the standard size abutments. However, these authors agreed that abutment height and height to width ratio were positively related to retention strength unlike abutment total surface area and width. They agreed with previous authors' findings that permanent luting cement (zinc phosphate) produced approximately three times greater retention than TempBond.

The retention of cemented implant crowns is influenced by several factors in addition to the cement used, including convergence angle, height and roughness of the abutment surface (Jorgensen 1955; Bernal et al, 2003; Oilo and Jorgensen, 1978).

2.7.3 In vitro simulation studies

A minority of studies have subjected samples to further simulations of biological factors encountered in the oral environment such as compressive cyclic loading forces, moisture contamination, and temperature cycling.

Akca et al (2002) confirmed that permanent cements provided greater resistance to failure than temporary cements on four different titanium abutment types. These workers placed samples in artificial saliva for 24 hours before testing. Their results agreed with previously outlined similar studies that did not expose samples to artificial saliva. Akca et al (2002) observed greater force was required to remove crowns cemented to long abutments, and concluded that temporary cementation may be more suitable for restorations retained by multiple implants.

Alfaro et al (2004) compared the retentive ability of 11 materials used to cement metal copings to SteriOss implant abutments 30 minutes after cementation in dry conditions at room temperature and after storage in saline solution for 72 hours at 37ºC. They found storage in saline for 72 hours at 37ºC affected different cements in different ways and the retention values of most cements differed from the 30 minute test. The resin based provisional cements suffered a reduction in their retentive properties in saline storage due to aging and water contact. This effect was explained by Soderholm (1981) and Diaz-Arnold et al (1989), who suggested the tensile and transverse strength of composite diminished slowly and proportionally to the time immersed in water.

Zinc phosphate cement demonstrated a 2780% greater retention in the 72 hour test when compared to the 30 minute dry storage test, due to a more complete setting reaction and surface contact with water (Alfaro et al, 2004). Storing TempBond in saline for 72 hours caused a 47% reduction in its mean retention value when compared to the retention value 30 minutes after cementation, proposedly due to its high solubility in water. The addition of petroleum jelly (33% by total mixed volume) to one sample of TempBond explained the 1800% reduction in mean retention, as previously similarly described by Olin et al

(1990). Alfaro et al (2004) concluded that their study of 11 cements may assist in selecting a material that was retentive enough to withstand occlusal forces, but weak enough to allow easy retrieval of cement-retained implant restorations.

Kaar et al (2006) investigated three luting agents used to cement gold cylinders to CeraOne abutments before and after 300,000 compressive cyclic loadings with a 100N (10.2kg) load. Specimens in this study were placed in a humidifier at 37ºC and 100% humidity for 84 hours, but not thermocycled. Kaar et al (2006) found TempBond exhibited no significant loss of retention with the mechanical stressing employed in this study, however its retention value was the least of the three tested cements both before and after compressive cyclic loading. TempBond specimens lost 8.8% of their initial retention with compressive cyclic loading, whereas the UltraTemp and Improv lost 27.2% and 20.8% respectively.

In formulating their ranking order for five luting cements, Squier et al (2001) placed samples in a humidor at room temperature prior to thermocycling for 24 hours before testing. On cementing cast noble metal crowns to 8º machined Straumann solid 5.5mm titanium abutments, these workers found composite resin demonstrated the highest mean retentive strength followed by zinc phosphate and resin-reinforced glass ionomer, then glass ionomer and zinc oxide / non-eugenol. Squier et al (2001) also found that retention was not altered by an anodized abutment surface as compared with standard surface preparation.

Breeding et al (1992) investigated the retentive strengths of cast noble metal implant abutments cemented into titanium fixtures with three permanent luting agents both dry and after storage in 0.9% physiologic saline for 30 days at 37ºC. They found glass ionomer (KetacCem) cemented abutments that were stored in saline exhibited a significantly higher mean retentive strength than abutments cemented with either Core Paste or Resiment resin luting agents. However, this finding applied to cementation of abutments to titanium fixtures, not castings to implant abutments. The results indicated a greater sensitivity of resin-based cements to moisture contamination.

GaRey et al (1994) compared the effects of thermocycling, load cycling, and human blood contamination on the retentive strength of five different cements for luting abutment posts to root form implants. Compared to an untested control group, there were significant retention differences with load cycling, but minimal effects on the retentive strength from thermocycling alone. Load cycling and thermocycling diminished the retentive strength of the cements more than either cyclic loading or thermocycling alone, suggesting an additive effect of compressive cyclic loading and thermocycling. Blood contamination in combination with thermocycling and load cycling substantially reduced the retention of all cements. Blood contamination reduced the retention of all cements more than thermocycling or compressive cyclic loading individually or combined. It should be stressed that although this appeared the first study of its kind to include the effects of blood contamination on resin cements, GaRey et al's (1994) study investigated cemented implant abutment posts, not cemented abutment crowns, and may have reduced relevance to the proposed study.

Ongthiemsak et al (2005) investigated the effect of compressive cyclic loading on the retention of TempBond used to cement gold castings to Zimmer abutments. These authors subjected cemented specimens to compressive cyclic loading that simulated an estimated six months, one year and five years of human mastication, and found compressive cyclic loading reduced the retentive forces opposing crown removal in each group. Ongthiemsak et al (2005) found that although compressive cyclic loading reduced the tensile force necessary to remove a coping from an abutment, the increased number of cycles beyond six months had little relationship to further decreased retentive forces of the temporary cement. The equivalent of six months loading caused 16.75% reduction in retention compared to no loading, one year caused 18.73% reduction and five years caused 19.68% reduction. Further cyclic loading beyond six months did not cause significant further loss of retention. This finding may raise the question of how rapidly retention is lost during the first six months of simulated function. These researchers stated "masticatory forces cause fatigue to cement-retained crowns and abutments and may adversely effect retention". However, their study was limited to the use of TempBond temporary cement.

The retentive forces from unloaded groups in the study by Ongthiemsak et al (2005) were higher than similar studies reportedly due to differences in the height and surface of the implant abutments. In this study, the height of the implant abutments was 7mm with 5 lateral grooves around the surface of the abutment and one third of the wall height was parallel (Ongthiemsak et al, 2005). The retentive forces ranged from 230N (23.5kg) to 240N (24.5kg) in the unloaded groups. In most comparative studies, which generally used CeraOne abutments, the abutments were at most 5mm in height, had smooth surfaces, and retentive forces that ranged from 67N (6.8kg) to 139N (14.2kg) (Kent et al, 1996; Kent et al, 1997; Clayton et al, 1997). Ongthiemsak et al (2005) concluded that “if the retention of cemented implant crowns in the oral cavity is as high as those observed in this study, implant restorations cemented with temporary zinc oxide / eugenol cements would be difficult to retrieve. With large implant abutments with parallel walls, weaker cements are indicated” (Ongthiemsak et al, 2005). Both studies by GaRey et al (1994) and Ongthiemsak et al (2005) prove that load cycling is a critical in vitro element in simulating the oral environment.

Pan and Lin (2005) evaluated the retentive strength of seven luting agents used to cement cast superstructures to SteriOss Esthetic abutment assembles after subjecting the assemblies to 100,000 cycles on a chewing machine with a 75N (7.6kg) weight then 1000 cycles on a thermocycling machine (between 5ºC and 55ºC for 30 seconds each). This, however, provided no comparison between different quantities of compressive cyclic loading cycles as did the study by Ongthiemsak et al (2005). Pan and Lin (2005) found resin cement (All-Bond 2, Panavia-F) was at least 37% more retentive than zinc phosphate and glass ionomer cement (Advance) mean values, and at least 426% more retentive than the mean values for provisional cements (ImProv, TempBond). The authors concluded that resin and zinc phosphate cements should be used for cementation of definitive implant-retained fixed prostheses without the need for possible retrieval, and provisional cements should be used for provisional cementation with the need for possible retrieval for maintenance. Glass ionomer cement was excluded from this conclusion. Resin cements were still regarded as the strongest luting agents amongst available cements. In using Fermit-N to seal the abutment screw access holes, a light-cured temporary non-eugenol composite resin frequently used for temporary restorations, additional composite resin may have contributed to increasing resin cement retention by means of a chemical bond, thus enhancing the retention of the resin cement. Alternatively, the inability of cement to escape into the internal abutment cavity thus creating a greater pressure of cement between the internal coping surface and the abutment may have increased the observed retention values.

In contrast to the findings of Pan and Lin (2005), Clayton et al (1997) showed zinc phosphate provided 164% greater retention than glass ionomer and 49% greater than resin cement (without using compressive cyclic loading) with the CeraOne 3.7mm tall abutment. The observations of Clayton et al (1997) agreed with evidence provided by Alfaro et al (2004) and Koka et al (1995) that greater time and water exposure increased the retentiveness of zinc phosphate cement, but these same conditions also reduced the retentiveness of composite resin as previously explained by Soderholm (1981) and Diaz-Arnold et al (1989). Certainly, zinc phosphate appears to benefit from increased time by allowing a complete setting reaction.

In comparing the studies of Pan and Lin (2005) and Clayton et al (1997), in vitro compressive cyclic loading (only used in the study by Pan and Lin, 2005) may affect the retention values of zinc phosphate and resin cement which may partially explain the opposing results. However, the additional potential effect of Fermit-N (a light-cured temporary composite resin) used to seal the abutment screw access holes in the study by Pan and Lin (2005) should not be underestimated in increasing the retention values of the resin cement. This aspect alone may account for the increased retention of the resin cements found in this study. Compounding the comparison was the operation of differing implant systems, different cements and different experimental conditions in both studies that may cloud more conclusive judgement.

In discussing cement versus screw-retained implant restorations, Michalakis et al (2003) recommended the use of the least retentive cements so that prostheses could be retrieved if necessary. Because of the ideal clinical height and taper of most implant abutments, it has been recommended that temporary or provisional cements, which would normally function well for restorations cemented to natural teeth, may act as a permanent luting agent for metal cemented to metal (Kent et al, 1997). However, McGlumphy et al (1992) declared provisional cementation was to some extent unpredictable due to the many different factors that influence the retentiveness of a restoration, and can result in difficult retrieval or premature loosening.

Zinc phosphate and resin cements have generally been proven to offer greater retention of implant abutment-retained crowns than most other cements and appear to set the gold standard. Resin cements have generally outperformed other cements except when exposed to moisture contamination, where many variations in experimental findings existed. Glass ionomer and resin-reinforced glass ionomer cements were frequently ranked below resin cements but above temporary cements. The retentive strength of zinc phosphate appeared to be maximized after sufficient time for a complete setting reaction and some exposure to moisture. Temporary cements were generally the least retentive when compared with permanent cements. Zinc oxide / eugenol cement reduced its retentive capacity when exposed to moisture because of its high solubility in direct contact with water and also required sufficient time for a complete setting reaction in order to maximize its retention. Variations existed when cements were exposed to different combinations of in vitro simulations.

2.7.4 Reusing abutments and crowns

A source of bias in many studies may be the results obtained from reusing components. During the testing and cleaning process, there is potential for damage to the abutment and / or crown that may influence data obtained on retesting.

Bresciano et al (2005) reused their copings after firstly removing cement by hand, then with a cleaning solution in an ultrasonic bath for 15 minutes. The samples were then rinsed, dried, and sandblasted with aluminium oxide powder of 50µm diameter prior to recementation.

After testing, Bernal et al (2003) placed abutments in an ultrasonic cleaner for 20 minutes, then rinsed and placed them in distilled water for five minutes. However, new crowns were made for further testing with the cleaned abutments.

Mansour et al (2002) and Ramp et al (1999) both followed identical extensive cleaning protocols for their castings and abutments. Castings were heated to 600ºC for 1.5 hours, allowed to cool at room temperature and then placed in an ultrasonic cleaner for 30 minutes with a cement removal solution. Abutments were cleaned in distilled water in an ultrasonic cleaner for 30 minutes, and then wiped with cotton gauze.

In their pilot study, Ongthiemsak et al (2005) found repeated cementation after cleaning the samples for 30 minutes in an ultrasonic cleaner with a cement-removal solution followed by 30 minutes in distilled water did not significantly alter crown retention. Alfaro et al (2004) reused their castings after thorough cleaning and grit blasting the surface in reference to other studies by Breeding et al (1992), Chee et al (1998), GaRey et al (1994), and Clayton et al (1997) where no effect on the surface texture of the castings or implant abutments was observed.

GaRey et al (1994) reused their abutments and cleaned them by firstly soaking for 24 hours in methylene chloride to soften residual cement. The residue was then removed using a modified chisel, followed by sandblasting for five minutes with 60μm aluminium oxide. One hour before cementing, the abutments were cleaned in acetone for 10 minutes, rinsed three times in deionized water and air dried. A pilot study suggested no significant differences in retention values of posts that were repeatedly used when cleaned and abraded as mentioned.

If specimens are to be reused, it is important a consistent testing surface is produced for each round of testing. A range of cleaning techniques exists in order to achieve this.

2.8 Conclusions

In vitro studies are limited by their very nature; they are simulations of in vivo conditions that are in general difficult to validate clinically. Permanent cements have generally been ranked above temporary cements for their retention of crowns to both natural teeth and implant abutments. The behaviour of dental cements appears to be different on implant abutments than on natural teeth.

Various abutment designs, surface textures, heights and convergence angles affect the retention of cement-retained crowns.

Different in vitro simulations affected different materials in different ways. With varying combinations of in vitro variables operating and a diverse range of implant and abutment systems available, it is difficult to present precise guidelines applicable to all implant systems. Instead, ranking orders of materials for specific implant systems under specific in vitro conditions can be provided. Ranking orders of materials may be compared but interstudy comparison is limited due to varying experimental conditions and specimens. In vivo research still remains the source from which definitive answers should be sourced.

Chapter 3 Materials and Method

3.1 Components

Straumann regular neck synOcta components were used (Straumann, Basel, Switzerland) (Figure 1):

- 13 titanium implant abutments with corresponding abutment screws (abutment 048.605)
- 13 stainless steel laboratory implant analogs of length 12mm (analog 048.124)
- 13 plastic copings of height 7mm (plastic coping 048.605)

Figure 1. Straumann synOcta components

The specifications of the synOcta abutments were:

- 8º taper
- height = 5.5mm
- 4.8mm diameter collar (0.5mm collar height)
- broad chamfer margin

Twelve specimens were used in the main study, and one in the pilot study.

3.2 Component construction

3.2.1 Crown coping construction

- The 13 crown copings were constructed by the same operator.
- Each plastic burnout coping was attached to a randomly selected implant abutment and confirmation of complete seating obtained by the audible click produced when the "snap-on mechanism" engaged (Figure 2). The snap-on mechanism allows the plastic coping to be perfectly positioned and fixed on the abutment during wax-up.

Figure 2. Attached implant components

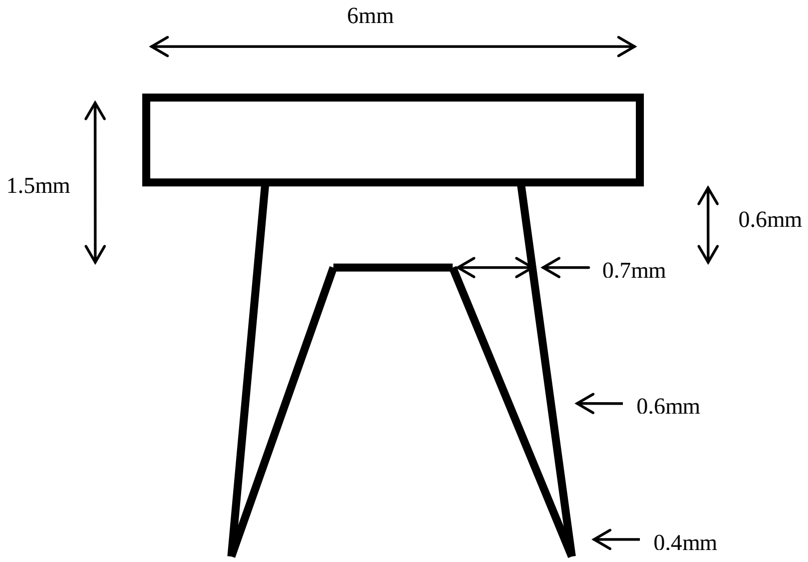
- A 6mm x 6mm flattened occlusal platform comprising a single thickness of modeling wax (1.2mm thickness) was added to the plastic coping. Additional wax was flowed to reinforce the connection of the underside of the occlusal platform to the plastic burnout coping (Figure 3).

Figure 3. Waxed coping on implant analog / abutment

- Wax patterns connected to plastic burnout copings were sprued, invested with Speedvest (Argibond, Germany) and cast with Matticraft-C (Matticraft, Johnson Matthey, United Kingdom), a 51.5% gold / 38.3% palladium alloy, using a vacuum casting machine (Easycast, Zubler, Germany).
- Castings were devested, desprued, and sandblasted with 110µm aluminium oxide particles (Renfert, Hilzingen, Germany) at a pressure of 2 barometers to remove residual investment material.

- Using calipers, all cast copings were confirmed they satisfied the dimensions as shown in Figure 4.

Figure 4. Coping dimensions



- In accordance with Straumann instructions, the “snap-on mechanism” (provided in the plastic burnout coping) was removed.
- Fitting surface nodules were removed using rotary instruments under 16x magnification.
- Each coping was numbered 1 to 13 for easy identification during testing.
- Completed copings were each seated onto the single abutment used in the pilot study and checked for quality and accuracy of fit using Micro-Red equilibrating and indicating emulsion (Culver Laboratories, Valley Centre, California). This ensured abutments used in the main study remained free of potential surface damage.

- The occlusal platform was flattened with silicone dioxide points so it aligned parallel to the horizontal bench surface, and finished with rubber wheels (Figure 5).

Figure 5. Completed coping seated on laboratory analog / implant abutment

- The intaglio of all copings were finally sandblasted with 110µm aluminium oxide particles (Renfert, Hilzingen, Germany) at a pressure of 2 barometers, and dried with compressed air before initial testing.

3.2.2 Laboratory analog / implant abutment / housing base construction

- In considering the materials readily available, the modulus of elasticity (which represents the relative stiffness of a material within its elastic range) of acrylic

(1.6GPa) approximated most closely to that of cancellous bone (0.49GPa) (University of Michigan, Biomaterials properties database).

- Each laboratory analog was mounted in an acrylic housing base to facilitate the testing procedures. The following procedure was followed for each of the 13 components:
    - An acrylic housing base (Orthoplast, Vertex-Dental, Netherlands) was constructed using a single split silicone mould (Figure 6). A screw thread was created to permit locking of specimens into the compressive cyclic loading apparatus during testing.

Figure 6. Acrylic housing base

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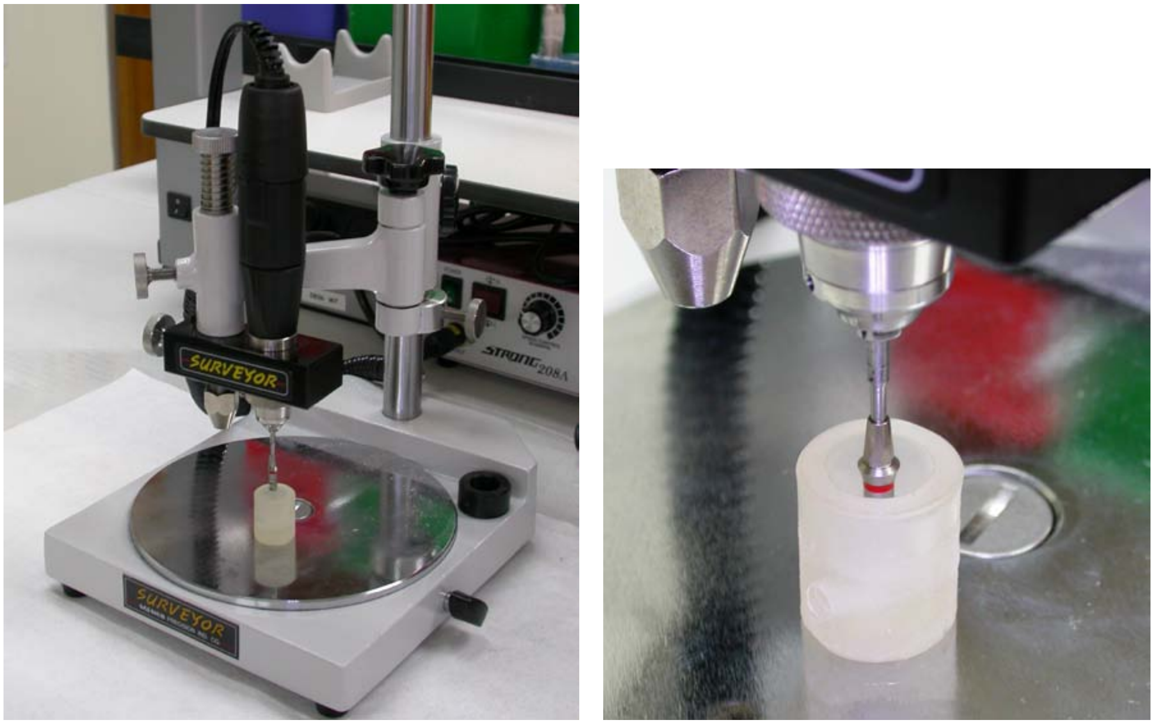
    - An abutment and laboratory analog were randomly paired and the abutment screw tightened to firm finger pressure only.
    - A stainless steel aligning tip was fabricated to fit precisely into the abutment screw access channel.

- The aligning tip was connected to a dental milling machine and inserted into the abutment screw access channel to align the implant abutment / laboratory analog vertically. The abutment, connected to its laboratory analog, was centrally positioned within a randomly selected previously constructed acrylic housing base (Figure 7).

Figure 7. Positioning abutment with analog in housing base



- The housing base was filled with acrylic (Orthoplast, Vertex-Dental, Netherlands) up to the red line of the laboratory analog and allowed to set.

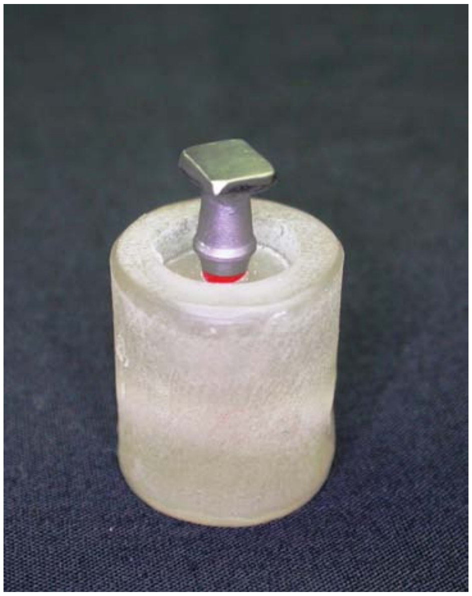
  - When completely set, the aligning tip was carefully removed from the mounted laboratory analog / implant abutment (Figure 8). Each housing base was numbered 1 to 13.

Figure 8. Completed mounted laboratory analog / implant abutment

- The implant abutment screws were torqued to 35Ncm using the SCS screwdriver and ratchet with torque control device (reference 046.049) (Straumann, Basel, Switzerland) as recommended by the manufacturer’s guidelines. Screws were subsequently retightened to 35Ncm after 10 minutes in accordance with recommendations by Winker et al (2003) to compensate for the settling effect.

- All abutment screw access channels were filled with two compacted cotton pellets and sealed flush with the occlusal surface with softened and compacted modeling wax.
- All abutments were inspected under 16x magnification to ensure the surface was free of debris. Any excess acrylic was removed with a teflon scaler tip, wiped clean with gauze, and dried with compressed air.
- Cast crown copings were positioned onto correspondingly numbered mounted laboratory analog / implant abutment complexes and again checked for accuracy of fit under 16x magnification (Figure 9). The stainless steel aligning tip was connected to a dental milling machine and used to confirm the occulsal platform of the coping lay parallel to the horizontal. Where required, final adjustment was performed using silicone dioxide points and final polishing with rubber wheels.

Figure 9. Completed mounted laboratory analog / implant abutment with coping



3.3 Specimen testing

3.3.1 Cementation

- Three commonly used and readily available luting agents that were representative of their class were tested:
  - Panavia-F (Kuraray Medical, Osaka, Japan)
    - A dual curing resin based cement system (with fluoride release) for metal, composite and silanated porcelain restorations.
  - KetacCem (3M ESPE, St Paul, Minnesota)
    - A permanent glass ionomer luting cement in powder / liquid form.

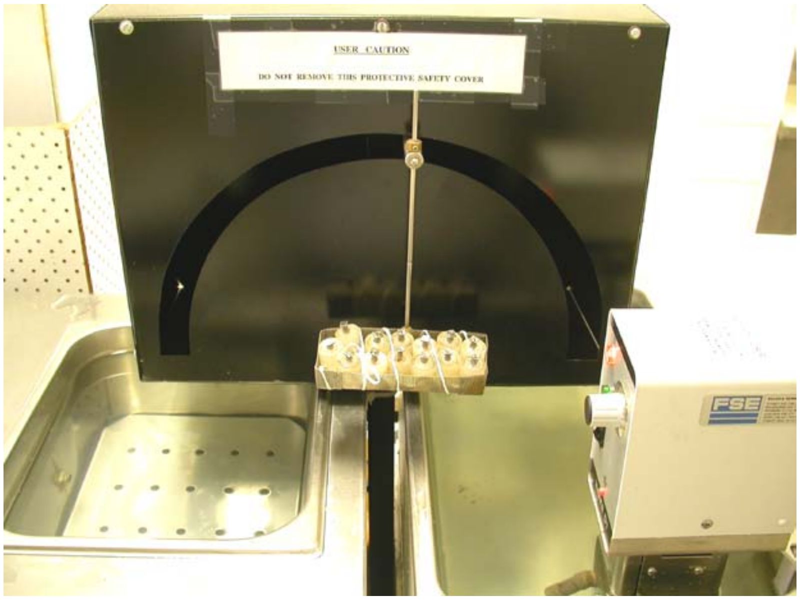
  - TempBond NE (Kerr, Romulus, Michigan)
    - A non-eugenol temporary cement for trial cementing restorations or cementing temporary crowns and bridges that will not inhibit the polymerization of resin cements and acrylic temporaries, but with the same retentive properties as TempBond.
- The cementation protocol for the three cements was in accordance with each manufacturer's instructions for mixing time, mixing conditions and cement component ratios. All cements were mixed by the same experienced dental assistant, and all crown copings cemented by the same operator.
- Panavia-F was stored in the refrigerator until immediately prior to cementation. KetacCem and TempBond NE were stored at room temperature.
- Luting agent was applied to completely cover all internal walls of the castings, and castings were then seated onto abutments with firm finger pressure for 10 seconds, followed by a 5kg axial compressive load for 5 minutes.
- Excess cement was removed using a Hollenback carver.
- The mixing spatula was thoroughly cleaned between rounds of mixing to eliminate the potential for cement cross-contamination.
- Specimens were examined visually to confirm complete seating of the coping onto the abutment, referenced by marginal integrity and the absence of marginal space.
- Panavia-F cementation

  - ED Primer and Alloy Primer (for precious metal alloys) were not used in this cementation technique, as the purpose of the study was to investigate purely the physical retention of cements rather than include the additional potential chemical retention mechanism of resin cement (further discussed in Discussion).
  - After 10 seconds of firm finger pressure, gross excess cement was removed and Oxyguard II applied for 5 minutes.
  - After 5 minutes, Oxyguard II was rinsed away and any remaining excess cement removed using a Hollenback carver.

3.3.2 In vitro experimental conditions

- Immediately after cementation, and in accordance with ISO standard ISO/TR 11405:1994(E), specimens were:
  - Placed in a humidifier at 100% humidity and 37ºC for 24 hours.
  - Subjected to 500 cycles of thermocycling between 5ºC (±2ºC) and 55ºC (±2ºC) with a 20 second dwell time in each water bath, and 5-10 second interlude between water baths. One cycle constituted a combined hot and cold water bath immersion (Figure 10).

Figure 10. Thermocycling machine



- Specimens within each cement group were subsequently subjected to one of four quantities of compressive cyclic loading (Figure 11) in a tooth wear machine.
- Interpolating from an estimation that, using the same tooth wear machine, 20,000 compressive loading cycles of between 3.2kg and 9.95kg load simulated approximately two years of average human masticatory function:
    - 192 cycles were used to simulate one week of average human mastication
    - 5,000 cycles were used to simulate six months of average human mastication

  - 10,000 cycles were used to simulate one year of average human mastication

- These times pose relevance in terms of patient review following crown delivery. Specimens that received no compressive cyclic loading acted as the baseline.

Figure 11. No. of specimens in each experimental group

		Compressive Cyclic Loading			
		Baseline (0)	1 week (192)	6 months (5000)	1 year (10000)
Cement	TempBond	1	1	1	1
	KetacCem	1	1	1	1
	Panavia-F	1	1	1	1
Total:		3	3	3	3

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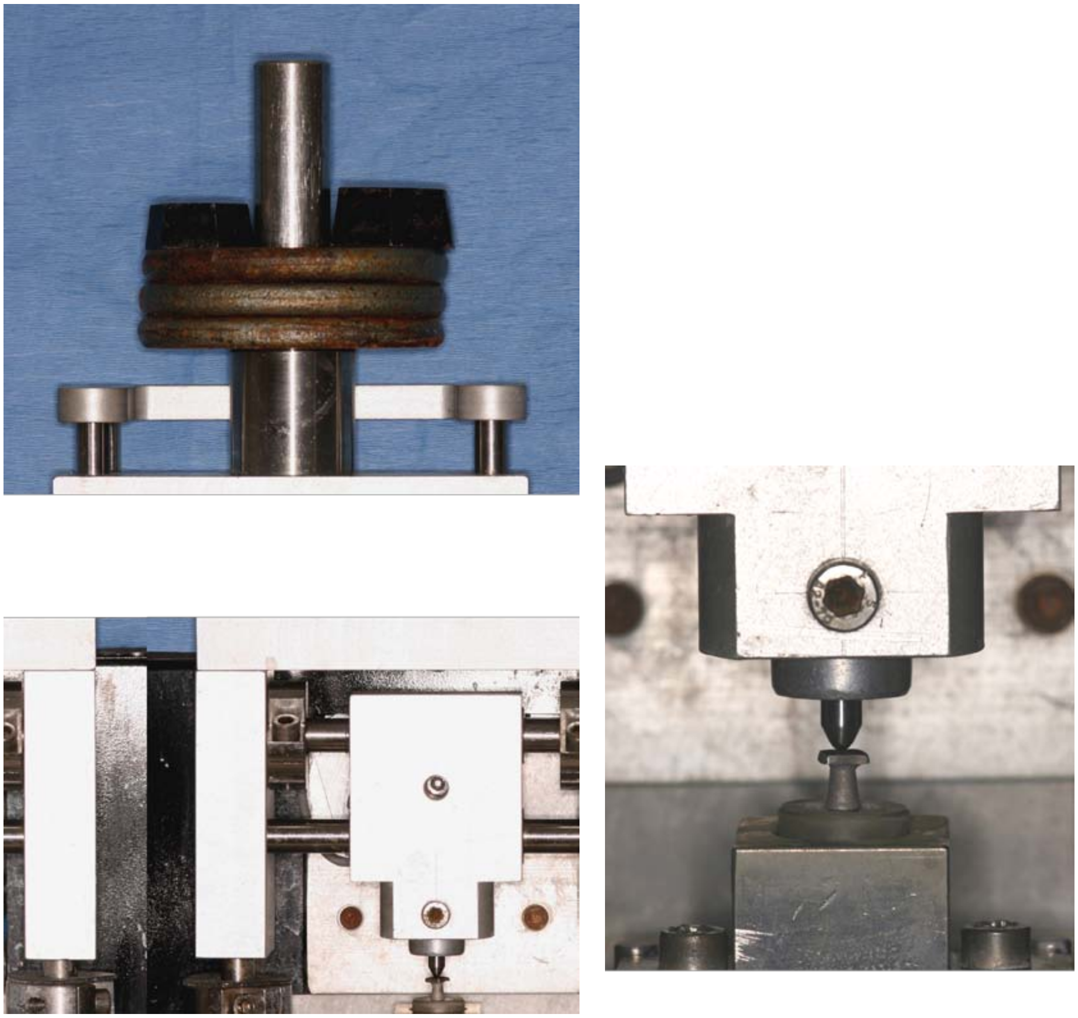
- A rounded stainless steel stylus was used to apply the load at 80 cycles / minute under a 5kg total load at room temperature in reference to previous work using the same tooth wear machine by Kaidonis et al (1998).
  - The stainless steel stylus (or cusp) was machined so it formed a spherical contact surface and was able to deliver a controlled “rubbing” force to the occlusal platform of the crown coping simulating mastication (Figure 12). Stainless steel was used as it is resistant to wear against the casting alloy.

Figure 12. Stainless steel stylus

- The tooth wear machine consisted of a stainless steel base and frame onto which components were attached (Figure 13). A 75Watt electric motor powered a 10:1 reduction gearbox that in turn moved a series of interchangeable cams controlling the movement of specimen holders. The holders allowed the accurate positioning of specimens at each test. A magnetic counter attached to the gearbox recorded the number of cycles. The upper section of the machine supported weights for applying loads to the specimens. The mass of the upper component without added weights was 3.2kg. Additional weight of 1.8kg was added to provide a total load of 5kg.

Figure 13. Tooth wear machine



- An additional aspect to the generated experimental conditions was the observation that previously, using the same tooth wear machine, the heat produced at the surface when rubbing two enamel surfaces together was 32ºC to 35ºC, closely approximating that of the oral environment (Kaidonis et al, 1998).

- One functional wear cycle constituted a uni-directional movement where the moving upper stainless steel stylus rubbed against a fixed lower specimen in one direction, after which the cam lifted the stylus and repositioned it for the beginning of a subsequent stroke (Kaidonis et al, 1998).

3.3.3 Testing protocol

- Two customized housing jigs were constructed to allow specimens to be tested within a Universal Testing Machine (Hounsfield H50KM, Hounsfield Testing Equipment, United Kingdom) (Figure 14).

Figure 14. Universal testing machine and testing apparatus

- Specimens were rigidly fixed within the base of the Universal Testing Machine (Figure 14) (Hounsfield H50KM, Hounsfield Testing Equipment, United Kingdom).
- The Universal Testing Machine with a load cell of 2000N was used to apply a uniaxial tensile force to the copings at a cross-head speed of 1mm / minute, and the force at which cement failure occurred was recorded in Newtons.
- The approximate surface area covered and uncovered by residual cement was recorded.
- Abutments and copings were examined under scanning electron microscopy after rounds one, five and eight of testing.

3.3.4 Cleaning protocol

- The crown copings were cleaned between rounds of testing by short duration sandblasting with aluminium oxide 110µm particles (Renfert, Hilzingen, Germany) at a pressure of 2.5 barometers and dried using compressed air.
- Abutments were cleaned using glass bead abrasion (ArgiBond Dental Laboratory Supplies, Cheltenham, Victoria) at a pressure of one barometer for 5-10 seconds, then wiped with gauze and dried using compressed air.
    - This practice was employed due to the initial resistance to more conservative gross cement removal with a teflon coated scaler.
- Sixteen times magnification was used to ensure the abutment and coping surface was free of residual cement.

3.3.5 Testing schedule

- Due to availability of testing facilities, the following strict standard schedule was used for all rounds of testing:
    - Day 1
        - Cementation 4pm
        - Humidifier 5pm (24 hours duration)
    - Day 2
        - Thermocycling 5pm (7 hours duration)
    - Day 3
        - All specimens rested
    - Day 4

        - Compressive cyclic loading 8am-6pm
    - Day 5
        - Uniaxial tensile testing 10am
- As only one specimen could be used in the tooth wear machine at one time, and in order to permit similar lay times between stages of in vitro testing, all specimens were rested for at least 24 hours between thermocycling and compressive cyclic loading, and at least 12 hours between compressive cyclic loading and uniaxial tensile testing.

3.3.6 Repeated procedure

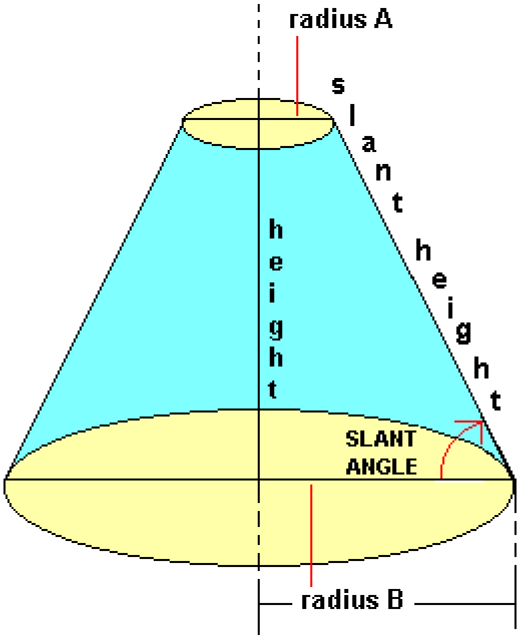
- The experimental procedure and cleaning protocol previously described was repeated eight times for each crown coping / abutment complex. The 13 castings and paired laboratory analog / implant abutment / housing bases were reused for each round of testing.
- Similar cleaning practices (involving combinations of immersion in cleaning solutions and various grit blasting techniques) have been previously used to permit reusing abutments and copings for further rounds of testing (Alfaro et al, 2004; Breeding et al, 1992; Chee et al, 1998; GaRey et al, 1994; Clayton et al, 1997; Bresciano et al 2005; Ongthiemsak et al 2005). In other comparable experiments, similar cleaning practices were found to have no observable effect on crown retention values (Alfaro et al, 2004; Breeding et al, 1992; Chee et al, 1998; GaRey et al, 1994; Clayton et al, 1997).

- Indentations in the wax seal of the abutment screw access channels were repaired and re-sealed with modeling wax flush with the top of the abutment screw access channel.
- The same crown coping was used with the same abutment complex within the same cement group to eliminate the possibility of surface cross contaminations from different cements and avoid interactions between material residues, as proposed by Schneider (1987).
- Within each of the three cement groups, specimens were tested under different numbers of compressive load cycles during different rounds of testing.
    - In round 1 testing, specimen 1 was used with no compressive load cycles (Panavia-F cement).
    - In round 2 the same specimen was used with 192 compressive load cycles (Panavia-F cement), in round 3 for 5,000 compressive load cycles (Panavia-F cement), and in round 4 for 10,000 compressive load cycles (Panavia-F cement).
    - As eight rounds of testing were completed, each specimen was used in each number of cyclic loadings twice.
    - Specimen rotations were performed to remove the potential biasing effects (such as wear, coping fatigue and distortion) that may be seen if some specimens received no compressive load cycles, while others received the maximum number of compressive load cycles over the duration of testing.

3.4 Calculation of abutment surface area

- Calculation of abutment surface area was performed to permit conversion of cement failure loads to megapascals and subsequent comparison with other studies (1728 Software Systems).
    - 1 Pascal = 1Newton of force applied over 1m^2
- The abutment was considered a cone for the purpose of surface area calculation. The wax sealed screw access channel was included in the surface area calculations. The surface area was calculated by adding the surface areas of the frustum of the cone (Figure 15 - shaded blue) and the surface area designated at radius A (Figure 15 – area shaded orange at radius A).

Figure 15. Abutment surface area (1728 Software systems)



3.5 Statistical analysis

- A two-way without replication ANOVA test was used to determine the effect of cement type and compressive cyclic loading on crown coping retention.
- Post tests between all comparable pairs of mean values were conducted (GraphPad software, Post test calculator). The Bonferroni correction was used to adjust for multiple comparisons. Confidence intervals of 95% were applied to all comparisons, not simply each individual comparison.

3.6 Pilot study

- One test specimen was cemented with Panavia-F (Kuraray Medical, Okayama, Japan) and subjected to all experimental conditions with the maximum 10,000 compressive load cycles to confirm:
    - All experimental stages could be completed
    - The proposed cleaning procedure was effective
        - After cleaning, the specimen was examined under 16x magnification to check for cement residue
    - Specimens could be reused intact
- Following successful completion of the pilot study, the main study was commenced.

Chapter 4 Results

4.1 Data

The retention values following each round of uniaxial tensile testing for Panavia-F, KetacCem and TempBond NE are presented in Tables 1, 2 and 3 (n=8). All data presented in this section are recorded in Newtons unless otherwise specified. Figures 16, 17 and 18 provide mean crown coping retention value comparisons (with standard deviation bars) for each quantity of compressive cyclic loading for each cement.

Table 4 shows summary values, standard deviation (SD), minimum and maximum values for each cement (n=8). Figure 19 demonstrates a comparison of the mean retention values obtained for all cements for all quantities of compressive cyclic loading.

Following thermocycling, TempBond NE copings had visibly lifted off their abutments. These copings were maintained within the experiment and tested as normal (discussed further in Discussion section).

Table 1. Retention values of Panavia-F specimens (Newtons)

Cycles	0	192	5000	10000	Rnd Total
Test Rnd					
1	697	127	221	184	1229
2	141	162	207	152	662
3	350	125.5	134	79	688.5
4	214	260.5	303	299.5	1077
5	207.5	159	335	350	1051.5
6	419	223.5	202	114.5	959
7	224.5	283.5	195.5	199.5	903
8	137	72.5	78	196	483.5
Total	2390	1413.5	1675.5	1574.5	
Mean	298.7	176.7	209.4	196.8	
Median	219.3	160.5	204.5	190	

Figure 16. Mean retention of Panavia-F specimens

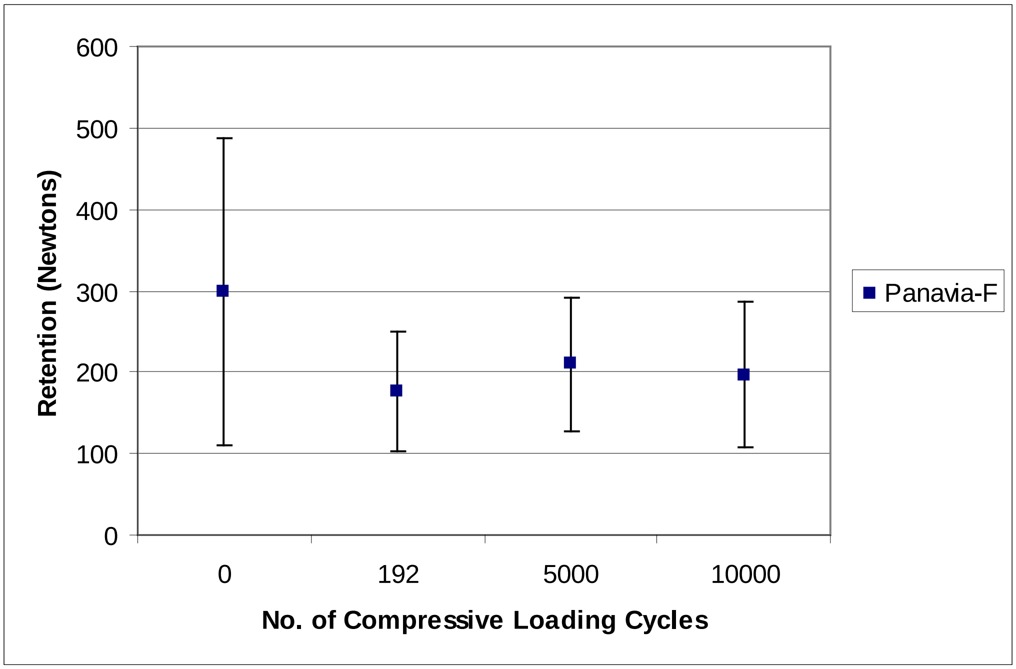


Table 2. Retention values of KetacCem specimens (Newtons)

Cycles	**0**	**192**	**5000**	**10000**	**Rnd Total**
Test Rnd					
1	10	17	24	33.7	84.7
2	31	25.8	70.8	42	169.6
3	26	171	78.5	44	319.5
4	172	31.5	85	96	384.5
5	44.5	32	223	92.5	392
6	19	28	42.5	35	124.5
7	21	46.5	30	30	127.5
8	17	18	17	108.5	160.5
Total	340.5	369.8	570.8	481.7	
Mean	42.6	46.2	71.4	60.2	
Median	23.5	29.8	50.7	43	

Figure 17. Mean retention of KetacCem specimens

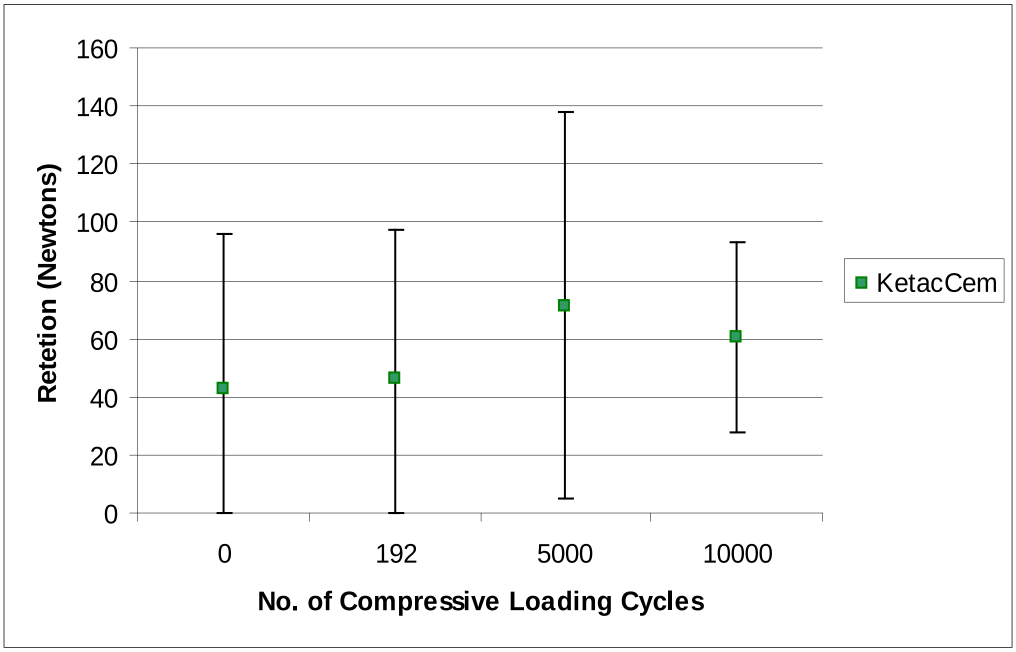


Table 3. Retention values of KetacCem specimens (Newtons)

Cycles	0	192	5000	10000	Rnd Total
Test Rnd					
1	5.9	8.6	10.6	23.3	48.4
2	1.6	22.8	10.5	28.6	63.5
3	5.8	6.2	14.7	19.6	46.3
4	4.1	10	9	12.1	35.2
5	8.5	10.1	25	12.7	56.3
6	7	10.5	12.5	23	53
7	4.5	13.8	7	17.3	42.6
8	1.4	13	11	23.7	49.1
Total	38.8	95	100.3	160.3	
Mean	4.9	11.9	12.5	20	
Median	5.2	10.3	10.8	21.3	

Figure 18. Mean retention of TempBond NE specimens

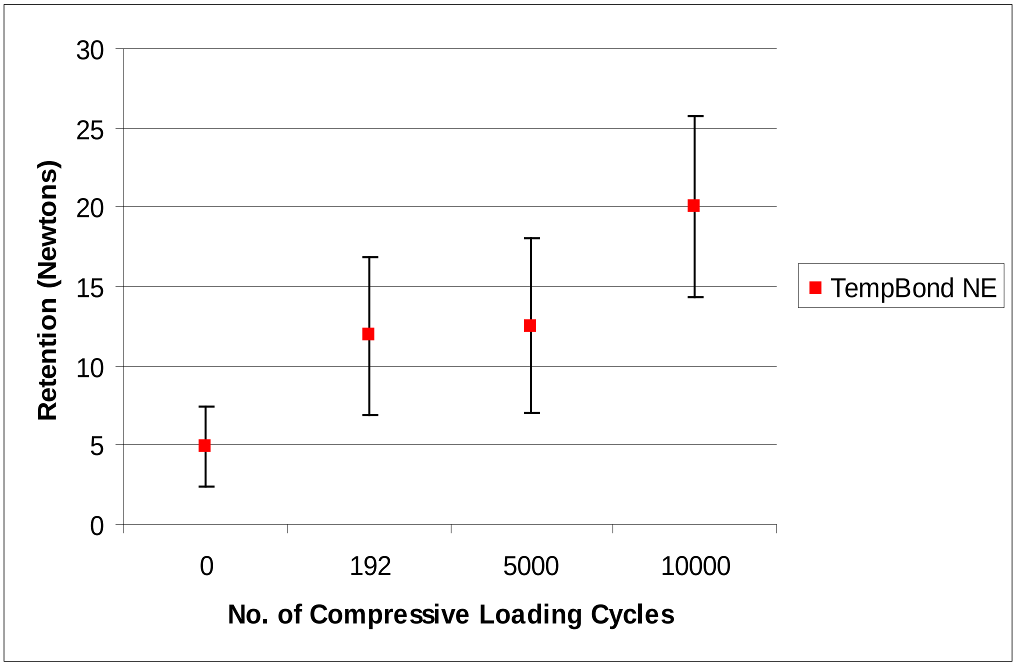
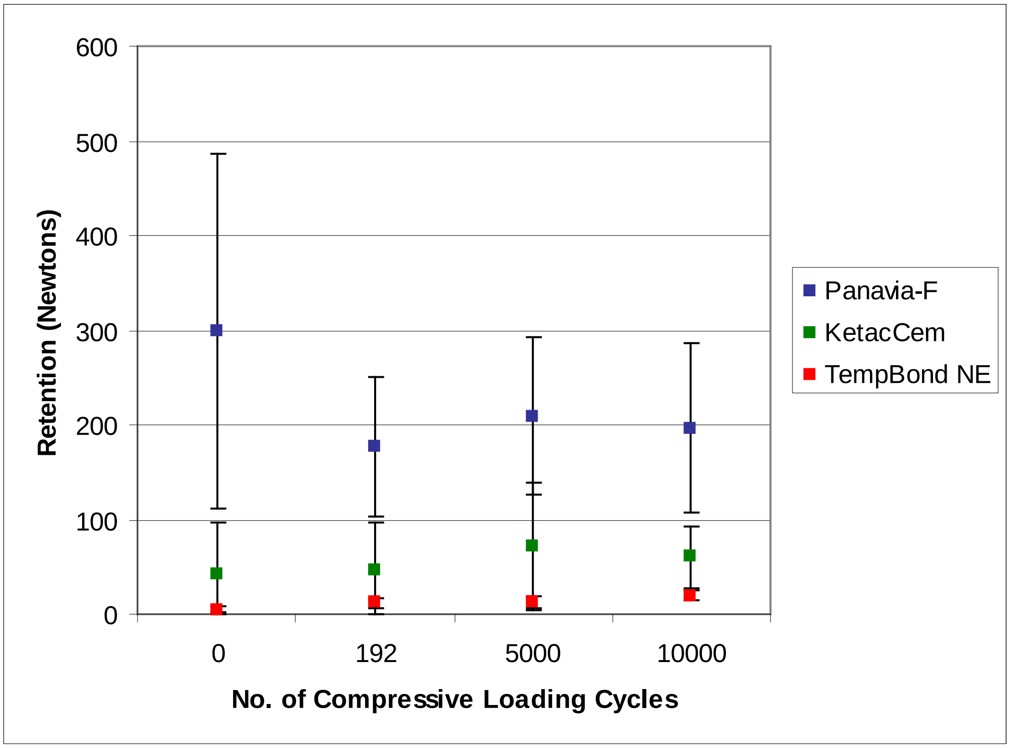


Table 4. Summary data for all tested cements (Newtons)

Cycles	0	192	5000	10000
Cement				
Panavia-F				
Mean	298.7	176.7	209.4	196.8
Median	219.3	160.5	204.5	190
SD	188.1	72.8	82.7	90.1
Minimum	137	72.5	78	79
Maximum	697	283.5	335	350
Ketac Cem				
Mean	42.6	46.2	71.4	60.2
Median	23.5	29.8	50.7	43
SD	53.3	51.3	66.5	32.7
Minimum	10	17	17	30
Maximum	172	171	223	108.5
TempBond NE				
Mean	4.9	11.9	12.5	20
Median	5.2	10.3	10.8	21.3
SD	2.5	5	5.5	5.7
Minimum	1.4	6.2	7	12.1
Maximum	8.5	22.8	25	28.6

Figure 19. Comparison of mean retention values for all specimens



4.2 Repeated testing

In the right column of Tables 1, 2 and 3, the combined coping retention values for the four specimens tested in each round with each cement are totaled (Rnd total). These are summarized and presented in Table 5. Figure 20 plots these values to provide an overview of the effect of re-using the same components for each round of testing with each cement.

Figure 21 shows the combined total coping retention values for all specimens for all cements in each round of testing (values obtained from the total column in

Table 5. This provides a broad comparison of variations in total coping retention provided by all combined cements with repeated rounds of testing in comparison to the mean.

Table 5. Summary of combined retention values for 4 specimens tested in each round for each cement group

Cement	**Panavia-F**	**KetacCem**	**TempBond NE**	**Total**	
Testing Rnd					
R1	1229	84.7	48.4	1362.1	
R2	662	169.6	63.5	895.1	
R3	688.5	319.5	46.3	1054.3	
R4	1077	384.5	35.2	1496.7	
R5	1051.5	392	56.3	1499.8	
R6	959	124.5	53	1136.5	
R7	903	127.5	42.6	1073.1	
R8	483.5	160.5	49.1	693.1	
				9210.7	Mean = 1151.3

Figure 20. Comparison of cement specific total retention of all specimens by round

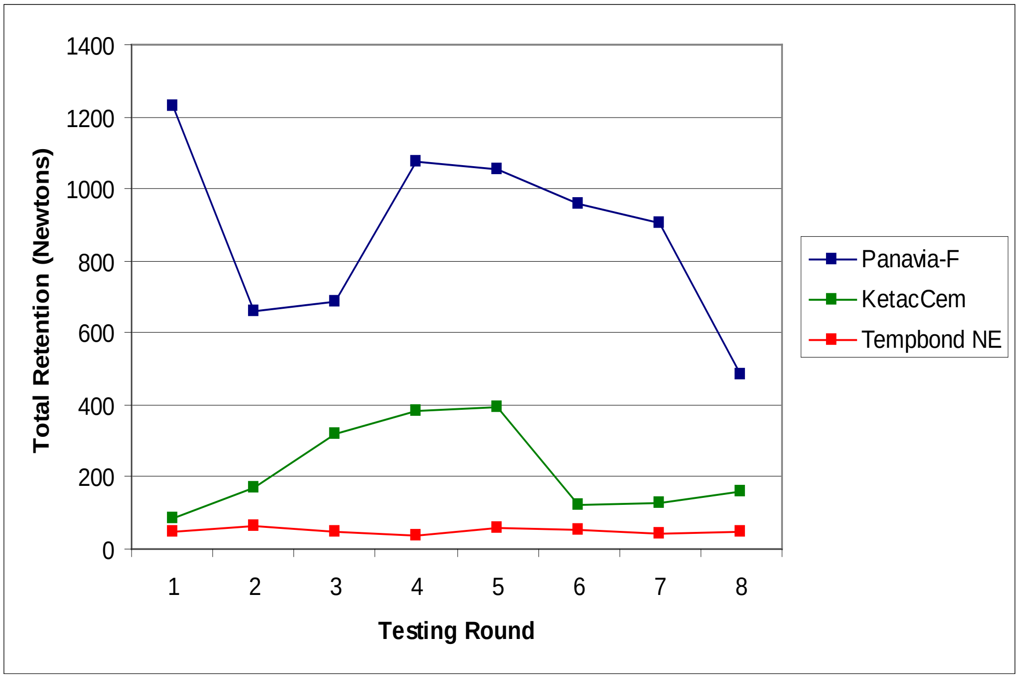
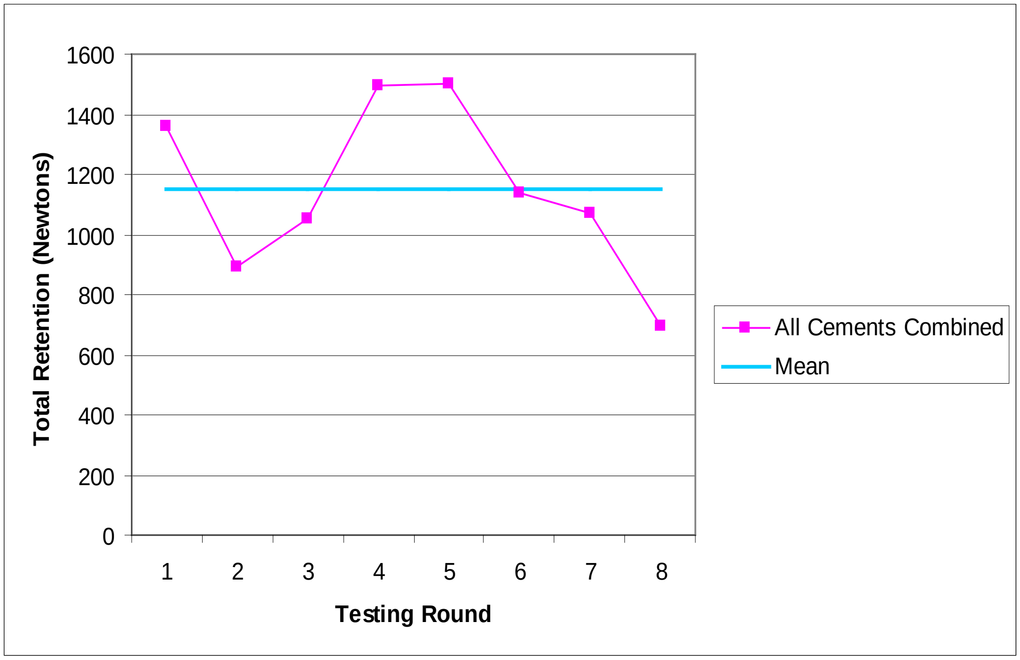


Figure 21. Comparison of total retention of all cements combined by round



Components remained structurally intact throughout testing. No fracture of components was observed, and no visible movement of the laboratory implant analogs within the acrylic housing base was detected. No abutment screw loosening was detected following the completion of all testing.

4.3 Conversion of mean retention values to megapascals

The results of the current study are presented predominantly in Newtons for comparative purposes only, but are also converted to megapascals for comparison to some other studies. The surface area (SA) of the abutment was calculated in reference to Figure 16 (1728 Software systems):

1. Surface area of frustum of cone (radius B = 2.4mm, radius A = 1.1mm, height = 5.5mm)

   = 62.1mm^2

Plus

2. Surface area of occlusal wax portion of abutment:

SA (of a circle) = πr^2 where r = 1.1mm

   = 3.8mm^2

Total abutment SA = $65.9\text{mm}^2 = 0.0000659\text{m}^2$

The mean retention values and standard deviations from Table 4 (presented in Newtons) are represented in megapascals in Table 6 (1 Pascal = 1Newton of force applied over 1m^2; 1 MPa = 1,000,000 Pascals).

Table 6. Mean retention values and standard deviations for all tested cements converted to megapascals

Cycles	0	192	5000	10000
Cement				
Panavia-F				
Mean	5.103	2.681	3.178	2.986
SD	2.854	1.105	1.255	1.367
Ketac Cem				
Mean	0.646	0.701	1.083	0.914
SD	0.809	0.778	1.009	0.496
TempBond NE				
Mean	0.074	0.181	0.19	0.303
SD	0.038	0.076	0.083	0.086

4.4 Statistical analysis

4.4.1 Two-way ANOVA analysis

A two-way without replication ANOVA analysis of results (Table 7) demonstrated a statistically significant effect of cement type (p=0.0003), but no statistically significant effect of compressive cyclic loading (p=0.6458) with respect to mean retention values.

Table 7. Two-way without replication ANOVA analysis

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Panavia-F	4	881.6	220.4	2906.18
KetacCem	4	220.4	55.1	175.72
TempBond NE	4	49.3	12.325	38.0825
0	3	346.2	115.4	25554
192	3	234.8	78.2667	7560.96
5000	3	293.3	97.7667	10213.8
10000	3	277	92.3333	8588.97

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Cement	96599	2	48299	40.039	0.0003	5.14325
Loading	2122	3	707	0.5864	0.6458	4.75706
Error	7238	6	1206			
Total	105958	11				

4.4.2 Post test analysis

Mean retention values from Table 4 were assigned abbreviations for paired post test comparison recognition (Table 8). Post test data, statistical significance ($p<0.05$) and 95% confidence intervals are presented in Table 9.

Table 8. Abbreviations used for paired post tests

Cycles	**0**	**192**	**5000**	**10000**
Cement				
Panavia-F				
Mean	298.7	176.7	209.4	196.8
Abbreviation	PF0	PF192	PF5000	PF10000
Ketac Cem				
Mean	42.6	46.2	71.4	60.2
Abbreviation	KC0	KC192	KC5000	KC10000
TempBond NE				
Mean	4.9	11.9	12.5	20
Abbreviation	TB0	TB192	TB5000	TB10000

Post tests were conducted between all comparable pairs of mean values (GraphPad software, Post test calculator) using the Bonferroni correction to adjust for multiple comparisons at 95% confidence intervals applied to all comparisons, not simply each individual comparison (Table 9).

Table 9. Post test data

Comparison	Mean1 - Mean2	95% CI of difference	Significant? (P <0.05?)	t
PF0 - PF192	+ 122.0	+ 28.3 to + 215.7	Yes	7.026
PF192 - PF5000	- 32.7	- 126.4 to + 61.0	No	1.883
PF5000 - PF10000	+ 12.6	- 81.1 to + 106.3	No	0.726
KC0 - KC192	- 3.6	- 97.3 to + 90.1	No	0.207
KC192 - KC5000	- 25.2	- 118.9 to + 68.5	No	1.451
KC5000 - KC10000	+ 11.2	- 82.5 to + 104.9	No	0.645
TB0 - TB192	- 7.0	- 100.7 to + 86.7	No	0.403
TB192 - TB5000	- 0.6	- 94.3 to + 93.1	No	0.035
TB5000 - TB10000	- 7.5	- 101.2 to + 86.2	No	0.432
PF0 - KC0	+ 256.1	+ 162.4 to + 349.8	Yes	14.749
PF0 - TB0	+ 293.8	+ 200.1 to + 387.5	Yes	16.920
KC0 - TB0	+ 37.7	- 56.0 to + 131.4	No	2.171
PF192 - KC192	+ 130.5	+ 36.8 to + 224.2	Yes	7.516
PF192 - TB192	+ 164.8	+ 71.1 to + 258.5	Yes	9.491
KC192 - TB192	+ 34.3	- 59.4 to + 128.0	No	1.975
PF5000 - KC5000	+ 138.0	+ 44.3 to + 231.7	Yes	7.948
PF5000 - TB5000	+ 196.9	+ 103.2 to + 290.6	Yes	11.340
KC5000 - TB5000	+ 58.9	- 34.8 to + 152.6	No	3.392
PF10000 - KC10000	+ 136.6	+ 42.9 to + 230.3	Yes	7.867
PF10000 - TB10000	+ 176.8	+ 83.1 to + 270.5	Yes	10.182
KC10000 - TB10000	+ 40.2	- 53.5 to + 133.9	No	2.315
PF0 - PF5000	+ 89.3	- 4.4 to + 183.0	No	5.143
PF0 - PF10000	+ 101.9	+ 8.2 to + 195.6	Yes	5.869
PF192 - PF10000	- 20.1	- 113.8 to + 73.6	No	1.158
KC0 - KC5000	- 28.8	- 122.5 to + 64.9	No	1.659
KC0 - KC10000	- 17.6	- 111.3 to + 76.1	No	1.014
KC192 - KC10000	- 14.0	- 107.7 to + 79.7	No	0.806
TB0 - TB5000	- 7.6	- 101.3 to + 86.1	No	0.438
TB0 - TB10000	- 15.1	- 108.8 to + 78.6	No	0.870
TB192 - TB10000	- 8.1	- 101.8 to + 85.6	No	0.466

Mean Square = 1206, DF = 6, n=8

This demonstrated two statistically significantly different findings:

1. Within Panavia-F, between quantities of compressive cyclic loading: Panavia-F specimens subjected to 0 and 192, and 0 and 10,000 cycles each demonstrated statistically significantly different retention values, but not between 0 and 5,000, 192 and 5,000, 5,000 and 10,000, and 192 and 10,000 compressive cyclic loadings.
2. Panavia-F specimens demonstrated statistically significantly greater mean retention values than both KetacCem, and TempBond NE specimens at all quantities of compressive cyclic loading (0, 192, 5000, 10000).

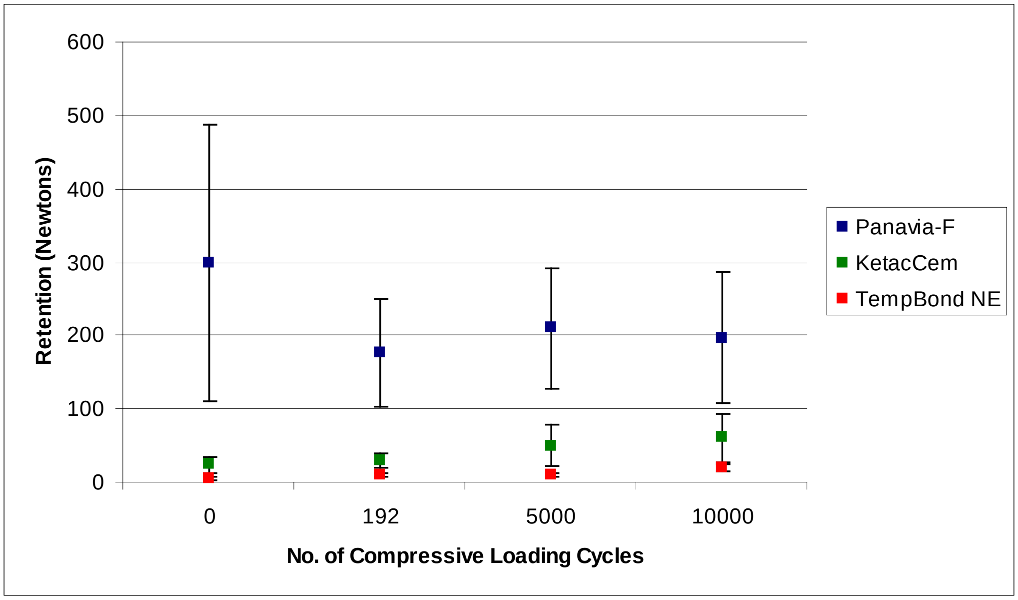
4.5 Data cleaning

Five values lay outside ±2 SD and were subsequently removed form the data set as they were thought to possibly represent deviations from normal distribution probability; one from each of KetacCem 0, 192, 5000, TempBond NE 192, 5000. With these values removed, mean values with a new 1 SD were recalculated and are presented in Table 10, and in graph form in Figure 22.

Table 10. Mean values with SD following removal of values outside 2 SD

Cycles	0	192	5000	10000
Cement				
Panavia-F				
Mean	298.7	176.7	209.4	196.8
SD	188.1	72.8	82.7	90.1
Ketac Cem				
Mean	24.1	28.4	49.7	60.2
SD	11.2	10	28	32.7
TempBond NE				
Mean	4.9	10.3	10.8	20
SD	2.5	2.6	2.4	5.7

Figure 22. Comparison of mean retention values following removal of values outside 2 SD



Subsequent two-way ANOVA analysis revealed a statistically significant effect of cement type (p= 0.0003), but no statistically significant effect of compressive cyclic loading (p=0.6637) with respect to mean retention values (Table 11).

Table 11. Two-way without replication ANOVA analysis

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Panavia-F	4	881.6	220.4	2906.2
KetacCem	4	162.4	40.6	296.02
TempBond NE	4	46	11.5	39.2467
0	3	327.7	109.23	27015
192	3	215.4	71.8	8334.91
5000	3	269.9	89.9667	11076.5
10000	3	277	92.3333	8588.97

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Cement	102418	2	51209	40.36	0.0003	5.14325
Loading	2111.5	3	703.8	0.5547	0.6637	4.75706
Error	7612	6	1268.8			
Total	112143	11				

Further post tests were conducted between comparable pairs of mean values that had changed due to the removal of values that lay outside 2 SD. (GraphPad software, Post test calculator).

No change in statistically significant results was obtained with the cleaned data compared with the initial raw data. For reporting purposes, the values outside two

SD were maintained within the experimental results as they were indicative of the large experimental variation of the current study and also other studies of this nature.

4.6 Null hypothesis

In considering the results, H_01 can be accepted:

- There is no influence of compressive cyclic loading on the physical retention of cast crown copings cemented to Straumann synOcta implant abutments with Panavia-F, KetacCem, and TempBond NE

H_02 can be rejected:

- There is no difference in the retention provided by Panavia-F, KetacCem, and TempBond NE for cementing cast crown copings cemented to Straumann synOcta implant abutments

Chapter 5 Discussion

This study investigated the influence of compressive cyclic loading on the physical retention of cast crown copings cemented to Straumann synOcta implant abutments using Panavia-F, KetacCem and TempBond NE cements. A statistically significant effect of cement type was found but no statistically significant effect of compressive cyclic loading was observed.

A number of influential aspects of the current study warrant further discussion and may aid in the explanation of the results and their applicability to clinical practice.

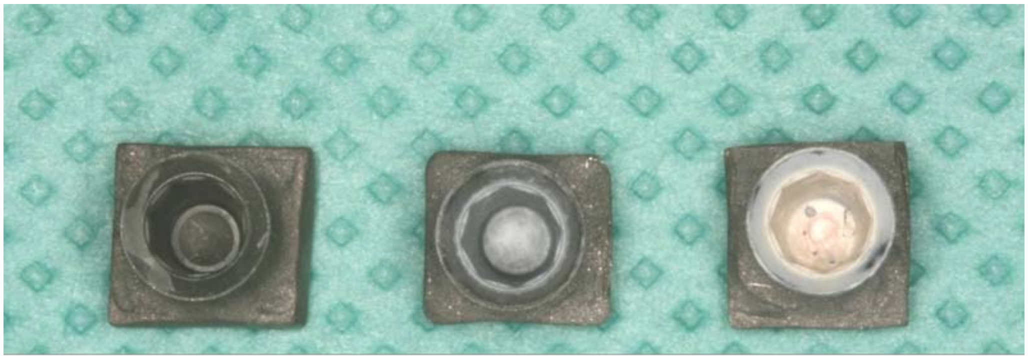
5.1 Method of cement failure

All tested cements demonstrated adhesive failure to the crown coping surface.

5.1.1 Crown copings

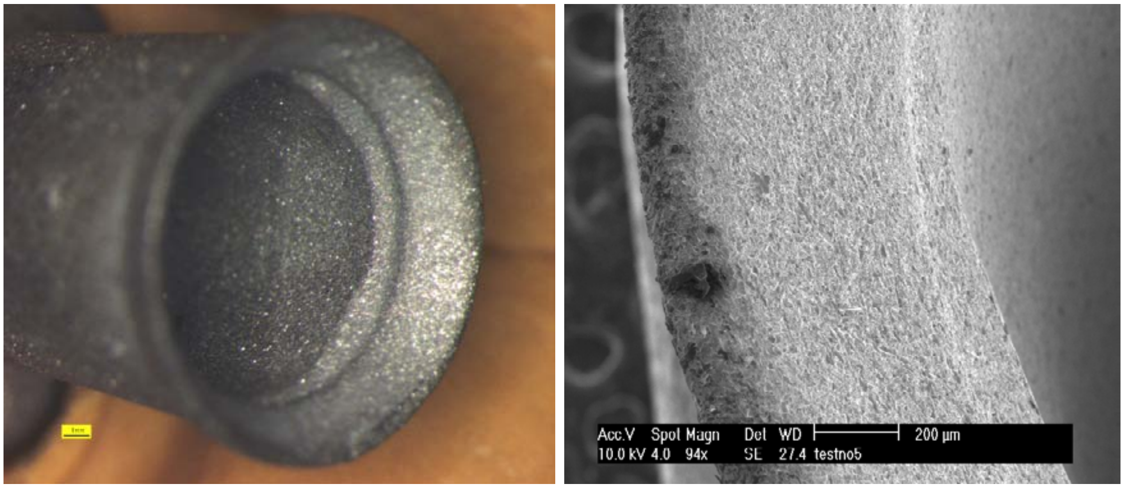
The rough sandblasted abutment intaglio provided greater micromechanical retention than the smooth titanium abutment surface, hence the cement adhered to the abutment (Figure 23).

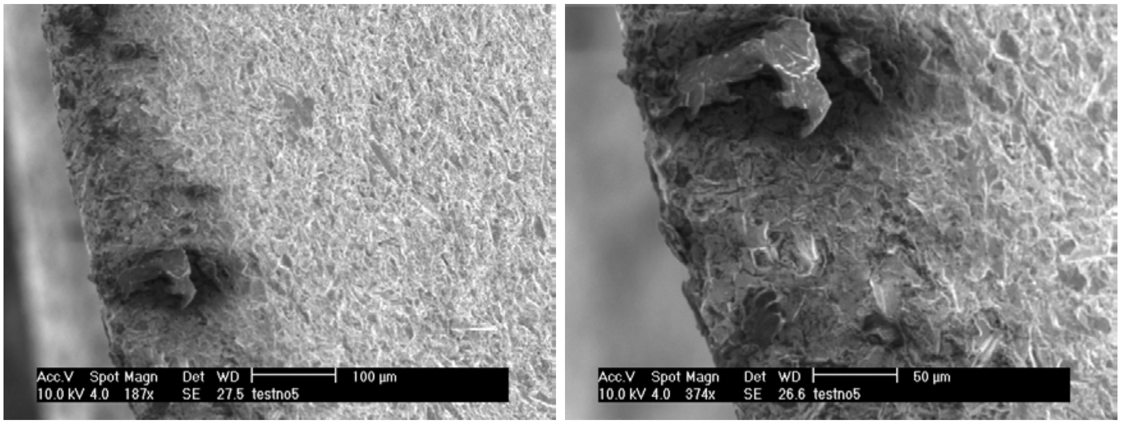
Figure 23. Typical appearance of crown copings immediately following testing (Panavia-F, KetacCem, TempBond NE – from left to right)



The high degree of micromechanical retention provided by the copings is illustrated by their surface irregularities in Figure 24.

Figure 24. Coping surface irregularities with increasing magnification





5.1.2 Abutments

The Straumann synOcta abutment provides a relatively smooth surface (Figure 25). Hence, minimal cement remained adhered to the abutment surface with each tested cement (Figure 26).

Figure 25. Straumann synOcta abutment

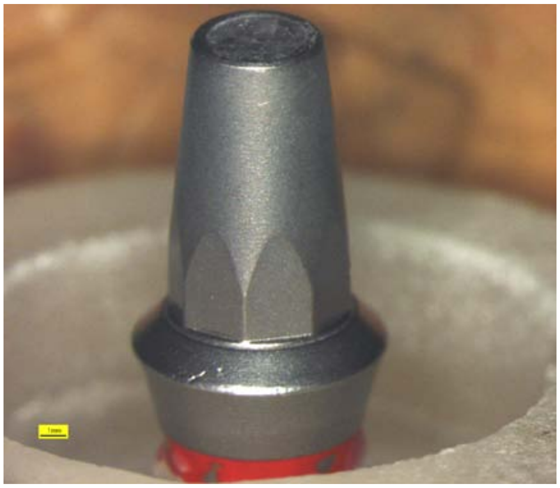
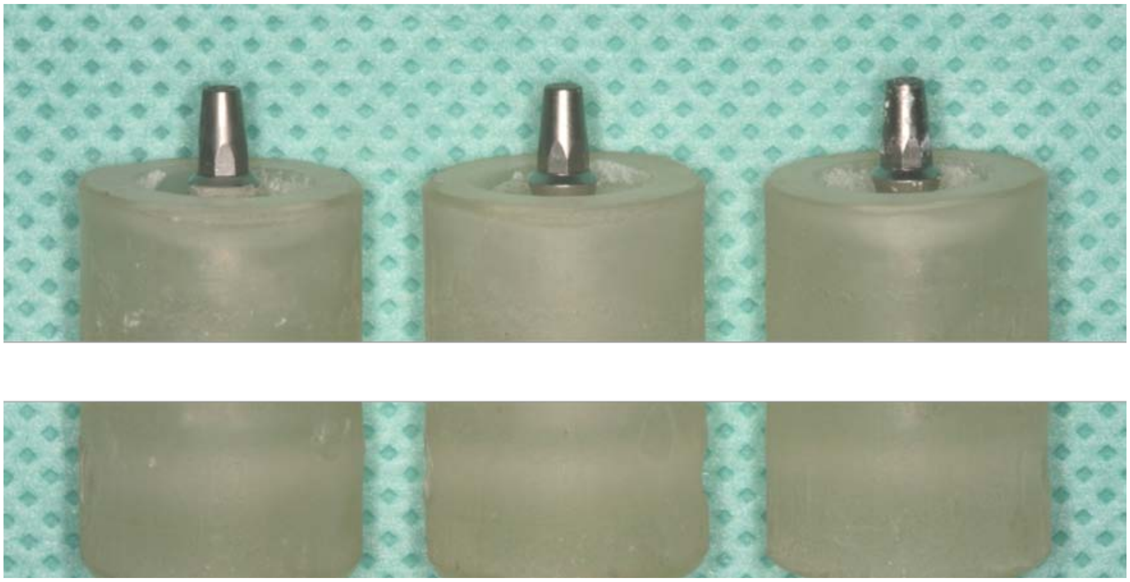
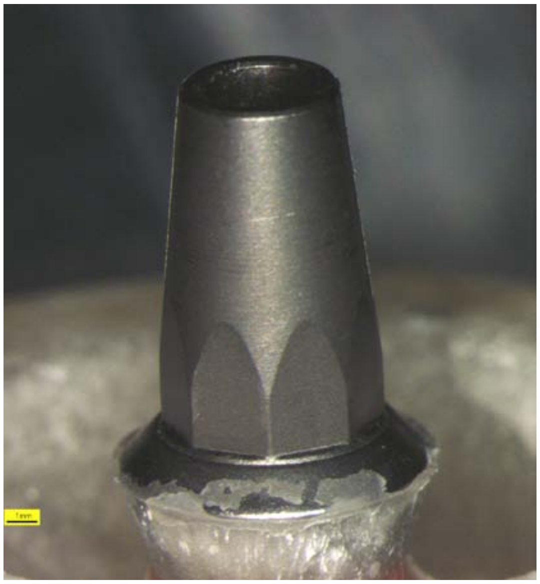


Figure 26. Typical appearance of abutments immediately following testing (Panavia-F (left), KetacCem (centre), TempBondNE (right)



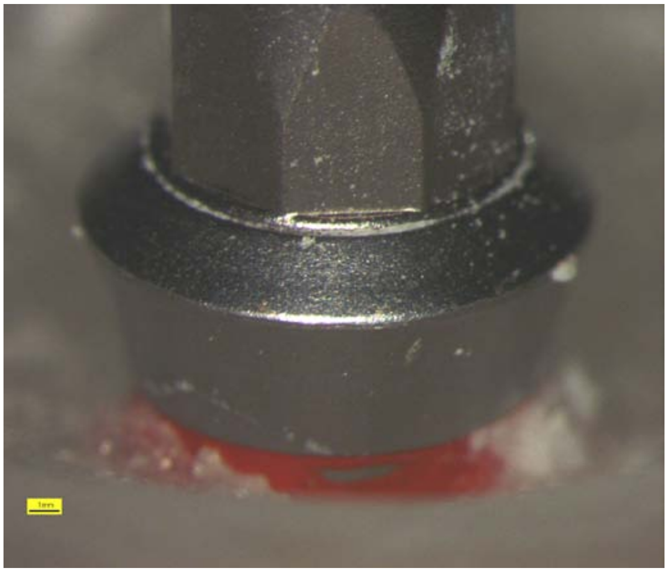
In a minority of Panavia-F specimens, residual cement remained on the abutment shoulder but never more than an estimated 5% of total abutment surface area (Figure 27).

Figure 27. Small amounts of residual Panavia-F cement confined to the abutment shoulder



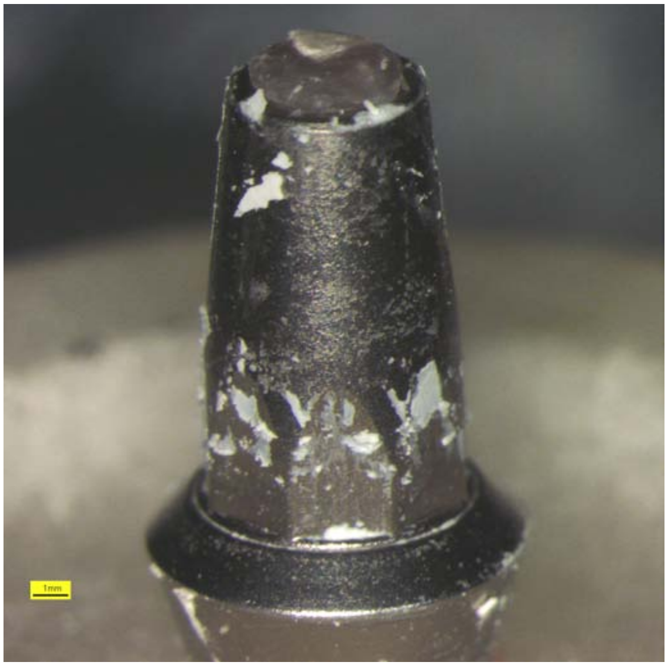
KetacCem abutments demonstrated very fine cement remnants confined to abutment crevices at the junction of abutment shoulder and wall (Figure 28).

Figure 28. Fine KetacCem cement remnants localized to abutment / shoulder junction crevices



Cement spicules remained on TempBond NE abutment walls covering no more than an estimated 10% of the abutment surface (Figure 29).

Figure 29. TempBond NE residual cement spicules



In the current study, and in agreement with previous work by Mansour et al (2002) that examined the retention of six cements for metal copings on ITI solid titanium abutments, the unaltered smooth machined abutment surface could have decreased the cement-abutment micromechanical interlocking, leading to comparatively decreased cement retention values. A rougher abutment surface may have resulted in greater retention values and possibly different modalities of cement failure.

5.1.3 Clinical implications

Clinically, cement that adheres to the abutment may be difficult to remove without damaging the abutment surface. There may also be reduced retention if a crown is cemented over the abutment again if the cement remains attached to the abutment (Kaar et al, 2006; Squier et al 2001). In the current study, residual Panavia-F cement on the abutment was resistant to manual removal with a teflon scaler, thus, adhesive cement failure to the coping is of benefit to the clinician.

Most cements used in implant dentistry today were originally developed for use with natural teeth. The mode of cement failure in this study appeared directly related to the greater physical retention provided by the two opposing surfaces the cement separates. In contrast to cementing crowns to natural teeth where some degree of chemical bonding is often possible to natural tooth structure, the use of most dental cements with implant components largely removes this potential for chemical bonding. However, some resin cements have developed the potential to bond to metal surfaces to aid in the enhancement of retention for cemented implant crowns.

5.2 Panavia-F specimens

Panavia-F specimens demonstrated the greatest mean retention values of all tested cements at each quantity of compressive cyclic loading (Figure 19). The mean retention values were statistically significantly greater than both KetacCem and TempBond NE at each compressive cyclic loading quantity (0, 192, 5000, and 10000 cycles) (Figure 19 and Table 9). In contrast to the overall findings of the study, examination of the Panavia-F group revealed specimens that received 192 and 10,000 cycles demonstrated a statistically significant decrease in mean retention compared with the unloaded group (ie. specimens subjected to 0 and 192, and 0 and 10,000 cycles each demonstrated statistically significantly different mean retention values; specimens subjected to 0 and 5,000 cycles demonstrated no statistically significantly different mean retention values, although t=5.143, but p>0.05) (Figure 16 and Table 9). But increased loading quantities produced no further statistically significant difference of mean retention (ie. mean retention values for 192, 5000 and 10000 cycles were not significantly different from each other) (Figure 16 and Table 9).

These results suggest minimal crown coping retention was lost following initial compressive cyclic loading. Should the current in vitro simulations be validated as accurately simulating in vivo conditions, then clinically crown copings that remain cemented to implant abutments in the short term may, in the absence of other deleterious factors, be expected to remain cemented in the long term.

Resin cements are regarded as the strongest luting agents among available cements, and Panavia cements are at the forefront of these (Pan and Lin, 2005). ED Primer is one component of the Panavia-F adhesive system that may be used to promote bond strength to tooth structure by dissolving the smear layer and penetrating the microstructure of enamel and dentine tubules. It was not used in the current study as there was no tooth structure for dissolution of the smear layer.

Alloy Primer is a metal surface treatment chemical that promotes bond strength to precious and non-precious metals. Alloy primer contains a thionic adhesive monomer, 6-[N-(4-vinylbenzyl)propylamino]-1,3,5-triazine 2,4-dithione (VBATDT) and a phosphate monomer, 10-methacryloyloxydecyl dihydrogen phosphate (MDP) (Kuraray Dental. Panavia-F Technical information). It was not used in the cementation technique employed in the current study, as the purpose of the study was to investigate the physical retention of cements rather than include the chemical retention mechanism of resin cement without that of other cements.

If Alloy Primer was used, retention values may potentially have been even greater than those observed, and failure may not have been solely adhesive to the crown coping if some degree of bonding to the titanium abutment was obtained. The sulfur atoms present on one end of VBATDT bond chemically to precious metal atoms of the coping and / or abutment, while on the other end the vinyl group co-polymerizes with the monomer in Panavia-F paste (Kuraray Dental. Panavia-F technical information).

Nonetheless, Panavia-F cement alone contains a phosphate monomer (MDP), also present in alloy primer, which unavoidably facilitates chemical bonding to non-precious metals (Kuraray Dental. Panavia-F technical information). Thus, the greater retention values observed with Panavia-F specimens in general in the current study may result, at least in part, from chemical adhesion via MDP to the non-precious metal oxide components of both the crown coping (indium 8%, gallium 2%) and the titanium abutment (predominantly titanium dioxide). However, the potential bond of Panavia-F to titanium oxide (via MDP) provided less retention than the combined chemical adhesion (via MDP) and micromechanical retention provided by the sandblasted surface irregularities of the crown coping intaglio.

No marginal deterioration was detected with Panavia-F specimens, despite the finding that resin-based materials are sensitive to moisture and display decreased strength when exposed to moisture (Alfaro et al, 2004). Soderholm (1981) and Diaz-Arnold et al (1989) suggested the tensile and transverse strength of composite diminished slowly and proportionally to the time immersed in water. In the current study, all specimens were exposed to moisture for identical durations, hence comparison of the deleterious effect of different times of moisture exposure was not possible. If specimens were not exposed to the deleterious effect of moisture, retention values may have been greater than those observed. Despite the small area of cement exposed purely at the marginal seal, the consistent moisture exposure of all Panavia-F specimens may have contributed to the retention values observed. If the marginal seal was compromised, there was potential for further moisture penetration between the cement and abutment and contamination of a larger area of Panavia-F cement. Panavia-F provided superior retention of crown copings to Straumann synOcta implant abutments despite exhibiting a significant loss of retention with compressive cyclic loading.

5.3 KetacCem specimens

KetacCem specimens demonstrated relatively low mean retention values with each quantity of compressive cyclic loading (Figure 19). KetacCem specimens showed greater mean retention values than TempBond NE, but both were not statistically significantly different at each level of compressive cyclic loading (Figure 19 and Table 9). There was no statistically significant effect of compressive cyclic loading on the mean retention values of crown copings cemented with KetacCem (Figure 17 and Table 9).

When KetacCem is used with natural teeth, 10% polyacrylic acid may be applied to the tooth surface for 15 seconds to remove the smear layer and permit chemical bonding to dentine and enamel. This was not used in the current study as there was no tooth structure for dissolution of the smear layer. There is no scope for the proposed polyacrylic acid pre-activation of calcium ions in dentine to render them more available for ionic exchange with the cement (Wilson and McLean, 1988). With implant components, the crown coping opposes a generally relatively smooth titanium abutment surface in place of a conditioned natural tooth, thus the cement properties, and its setting reaction, may be altered.

The initial setting reaction of glass-ionomer cement involves calcium ions and ionic cross-linking between polyacid chains and provides a rigid polyacid / salt matrix after 5 minutes, however these divalent linkages are unstable and readily soluble in water (Mount, 1990). Subsequent setting reactions over the following

24 hours involving aluminium ions and further cross-linking produces an increase in physical properties along with a reduction in solubility (Mount, 1990). Varnishes, such as unfilled bonding resin, have been recommended to seal glass-ionomer cements for the first 24 hours. With crown margins, this is generally not possible due to their often subgingival location. Both water uptake and water loss within the first 24 hours will affect the physical properties of glass-ionomer cements (Mount, 1990).

In the current study, only the cement at the marginal seal was initially exposed to moisture. All cements were exposed to identical durations of moisture throughout testing. Nevertheless, it was possible that moisture contamination affected the retentive properties of KetacCem.

The crown marginal seal was not examined in detail in the current study, but there was potential for loss of marginal seal throughout testing and further moisture contamination of the cement. No obvious marginal deterioration was detected with KetacCem specimens.

It would be prudent to investigate the material characteristics of glass ionomer cement when used with dental implants in further research to determine whether the findings related to KetacCem within the current study apply more widely to other glass-ionomer cements and implant systems.

5.4 TempBond NE specimens

TempBond NE specimens provided the lowest mean retention values (Figure 19). The mean retention values of Tempbond NE specimens were lower than those of KetacCem, but were not statistically significantly different at each level of compressive cyclic loading (Figure 19 and Table 9). No statistically significant effect of compressive cyclic loading was observed for TempBond NE specimens (Figure 18 and Table 9). In reference to Figure 18, the mean retention values increased, although not statistically significantly, with increasing quantities of compressive cyclic loading.

On subjecting TempBond NE specimens to the ISO standard ISO / TR 11405:1994(E) of 500 thermocycles of between 5ºC (±2ºC) and 55ºC (±2ºC) with a 20 second dwell time in each water bath (where one cycle constituted a combined hot and cold water bath immersion), crown copings visibly lifted from abutments resulting in an obvious marginal gap (Figures 30 and 31).

Figure 30. TempBond NE specimens before thermocycling (after humidifier)

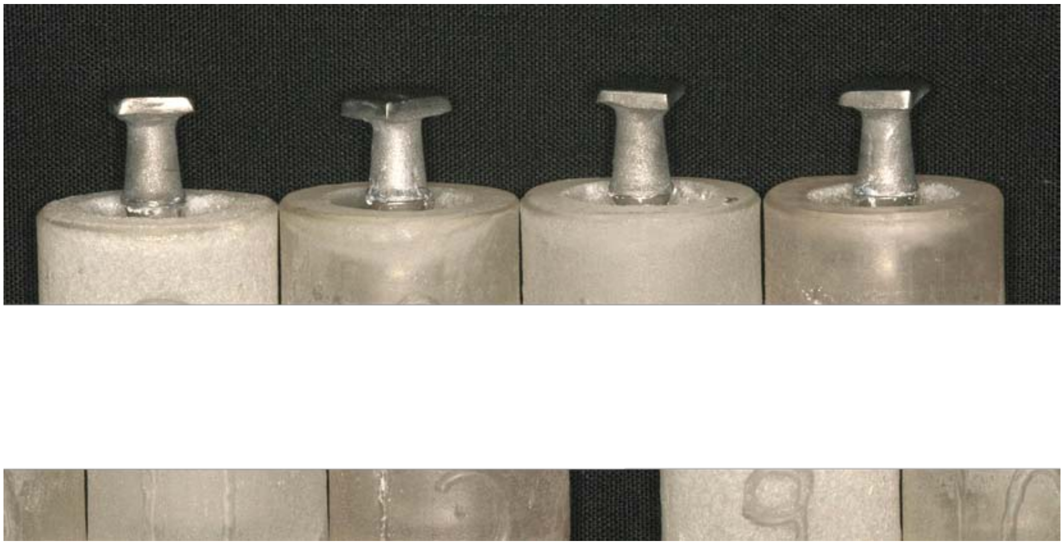
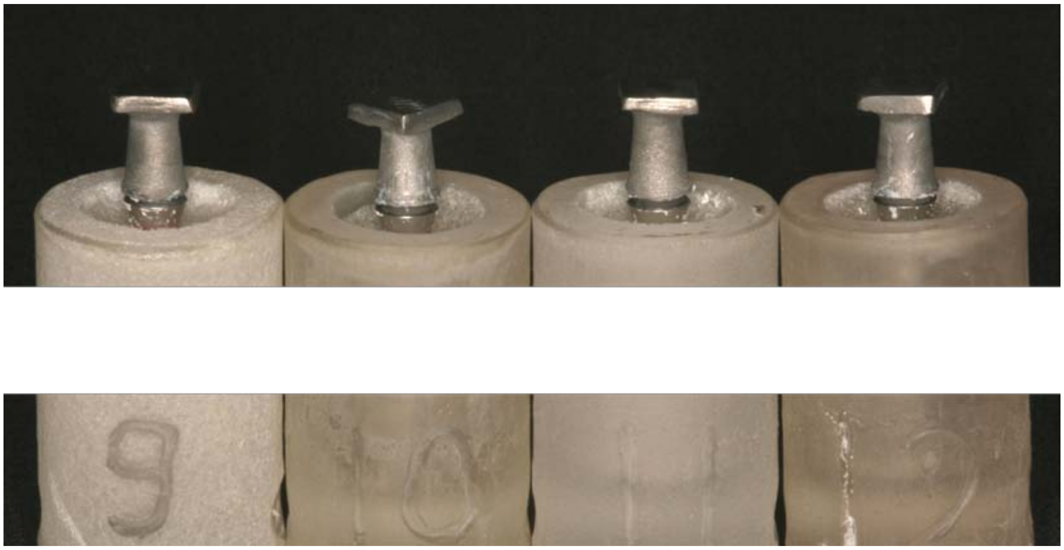


Figure 31.TempBond NE specimens after thermocycling



Varying degrees of marginal gap opening was observed, however all TempBond NE specimens demonstrated some degree of marginal gap opening. Attached TempBond NE cement lifted with the coping away from the abutment shoulder.

A comparison of the marginal gap after thermocycling is provided for the three tested cements in Figure 32. Panavia-F and KetacCem specimens demonstrated no detectable marginal gap opening during testing. The humidifier had no observable affect on marginal opening.

Figure 32. Comparison of marginal gap after thermocycling (Panavia-F (2), KetacCem (7), TempBond NE (11))

Despite the marginal gap opening following thermocycling, specimens were maintained within normal testing parameters and retention values measured after compressive cyclic loading. It was positioned that thermocycling, together with compressive cyclic loading, were experimental conditions common to all specimens and although applied sequentially in vitro, may be encountered simultaneously in vivo. Clinically, thermal changes may act to lift crowns away from abutments, but just as rapidly occlusal loading may reseat crowns back onto their abutments. It may be that some occlusal loading is required to maintain a degree of retention for crowns cemented to abutments with TempBond NE.

Three plausible theories are presented for the large marginal gaps observed with TempBond NE specimens following thermocycling:

1. Differing coefficients of thermal expansion (CTE). On subjecting specimens to thermal extremes, zinc oxide non-eugenol (CTE = 35 x 10^{-6} / ºC) expanded and contracted more than the gold / palladium alloy coping (CTE (25-500ºC) = 14.1 x 10^{-5} K^{-1}) and titanium abutment (CTE = 8.19ºC<$^{-1}$) which is generally described as a low CTE material (Craig, 2006; Matticraft, Johnson Matthey, United Kingdom; Straumann, written communication, 12 Dec 2006). On rapidly changing the temperature from 5ºC to 55ºC, expansion of the cement (within its confined cement space) more than the surrounding abutment and coping created a greater internal cement space pressure. The retention at the cement / abutment interface was insufficient to withstand the increased cement pressure causing the

coping to lift off the abutment. Linear expansion of the coping and abutment may on its own accord have reduced the available cement space and contributed to greater cement space pressure ie. as well as the coping expanding outwards, the coping may also expand inwards towards the abutment.

2. Marginal seal. A poor marginal seal permitted water seepage along the cement / abutment interface within the coping. Thermocycling then caused expansion of cement and / or water in the cement / abutment space creating internal cement space pressure as described in 1. above.
3. Cement solubility. Dissolution of the marginal TempBond NE, allowing water penetration via the cement / abutment interface and further dissolution of TempBond NE cement. Subsequently, water penetration into the cement space and internal cement space pressure created by water and / or cement expansion caused the coping to lift off its abutment.

Alternative rationales may explain the process responsible for this observation. Further research is required to elucidate the precise details. It is also feasible a combination of the above theories was responsible for the copings lifting off the abutments. Any of these explanations can explain the observation of wax remnants on the abutment walls of TempBond NE specimens. Subsequent warm water penetration between the cement and abutment permitted partial melting of the abutment screw access channel wax seal. When placed in the cold water bath, the molten wax rapidly cooled and was deposited along the walls of the abutment.

As a result of the marginal gap formation during thermocycling, water penetration was possible along the cement / abutment interface, and water droplets were commonly observed in the intaglio of the coping and at the abutment screw access wax seal following coping removal. As thermocycling had the effect of lifting copings from their abutments, compressive cyclic loading had the opposite effect of compressing the copings back onto the abutments.

Caution should therefore be exercised in interpreting the retentive forces required to remove TempBond NE copings. The retention of copings that underwent compressive cyclic loading, although very low, was more likely a measure of the duration of time for which copings were compressed back onto their abutments with compressive cyclic loading. In each round of testing, the coping that received no compressive cyclic loading and was not compressed back onto its abutment demonstrated the lowest retention value. With increased quantities of compressive cyclic loading, increased mean retention values were observed.

In comparison to zinc oxide non-eugenol (CTE = 35 x 10^{-6} / ºC), resin composites have a CTE range = 14-50 x 10^{-6} / ºC, and glass ionomer cements 10.2-11.4 x 10^{-6} / ºC. Although the CTE range of resin composites exceeds that of zinc oxide non-eugenol, the greater coping retention provided by resin cements may have resisted lifting of the coping from its abutment preventing marginal gap formation.

Previous studies have demonstrated significant reduction in the retentive ability of zinc oxide / eugenol cements in implant dentistry when exposed to moisture, but few appear to have specifically tested zinc oxide non-eugenol (eg. TempBond NE) (Ongthiemsak et al, 2005; Millstein et al, 1991; Markowitz et al, 1992; Alfaro et al 2004). Zinc oxide / eugenol cement has high solubility in direct contact with water and also requires sufficient time for a complete setting reaction in order to maximize its retention (Ongthiemsak et al, 2005; Millstein et al, 1991; Markowitz et al, 1992; Alfaro et al, 2004).

TempBond and TempBond NE differ only marginally; the base paste is the same for both cements, but eugenol is absent from the accelerator in TempBond NE. The accelerator in TempBond NE is a traditional resin-modified formulation, based on the use of ortho ethoxy benzoic acid. Further correspondence by the author with representatives from Kerr International, the manufacturers of TempBond and TempBond NE, suggested both cements have similar if not almost identical physical properties (Kerr International, written communication, 26 October 2006). The product information outline states, “TempBond NE provides the same flow and retentive properties as TempBond”. (Kerr International, TempBond and TempBond NE Product Summary). Therefore, one might assume that TempBond NE also exhibits high water solubility and a requirement for sufficient time for setting to maximize its retention.

In a study by Kent et al (1997) that examined the retention of gold cylinders to CeraOne titanium abutments with TempBond NE and TempBond, the retention values for TempBond NE were 7.1kg (with the access hole unfilled) and 7.4 kg (with access hole filled with an autopolymerizing resin), and for TempBond 6.7kg and 11.3kg respectively. This study suggests both cements have similar retention capabilities with CeraOne abutments.

The setting reaction of TempBond involves a chelation reaction where two molecules of eugenol react with zinc oxide in the presence of water to form zinc eugenolate plus excess zinc oxide (Craig, 2006). This setting reaction is accelerated by increases in temperature or humidity (Craig, 2006). The set material consists of an amorphous zinc eugenolate matrix that binds unreacted zinc oxide particles together (Craig, 2006).

However, TempBond NE lacks eugenol to react with zinc oxide. The setting of TempBond NE involves an acid-base reaction of 2-ethoxybenzoic acid and zinc oxide. In contrast to TempBond, the scientific literature appears relatively scarce on further details relating to TempBond NE and its setting reaction properties, apart from that related to its failure to inhibit the polymerization of composite resin materials and acrylic temporary crowns as eugenol does in TempBond

(Bayindir et al, 2003). Further research involving the properties of TempBond NE in various in vitro studies is required.

Cements differ in their ability to resist microleakage (Pan et al, 2006; Piwowarczyk et al 2005; Lindquist et al 2001). Causes of microleakage related to cast crowns include shrinkage of the cement on setting, poor cement adhesion, cement solubility and mechanical failure (Pan et al, 2006; White et al, 1995). Although only the marginal cement was exposed to moisture, once dissolution begins subsequent cement is exposed to moisture and suboptimal physical properties of the cement can result. Clinically, microgaps at restoration margins expose cements to oral fluids resulting in potential cement dissolution and microleakage which may subsequently enhance microbial colonization (and sensitivity in the case of a natural tooth) (Lewinstein et al, 2003).

The examination of the leakage characteristics of cement in vitro requires simulations of the conditions found in the oral cavity through placement of specimens in a humidifier and thermocycling (Pan et al, 2006; Rossomando and Wendt, 1995). The expansion and contraction of restorative materials in response to thermocycling induces mechanical stress on the cements (Pan et al, 2006; White et al, 1995). In order to measure the degree of marginal leakage, a stain such as basic fuschin dye could be used. As with other in vitro simulations, caution should be taken when interpreting in vitro marginal leakage studies, as they have not been shown to correlate with clinical performance (Rosensteil, 2001).

Lewinstein et al (2003) and Baldissara et al (1998) both reported relatively high microleakage of TempBond NE. Tjan and Chiu (1989) found the effect of thermocycling on marginal leakage was related to the thermal conductivity and coefficient of thermal expansion of the materials used (Pan et al, 2006). It is likely the same principles are responsible for the observations relating to TempBond NE in the current study. Despite the fact cement washout has been reported by a number of authors (Singer and Serfaty, 1996; Ramp et al, 1999) and that complications can and do occur, clinical success rates using TempBond NE remain high, and re-cementation is usually relatively simple (Levine et al, 1999).

5.5 Comparison to other similar studies

Comparison to other studies investigating the effect of compressive cyclic loading on cements used to retain implant abutment crowns is limited due to a paucity of similar studies and inconsistent experimental protocols. Many previous studies tested various dental cements for retention with various implant systems (Pan and Lin, 2005; Akca et al, 2002; Alfaro et al, 2004; Pan et al, 2006; Mansour et al, 2002; Ramp et al, 1999) but few looked specifically at the effect of varying compressive cyclic loading within the same context (Kaar et al, 2006; Ongthiemsak et al, 2005).

Kaar et al (2006) investigated three luting agents used to cement gold cylinders to CeraOne abutments before and after mechanical stressing. Three hundred thousand cyclic loadings with a 100N (10.2kg) load were used in this study which is significantly greater than the current study. Furthermore, thermocycling was not performed in the study by Kaar et al (2006).

Ongthiemsak et al (2005) tested castings cemented to Zimmer abutments with TempBond only, however the in vitro conditions included placement in a humidifier but excluded thermocycling. Compressive cyclic loading was performed for considerably longer durations of 500 000, 1 000 000, and 5 000 000 cycles with a 20-130N (2-13.3kg) load. Pan and Lin (2005) tested seven different cements under in vitro conditions including thermocycling and placement in a humidifier, but subjected all specimens to identical numbers of compressive cyclic loading.

With a scarcity of similar purpose studies involving similar in vitro conditions and varying the quantity of compressive cyclic loading, cautious broad comparison may be made between results obtained with specimens that received no compressive cyclic loading (unloaded specimens) in other studies. In the current study, thermocycling TempBond NE specimens had a marked effect on cement retention, and it is possible that Panavia-F and KetacCem were correspondingly affected without the visual evidence of marginal gap formation TempBond NE displayed. Further research into the effects of various combinations of in vitro conditions is required to confirm this observation. It is imperative to acknowledge that in comparing studies within this section, varied in vitro simulations and different implant systems may have played a significant role in the reported results.

5.5.1 Panavia-F

Different resin cements vary in their composition, hence accurate comparison can only be made if the same product is used. Pan and Lin (2005) reported a mean cement failure load using cast superstructures on SteriOss titanium alloy Hex-Lock Straight Esthetic abutments cemented with Panavia-F of 1.68MPa. Specimens in this study were placed in a humidifier, thermocycled and subjected to 100,000 compressive cycles of 75N (7.6kg). In the current study, Panavia-F specimens that received 10,000 compressive cycles under a 5 kg load (with placement in a humidifier and thermocycling) would most closely approximate the conditions in the study by Pan and Lin (2005). The mean retention value of the crown copings in the current study was 2.986MPa which is 77% greater than the value reported by Pan and Lin (2005). Reasons for this may relate to the different implant systems and also the more severe compressive cyclic loading conditions in the study by Pan and Lin (2005) that may stress and fatigue the cement more resulting in reduced cement retentiveness.

Mansour et al (2002) reported a mean load required to decement castings cemented to ITI solid abutments with Panavia-21 of 36.53kg (358.2N).

Specimens in this study were placed in a humidifier following cementation but not thermocycled or subjected to compressive cyclic loading. Unloaded Panavia-F specimens in the current study (that were placed in a humidifier and thermocycled) demonstrated mean retention values of 298.7N which is comparable to the study by Mansour et al (2002) despite the fact Panavia-F and not Panavia-21 was used. A closely comparable result may be expected as both experiments used Straumann abutments with a height of 5.5mm. The ITI solid abutment used in the study by Mansour et al (2002) has a groove on one side for screw driver engagement during abutment placement (that is not engaged by the coping intaglio) and a flat opposing side, whereas the Straumann synOcta abutment in the current study has the synOcta design base and 8º taper walls (Figure 1). It was not stated whether alloy primer was used in the study by Mansour et al (2002), which may enhance chemical bonding to metal surfaces and contribute to increased retention of castings.

The current study's finding for Panavia-F specimens that compressive cyclic loading results in a statistically significant loss of retention is in agreement with the only other available similar purpose study that investigated the effect of various quantities of compressive cyclic loading on crown coping retention (Ongthiemsak et al, 2005). The study by Ongthiemsak et al (2005) applied to gold castings cemented to Zimmer abutments but was limited to the use of TempBond. Both studies reported no statistically significant further loss of retention with greater quantities of cycles beyond the initial quantity of compressive load cycles. Increased loading quantities produced no further significant loss of retention.

5.5.2 KetacCem

KetacCem, and indeed glass ionomer cements in general, have been tested sparingly with cemented implant abutment copings in the past and no recent appropriate studies for comparison were located. Nevertheless, KetacCem initially appears to provide far less retention with implant systems than on natural teeth, most apparently due to the lack of cement bonding opportunities and potential sensitivity to moisture contamination.

5.5.3 TempBond NE and TempBond

TempBond is one of the more commonly tested materials for the cementation of implant abutment crown copings. Correspondence with representatives from Kerr International (the manufacturers of TempBond and TempBond NE) suggested both cements have very similar, if not almost identical physical properties, and therefore at least some degree of comparison is possible (Kerr International, written communication, 28 October 2006). However, it is still important to distinguish between the two subtly different materials.

5.5.3.1 TempBond NE

Kent et al (1997) cemented gold cylinders to CeraOne titanium abutments with TempBond NE and found mean retention values of 7.1kg (69.6N) (with the access hole unfilled) and 7.4 kg (72.6N) (with access hole filled with an autopolymerizing resin). However, these specimens were placed in a humidifier but not thermocycled or subjected to compressive cyclic loading. Interestingly, relatively similar values of 6.7kg (65.7N) and 11.3kg (110.8N) respectively were obtained with TempBond, which suggests some comparability of the two temporary cements. In the current study, a mean retention value of 4.9N for unloaded specimens (that were placed in a humidifier and thermocycled) was obtained which is significantly less than Kent et al (1997) predominantly due to the effect of thermocycling in the current study.

Mansour et al (2002) reported a mean load required to decement castings cemented to ITI solid abutments with TempBond NE of 3.18kg (31.2N), which is still significantly greater than the current study. Specimens in the study by Mansour et al (2002) were placed in a humidifier following cementation but not thermocycled or subjected to compressive cyclic loading. Even with 10,000 compressive loading cycles where copings were compressed back onto their abutments, the mean retention value of 20N in the current study fell appreciably short of that of Mansour et al (2002). Although similar components were used in both studies, the effect of thermocycling on TempBond NE specimens in the current study appears to have significantly reduced retention (as discussed in 5.4 TempBond NE specimens).

5.5.3.2 TempBond

The results of Pan and Lin (2005), of which one tested cement was TempBond, are presented in megapascals and are therefore limited in comparison to other studies that have not converted their results to megapascals. Under in vitro conditions including placement in a humidifier, thermocycling and 100,000 compressive cycles under a 75N (7.6kg) load, the reported mean cement failure load of cast superstructures cemented to SteriOss titanium alloy Hex-Lock Straight Esthetic abutments with TempBond was 0.274MPa (Pan and Lin, 2005). This is similar to the mean retention value for TempBond NE specimens in the current study subjected to similar in vitro conditions and 10,000 compressive loading cycles under a 5kg load of 0.303MPa.

Ongthiemsak et al (2005) obtained mean retention forces of 230N to 240N for unloaded copings cemented to Zimmer abutments with TempBond under in vitro conditions that included placement in a humidifier but excluded thermocycling. This value is significantly greater than most other studies and may be explained by the abutment height of 7mm with 5 lateral retentive grooves.

In a recent study, Kaar et al (2006) reported retention values of 95.2N for unloaded gold cylinders cemented to CeraOne abutments with TempBond and 86.7N after 300,000 compressive cycles with a load of 110N (11.2kg). However, specimens in this study were placed in a humidifier but not thermocycled, and this may account for the significantly higher values than the current study.

Kent et al (1996) reported retention values of 57.8N to 75.6N (which varied according to chimney height and cement volume) for cementing gold alloy cylinders to CeraOne abutments with TempBond, while Akca et al (2002) demonstrated mean uniaxial resistance with TempBond of 40.6N to 81.6N depending on abutment type. Clayton et al (1997) reported a mean retention value of 67.2N (converted to 1.17MPa) for CeraOne gold cylinders cemented to 3.7mm tall CeraOne abutments with TempBond.

Ramp et al (1999) conveyed a mean retention value of 14.2kg (139.3N) (converted to 1.29MPa) for their castings cemented to SteriOss abutments with TempBond. Specimens were stored in distilled water between cementation and testing, but not thermocycled or subjected to compressive cyclic loading.

The mean retention values for TempBond NE in the current study (4.9N – 20N) are notably lower than those of other comparative studies investigating the use of TempBond or TempBond NE with cemented implant abutment crown copings. The effect of thermocycling appears to have considerably reduced coping retention in the current study.

5.5.4 Conclusions

The use of abutments with various dimensions requires the expression of cement retention values in universal units such as Megapascals (conveying force per unit area) in order for more meaningful interexperimental comparisons to be made.

The majority of studies conveyed findings in Newtons or kilograms (which are simply interconverted; 1kg = 9.8N), but further conversion to megapascals was not possible if the crown coping surface area was not provided.

The differences in retention values between studies can predominantly be explained by different combinations of in vitro experimental conditions but also different implant systems and components. Coping retention is multifactorial in nature and requires consideration of preparation taper, cervico-occlusal wall height and surface finish of the preparation and casting. In some studies, abutments contained retentive grooves while others provided relatively smooth surfaces. Standardized experimental conditions are required for cement testing with implant components if accurate and meaningful comparisons are to be made.

5.6 Cement film thickness

The Straumann synOcta plastic coping provides for an ideal cast crown coping cement film thickness as shown in Figure 33 (Straumann, Basel, Switzerland). This is comparable to the 20-40µm of spacing provided for with natural teeth crowns (Luthra, 2005; Eames et al, 1978; Fusayama et al, 1964).

Figure 33. Ideal cement film thickness at abutment wall and margin (illustration kindly provided by Straumann, Basel, Switzerland)

NOTE:
This figure is included on page 127
of the print copy of the thesis held in
the University of Adelaide Library.

The cement film thickness obtained clinically after crown cementation may not always equate to that of the ideal. Factors that influence the actual cement film thickness obtained include casting accuracy, cement viscosity (grain size), seating pressure, type of cement used, cement mixing ratios and techniques and cement volume.

Larger grain cements, such as some of the earlier developed resin cements, may require greater cement space as their grain size approaches the cement space allowed for in order to permit complete restoration seating. Less viscous cements may require greater cement space, less cement volume and greater seating pressure to permit extrusion of excess cement and complete seating of the restoration. The smallest marginal cement film thickness achievable is that equal to the grain size of the cement, as on crown cementation some excess cement is usually extruded at the margin. Crown venting may permit excess cement extrusion via an alternative location to the margin and allow close approximation of coping margins to abutment finish lines less than that of the cement grain size. Finer grain cements may better penetrate the micromechanical irregularities of the crown coping intaglio. Larger grain cements may not be able to enter such irregularities due to their increased grain size.

Previous studies concluded that ideal cement spacing was cement specific, and ranged from 25-75µm (Wu and Wilson, 1994; Dixon et al, 1992; Vermilyea et al, 1983; Passon et al, 1992; Carter and Wilson, 1996). In reference to Figure 33, a cement spacing of 25-75µm is slightly greater than the ideal cement space provided for by the Straumann plastic coping at the margin (20µm), but includes within its range the 55µm space provided for at the abutment walls. Clinically, if greater marginal cement film thickness results from crown cementation than is provided for by the plastic coping, marginal fit discrepancies and incomplete crown seating may result that may require occlusal adjustments.

The ideal film thickness for zinc oxide non-eugenol cements has been recommended by the American National Standards Institute / American Dental Association specification no. 30 (ISO 3107) at no more than 25µm for permanent cementation and no more than 40µm for temporary cementation (Craig, 2006; Kerr International, TempBond and TempBond NE Product Summary). In comparison, KetacCem is recommended for use in film thicknesses of 17µm, and Panavia-F for 18µm (3MESPE, KetacCem Technical Product Profile; Kuraray Dental. Panavia-F product overview). All recommendations would presumably apply to natural teeth. Each cement's recommended film thickness appears achievable for use with the Straumann synOcta cementable crown specifications at the margin but is significantly less than that provided for at the abutment walls (55µm) (Figure 33).

The minimal cement thickness and grain size of a particular cement should be less than the cement spacing provided for with the restoration. It is critical the type of cement is carefully chosen so it may function in its ideal film thickness within the cement space provided for. Further research into ideal cement thicknesses for specific cements in specific clinical circumstances (both natural tooth and implants) is needed to provide more detailed recommendations.

It was accepted that increased cement film thicknesses would result with further rounds of testing with the cleaning technique employed in the current study. This was evidenced by the observation of increasing degrees of coping rotation on abutments before cementation with further rounds of testing. Passon et al (1992) and Carter and Wilson (1996) suggested large increases in cement spacer did not affect crown retention. Thus, according to this research, in the current study it was feasible to increase the cement film thickness (as a result of the employed cleaning technique) to a certain extent without influencing crown coping retention.

Although the cement film thickness was known at the beginning of the current study (according to the ideal in Figure 33), the cement film thickness at the conclusion of testing was not calculated as this was beyond the scope of the current study. This would require sectioning of cemented specimens and measurement of cement film thickness under magnification. The cements used in the current study may demonstrate different properties in different thicknesses, however, as can be seen in Figures 20 and 21 (in Results), there was no overriding trend in coping retention values with repeated testing using the same components with increasing cement film thickness.

The marginal cement gap was not measured in the current study as this was not within the extent of this research. TempBond NE specimens developed obvious marginal gaps following thermocycling. It was possible that marginal cement gaps varied with different cements tested following initial crown coping cementation.

5.7 Abutment screw access channels

There is no consensus on whether abutment screw access channels should be filled, partially filled or left open, and if filled with what type of material. Previous studies found different cements responded in different manners to filled (with various materials) or unfilled abutment screw access channels (Koka et al, 1995; Kent et al, 1997; Chu et al, 2005). The recommendation provided by Straumann was to seal the abutment screw access channel with wax or gutta percha prior to crown cementation (Straumann International, Straumann Prosthetics). Composite resin, polyvinylsiloxane impression material, gutta percha and cotton pellets have also been used to seal abutment screw access channels during previous in vitro testing.

It may be possible that filling abutment screw access channels with composite resin, and indeed some other materials, allows a chemical bond between the filling material and luting cement that may aid in crown coping retention. Filling the abutment screw access channel with a rigid material may also prevent cement escape into the internal abutment cavity thus creating a greater internal cement pressure between the coping intaglio and abutment. Cement may subsequently be forced into the micromechanically retentive sandblasted crown coping intaglio under greater pressure and influence coping retention. Also, the presence of only one area of cement escape at the margin may require greater seating pressure to express residual cement and avoid marginal gap formation.

In the current study, the abutment screw access channels were filled with cotton pellets to cover the abutment screw and softened, compacted modeling wax. In this manner, there was no possibility of a potential chemical bond between the material used to fill the abutment screw access channel and some cements (but not others). The wax seal was also easily repairable between rounds of testing resulting in a consistent screw access channel seal.

5.8 Abutment screw access channel wax seal

It is probable the wax seal in the current study influenced the observed retention values to some extent. On cementing the crown coping, an internal cement seating pressure was created between the coping and abutment resulting in the extrusion of excess cement via the margins or displacement of the wax seal and penetration of cement into the abutment screw access channel. Excess cement extruded via the path of least pressure resistance. If the abutment screw access channel wax seal provided less resistance to cement extrusion than at the margin, then excess cement indented into the wax surface and / or displaced the wax seal further into the abutment screw access channel. At the time of coping cementation, it is possible that either, and most likely a combination of, two processes transpired at the coping / abutment screw access channel wax seal interface:

1. Cement intermingled with the soft wax surface and subsequently set within the wax surface
2. The internal cement seating pressure displaced wax further into the abutment screw access channel allowing cement penetration and a mechanical lock of the cement into the natural undercuts present in the “inverted cone” tapered shape of the abutment screw access channel

The observations of the mode of cement failure at the coping / abutment screw access channel wax seal interface may be explained by the interplay of the greater retentive forces provided by:

1. Abutment
    a. Cement retention provided by the intermingling of cement setting within the wax of the abutment screw access channel
    b. Cement retention provided by the penetration of cement into the screw access channel (following wax displacement) and mechanically locking into the natural undercuts of the abutment
2. Coping
    a. Intra-cement tensile force resistance
    b. Cement retention provided by the sandblasted coping intaglio

When cement retention from the abutment (1a and 1b above) was greater than the coping (2a and 2b), intra-cement failure resulted and cement was retained within the abutment screw access channel (all failures were adhesive to the crown coping). When retention from the coping (2a and 2b) was greater than the abutment (1a and 1b), failure at either the cement / wax interface or within the wax resulted and all cement remained attached to the removed coping with or without some attached wax.

The wax seal was altered in one of 3 manners:

1. Part of the wax seal was removed from within the abutment screw access channel (Panavia-F specimens)
2. The wax seal was indented and pushed further into the screw access channel with no residual cement remaining within the screw access channel (KetacCem specimens)
3. The wax seal was indented and pushed further into the screw access channel with residual cement remaining within the screw access channel (TempBond NE specimens)

The crown coping provided the corresponding observations to that of the abutment screw access channel wax seal:

1. The cement penetrated the screw access channel and lifted out with some wax attached to cement within the coping (Panavia-F specimens)
2. The cement penetrated the screw access channel and lifted out without attached wax while still attached within the crown coping (KetacCem)
3. The cement penetrated the screw access channel, fractured within the cement within the screw access channel, but with some cement attached to the coping (TempBond NE)

It was feasible that the mechanical locking effect of cement into the natural undercuts present in the abutment screw access channel contributed to the observed retention values. However, it is not possible to clarify this sole effect on the observed results due to the complexity in isolating this aspect of testing. In order to confirm the influence of the abutment screw access channel seal on retention values, specimens would require testing with and without various materials that may be used to seal the screw access channel and with all other variables constant, but to date such studies have produced mixed results (Koka et al, 1995; Kent et al, 1997; Chu et al, 2005).

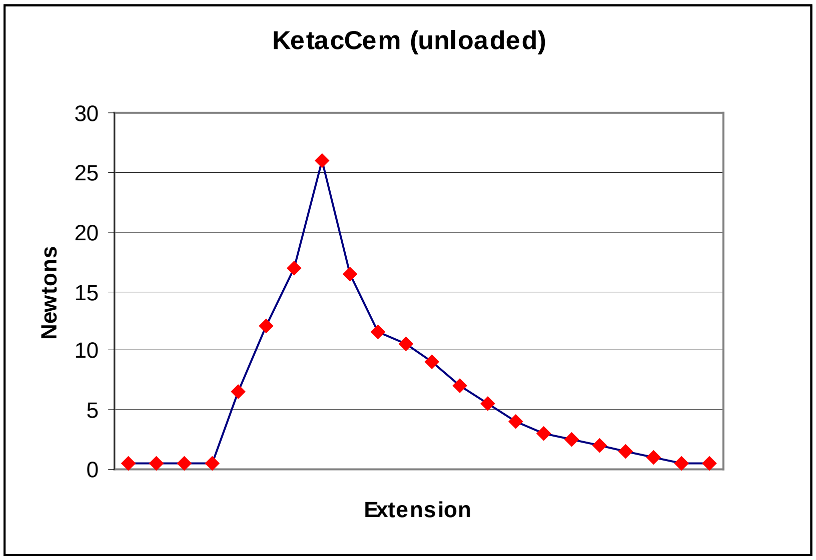
The influence of the coping / abutment screw access channel wax seal interface on cement retention and mode of cement failure at this site introduces additional aspects of cementation technique and its influences on coping retention. Variables such as cement volume, individual cementation technique, force to cement crowns and resistance to cement penetration into the abutment screw access channel may influence internal cement seating pressure, cement strength and coping retention. Kent et al (1996) cemented gold alloy cylinders to CeraOne abutments with both 0.01ml to 0.02ml of TempBond but discovered no significant difference in retention values. Further studies in this area appear scarce.

5.9 Cement failure values and the "hang-on" effect

An additional observation during uniaxial tensile testing was a phenomenon that is most appropriately termed the "hang-on" effect. KetacCem and TempBond NE specimens demonstrated a slower lifting of the coping from the abutment rather than a definitive and sudden failure point. Following the cement failure of KetacCem and TempBond NE specimens (generally at lower retention values than Panavia-F), residual retentive forces were observed for a considerable period of time before returning to zero Newtons or near zero Newtons (Figure 34). Despite visible evidence that copings had lifted off abutments, additional force was required to completely remove the copings. Residual retention was evident following the point of cement failure.

Panavia-F specimens demonstrated no “hang-on” effect, rather a distinct and definite failure point, with a sudden fall of tensile force to zero Newtons (Figure 35). It is possible the sudden fall to zero Newtons was related to the greater tensile forces required before cement failure.

Figure 34. The typical failure pattern of KetacCem and TempBond NE specimens closely representative of the mean retention value (specimens received 0 compressive cyclic loading)



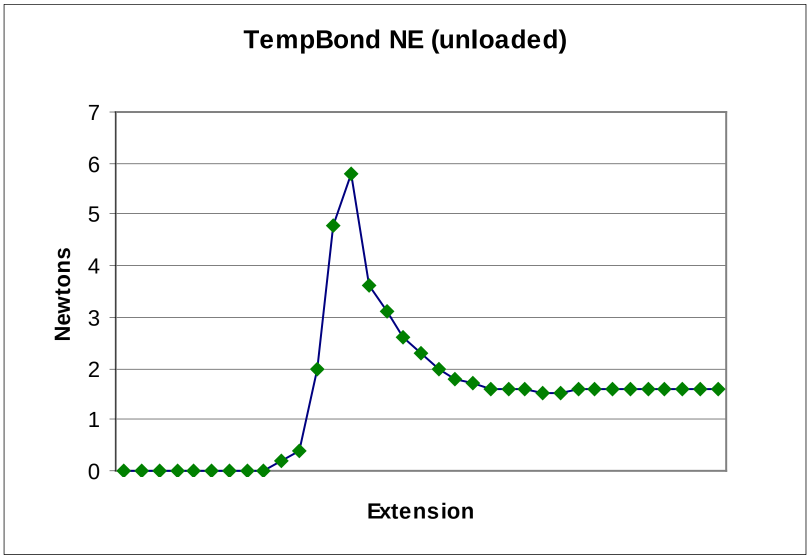
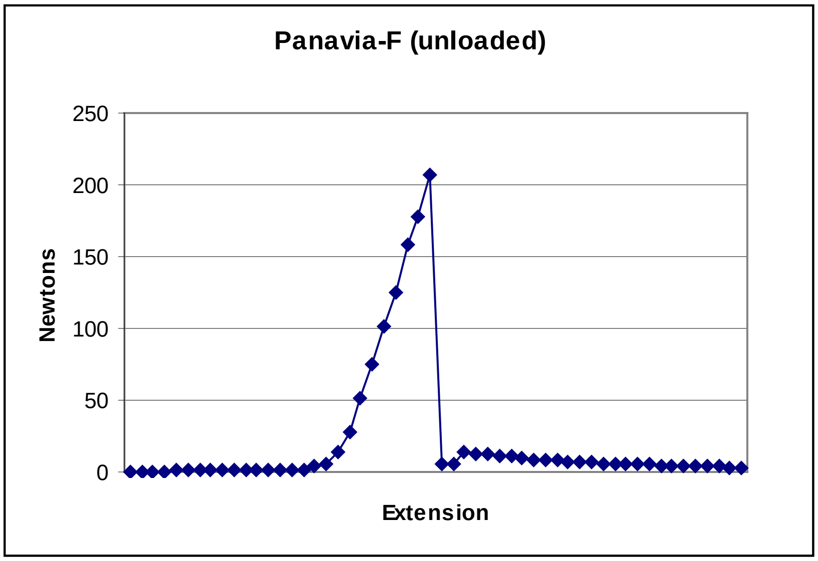


Figure 35. The typical failure pattern of Panavia-F specimen closely representative of the mean retention value (specimen received 0 compressive cyclic loading)



There are two predominant aspects combining to provide coping retention within the Straumann synOcta abutment system that is common to all cements. Firstly, the parallelism of synOcta abutment walls at the base of the implant abutment and subtle 8º taper, and secondly, the closeness of fit of the coping to the abutment, defined by the closeness of fit of the plastic copings used to construct the cast copings.

The parallelism of the synOcta abutment walls was a likely factor that contributed to the “hang-on” effect. After cement failure at the abutment / cement interface, cement attached to the crown coping continued to rub against the parallel abutment surface, and although a relatively smooth surface, provided some friction and resistance to further crown coping removal that required additional extension to overcome. This small residual retentive force was comparable to the retention at cement failure and thus inhibited sudden coping removal.

It is also possible that the “hang-on” effect was related to the penetration of cement into the abutment screw access channel wax seal as described in section 5.8 Abutment screw access channel wax seal. On removal of the coping, the cement may initially fail predominantly at the cement / abutment interface, but subsequently require continued force to remove wax (that was now attached to cement retained within the coping) or cement that had penetrated into the “inverted cone” tapered shape of the abutment screw access channel. At higher retention values found with Panavia-F cement, cement retention forces were likely to have been far greater than any retention provided at the wax seal in the screw access channel. Therefore, on failure of Panavia-F specimens, the wax had an unobservable further retentive effect on the coping.

5.10 Sources of potential bias during testing

Sources of bias may exist in both the in vitro experimental design and its attempt to simulate in vivo conditions, but also the experimental testing relating to identical specimen construction and reproducibility of repeated testing.

5.10.1 In vitro conditions bias

In vitro conditions attempt to artificially simulate those conditions that exist in the natural oral environment, but generally do not entirely reflect all variables encountered in vivo. For example, thermocycling attempts to thermally stress cements, but abiding by the ISO standard of 500 repeated 20 second cycles between 5ºC and 55ºC may not realistically represent in vivo behaviour. Many restorations and prostheses are coupled systems of numerous materials, and their overall clinical behaviour involves the properties of each material and the quality of interfaces between them (Kelly, 2006). For systems involving the interplay of components, clinical data or validated laboratory simulations remains the only sources of reliable evidence (Kelly, 2006). In vitro tests can not accurately reproduce all oral factors such as temperature changes, occlusal forces, salivary pH, salivary buffering capacity and saliva flow rate.

5.10.2 Experimental bias

Elements of potential experimental bias may be identified at nearly all stages within the methodology. While every effort was made to manage all specimens identically, inadvertent unequal treatment of specimens should be recognized and may be responsible for some of the observed variations and results.

5.10.2.1 Component construction

During crown coping construction, variations in individual copings may be introduced at any point of the construction process from initial waxing through casting to final adjustment. Abutments are proposed to be identical due to their high precision computer-aided machining.

5.10.2.2 Cementation

Subtle variations in the mix of cement components and mixing technique may have been introduced even though the same experienced dental assistant mixed all cements with a consistent technique. Wacker and Tjan (1988) revealed that lowering the powder / liquid ratio of zinc phosphate cement reduced the retention of paraposts to human mandibular premolars, and this may also apply to additional two component powder / liquid mixed cements. The mixing spatula was thoroughly cleaned between rounds of mixing, but the potential exists for cement cross-contamination.

Some cements were mixed prior to others, and bench top setting times may affect the properties of cements in different manners. For example, Panavia-F specimens were cemented onto abutments first, and remained on the bench top at room temperature and humidity until KetacCem and finally TempBond NE specimens were cemented. Subtle variations in room temperature resting times between stages of testing may have affected the cements in different manners.

Optimal conditions for crown coping seating duration have not yet been defined, nonetheless the loading conditions of 5kg for 5 minutes may influence different cements in different manners.

5.10.2.3 Thermocycling

If in vitro thermocycling is assumed to be an accurate representation of in vivo conditions, then its effect on luting cement may be more pronounced than in vivo due to differing crown coping thicknesses. Crown copings in the current study were thin compared with in vivo crowns, as no additional wax thickness was added to the plastic burnout coping and porcelain was not layered. Additional material thicknesses may further insulate the cement from thermal stresses. Therefore, cements in this experiment may have been exposed to more severe temperature extremes than in vivo.

The ISO standard ISO / TR 11405:1994(E) was applied universally to all specimens, irrespective of the fact that specimens were tested for four different compressive cyclic loading times. One group of specimens was tested for the equivalent of one year of simulated oral loading function and it might reasonably be expected to be subjected to 500 exposures of hot and cold (not necessarily 5ºC and 55ºC) within this time period. Another group of specimens was tested for the equivalent of one week of simulated oral loading function where it would be very unlikely to be subjected to 500 hot and cold exposures within one week. Modifying this experimental condition to be proportional to simulated oral function times would violate the ISO standard and introduce additional experimental condition variations that may influence the validity of results.

5.10.2.4 Compressive cyclic loading

Unlike the humidifier and thermocycling machine where all specimens were exposed simultaneously to its simulations, only one specimen could be placed in the tooth wear machine at a time. Variables in the centring of specimens combined with subtle angulation variations during specimen construction may have produced off-centre loading and different vectors of force causing cements to be stressed in subtly different manners. It was observed that the occlusal table of Panavia-F copings demonstrated greater wear and “ditching out” that was not as apparent in KetacCem and TempBond NE specimens. Inadvertent variations in the stylus slide durations on the coping platform may have exposed specimens to different loading conditions and contribute to the observed results.

As stated in the methodology, an added element to the experimental conditions was the estimated 32ºC to 35ºC temperature produced when the two experimental surfaces were rubbed together that was proposed to closely approximate that of the oral environment (Kaidonis et al, 1998). If this observation was applied to the specimens used in the current study, then specimens that received greater quantities of compressive cycles (eg. 10,000 cycles) were exposed to greater durations of higher temperatures. Contrastingly, specimens that received no compressive cyclic loading were exposed to no additional higher temperatures, instead these specimens rested at room temperature. Specimens that received 5,000 compressive cyclic loadings were exposed to approximately $1^1/_2$ hours (the time for 5,000 cycles) of 32ºC to 35ºC temperatures. The effect of temperature exposure of 32ºC to 35ºC for an additional 3 hours (the time for 10,000 cycles) to some specimens was therefore an in vitro experimental condition that was not uniformly applied to all specimens, and may contribute to observed results.

With the exception of resin cements, most luting cements are prone to tensile failure because of their brittle nature (Pan et al, 2006). In the current study, compressive cyclic loading was directed axially to minimize lateral loading and tipping forces that may be unfavourable to implants. However, it was inevitable that at least some lateral force was applied to specimens as the stainless steel stylus rubbed across the occlusal platform of the crown coping, resulting in some tensile forces. These tensile forces may be more harmful to cements that were more prone to tensile failure.

5.10.2.5 Uniaxial tensile testing

Uniaxial tensile testing was employed to minimize lateral forces. When specimens were tested, potential existed for the underside of the flat coping platform to be engaged by one side of the testing apparatus before the other, resulting in a non-uni-axial tensile force being applied. The resultant cement failure force may not be a true indication of the uniaxial force required to remove copings.

Assuming the tensile test was directed uniaxially, a purely tensile test may not represent clinical stresses where other non-axial forces may contribute to crown de-cementation. Mansour et al (2002) remarked that tensile testing permitted the comparison with previous investigations of a similar nature, but Kaar et al (2006), mentioned that a standardized test to determine the retention strength of crowns to abutments was not currently available. The Universal Testing Machine (Hounsfield H50KM, Hounsfield Testing Equipment, United Kingdom) in the current study used a 1mm / minute cross-head speed, whereas other studies have used varying speeds ranging between 0.125 and 5mm / minute (Ongthiemsak et al 2005; Pan and Lin, 2005; Kaar et al, 2006).

5.10.2.6 Cleaning specimens

Panavia-F cement was particularly resistant to initial aluminium oxide sandblasting and required greater time and pressure to remove residual cement compared with KetacCem and TempBond NE specimens. Although the loss of intaglio coping surface was not able to be definitively measured, greater rotation of pre-cemented Panavia-F crown copings on abutments compared with KetacCem and TempBond NE copings (particularly in later rounds of testing) suggested more Panavia-F specimen intaglio surface had been lost due to cleaning. Therefore, Panavia-F cement was most likely acting in greater thicknesses with further rounds of testing than the other cements. Importantly, a consistent intaglio coping surface was produced for each round of testing.

5.11 Compressive cyclic loading

In the current study, the quantity of compressive cyclic loading was varied to simulate estimated average oral function for one week, six months and one year. Specimens that received no compressive cyclic loading acted as the baseline. All other in vitro conditions were kept consistent for all specimens. This appears to be the first study of this kind that investigated the way in which varying the quantities of compressive cyclic loading influenced different types of luting agents used to cement crown copings to implant abutments.

The number of compressive cycles and load used in this study were smaller than other studies, although great variation in the estimation of numbers of cycles that equate to average human daily, weekly and yearly masticatory function exists (Ongthiemsak et al, 2005; Kaar et al, 2006; Pan and Lin, 2005; Graf et al, 1974; Leinfelder et al, 1989; Kaidonis et al, 1998). Chewing rate is subjective and varies from person to person and may be related to the type of food. It also varies within the same person. No known study has validated this due to apparent difficulties in ethics and measurement.

Few other studies have incorporated compressive cyclic loading into their investigation of dental cements with implant components. In order to equate to one year of simulated chewing function, Ongthiemsak et al (2005) estimated 1,000, 000 cycles of 20-130N (2-13.3kg) load, Kaar et al (2006) 600,000 cycles under 110N (11.2kg) (from an estimation that chewing takes place for 20 minutes per day), and Pan and Lin (2005) 33,333 cycles with a force of 75N (7.7kg). The current study referred to the historical work of Graf et al (1974) (see Literature Review 2.5.5 Specific in vitro tooth wear conditions) and used an estimation from previous users of the same tooth wear machine (who investigated the wear of human enamel) of 20,000 compressive loading cycles of between 3.2kg and 9.95kg load simulating approximately two years of average human masticatory function. Thus, 10,000 cycles with a 5kg load was used to represent average mastication over one year, and interpolations for smaller timeframes were made. It should be emphasized that two factors combine to produce compressive cyclic loading simulation: quantity of cycles and compressive load.

The simulated time frame selected to investigate the effects of compressive cyclic loading was established in reference to the work by Ongthiemsak et al (2005) and Singer and Serfaty (1996). Ongthiemsak et al (2005) demonstrated that TempBond fatigued significantly with 500 000 cycles (simulating an estimated six months of in vivo mastication) but not with additional cycling. Singer and Serfaty (1996), in a clinical follow-up of implant-retained prostheses over six months to three years, reported that the greatest loss of retention between a cemented crown and an implant abutment occurred during the first year of function. Therefore, the equivalent number of compressive cycles representing one year of loading was chosen as the limit of testing since previous studies demonstrated little change in retention beyond this point.

5.12 Cleaning specimens

In the current study, it was decided to use the sandblasting method of cleaning the coping intaglio as this was most likely to be used in practice should a cemented implant abutment crown de-cement and require re-cementing. This method provided a reproducible roughened coping intaglio for micromechanical cement retention for each round of testing.

It was recognized that repeated sandblasting would gradually remove the coping intaglio and reduce the closeness of fit to the abutment, resulting in a greater cement space. But, it was proposed that chemical cleaning solutions alone may not completely remove all residual cement, especially the more resistant resin cement that had penetrated into the deeper coping intaglio micro-crevices. Additionally, access to appropriate cleaning solutions at the time of testing, particularly for resin cement, was limited.

Panavia-F cement proved difficult to remove with aluminium oxide sandblasting and required repeated inspection under 16x magnification and cleaning episodes to remove all residual cement. Initially, on fully seating the copings, minimal rotation was possible due to the synOcta abutment shape and closeness of fit of coping to abutment. With further rounds of testing, all copings were able to be rotated more and more on their abutments. Noticeably greater rotation was evident with the Panavia-F specimens compared with both KetacCem and TempBond NE specimens, due to the requirement for greater sandblasting time resulting in greater surface abrasion.

In the pilot study, abutments were cleaned by gross cement removal with a teflon coated scaler, but Panavia-F proved too difficult to completely remove. Subsequently, short duration glass bead abrasion was used which was effective in providing a clean abutment surface. As failure occurred at the cement / abutment interface (adhesive failure), the cleaning technique used in the current study (sandblasting the coping and short duration glass bead abrasion of the abutment) appeared to have little apparent effect on the results. Sandblasting, whilst abrading the coping intaglio, provided a consistent surface for cement to micro-mechanically adhere to, but did not alter the cement / abutment surface where failure occurred.

With further rounds of testing, no predominant trend in coping retention values from re-using the same components was observed (Figures 20 and 21). Figure 20 provides a cement-specific comparison of coping retention values for each round of testing obtained through re-using the same components. Figure 21 combines all coping retention values in each round for all cements to provide an overall trend in re-using the same components. It should be noted that Figure 21 is dominated by the greater retention values of Panavia-F. The observed variations in retention values appear attributable to experimental error. Therefore, it may be assumed that the current specimen cleaning regime used to permit re-use of components had no apparent significant effect of the observed results. However, different cleaning practices of different studies may predispose to variations in observed results and limit comparison.

5.13 SEM analysis

SEM analysis after rounds one, five and eight of testing revealed no apparent differences in the appearance of cements in loaded versus unloaded specimens, except for TempBond NE unloaded and loaded specimens. TempBond NE specimens demonstrated different cement appearances at the shoulder where there was compaction and no compaction of cement due to compressive cyclic loading (Figures 40 and 41). After the copings had lifted off the abutments following thermocycling, specimens that received compressive cyclic loading were compressed back onto their abutments. This resulted in compaction of cement at the shoulder. The cement at the shoulder of these specimens demonstrated a compressed appearance, whereas the cement of unloaded specimens showed a wavy and undulating appearance (Figures 40 and 41).

On the crown coping intaglio walls, all cements demonstrated a smooth, homogeneous appearance. On the crown coping shoulder, cements demonstrated a roughened, more irregular appearance. In loaded specimens, this may be explained by the shoulder region enduring more direct axial loading of the compressive cyclic loading force. However, in unloaded specimens no force was applied, but similar SEM appearance was observed. The uniaxial tensile testing method may therefore play some role in this observation, as on applying a uniaxial tensile load, the cement at the shoulder was potentially "stretched" away from the shoulder.

Comparisons of crown coping intaglios for each cement type are provided in Figures 36-41 for specimens that received 0 and 10,000 compressive loading cycles.

Figure 36. Panavia-F specimens - 0 compressive cyclic loading

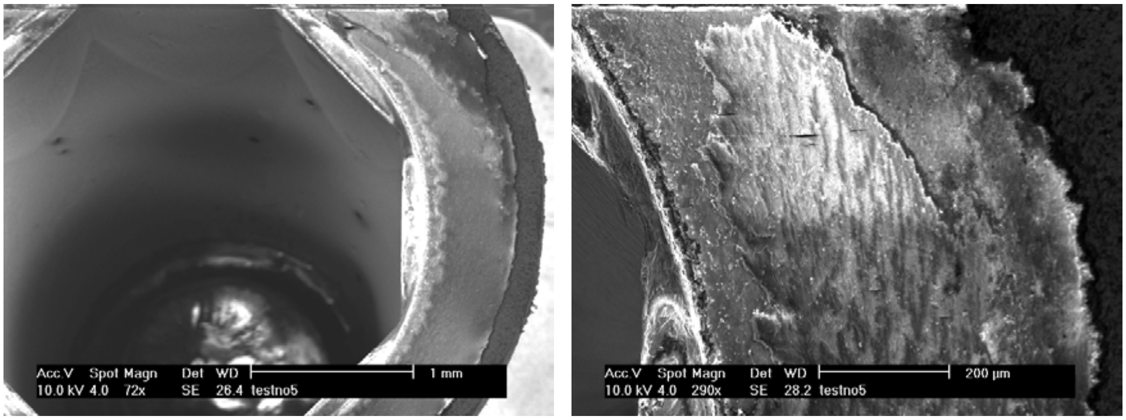


Figure 37. Panavia-F specimens - 10,000 compressive cyclic loading

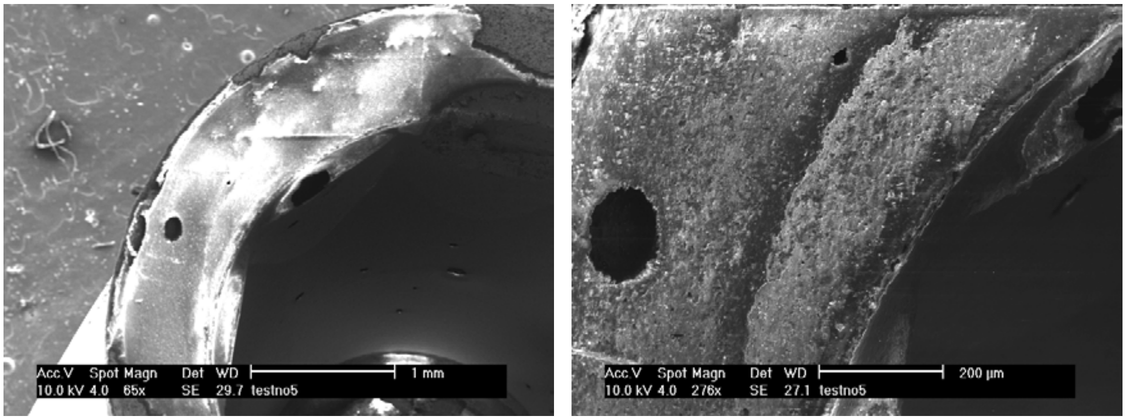


Figure 38. KetacCem specimens - 0 compressive cyclic loading

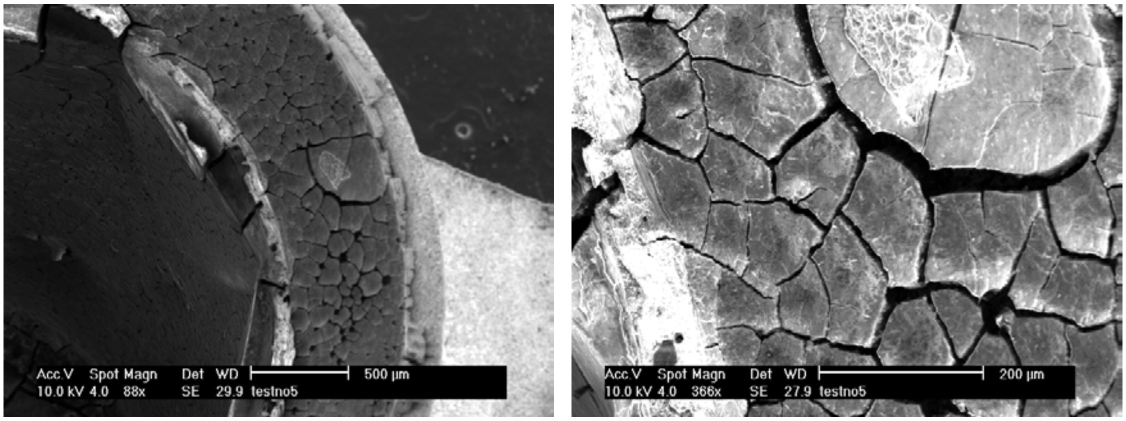


Figure 39. KetacCem specimens - 10,000 compressive cyclic loading

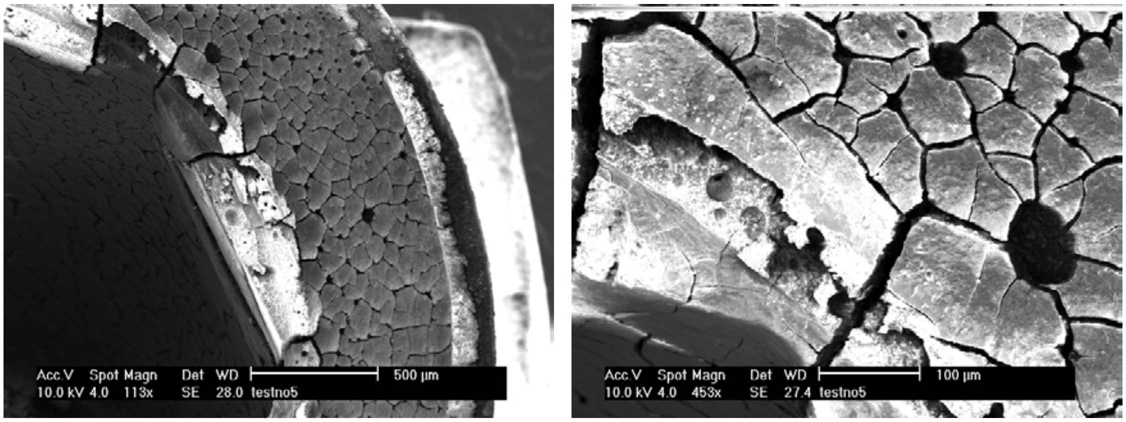


Figure 40. TempBond NE Specimens - 0 Compressive Cyclic Loading

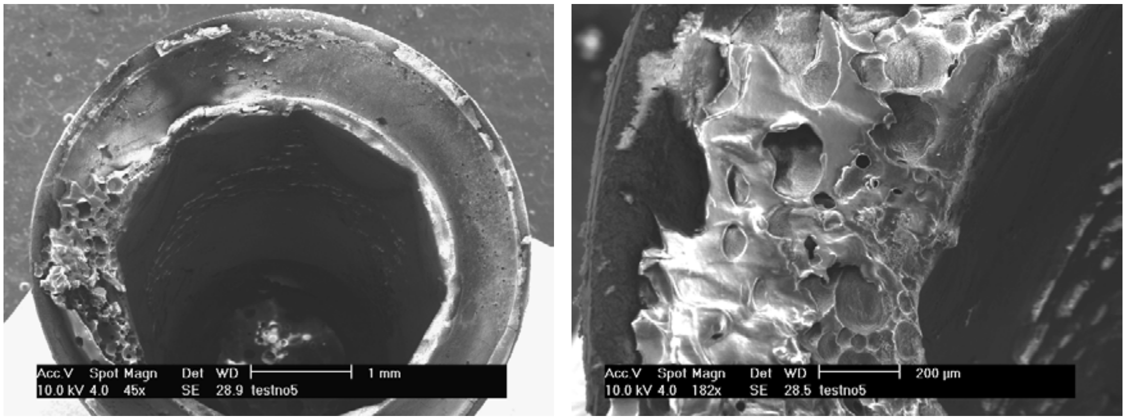
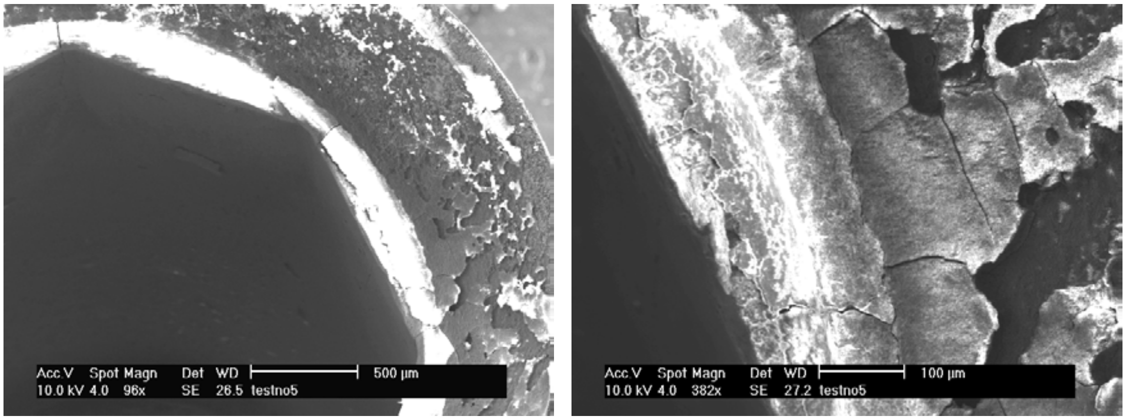


Figure 41. TempBond NE specimens - 10,000 compressive cyclic loading



Interestingly, the “snap-on mechanism” from the coping construction (see Materials and Method 3.2.1 Crown coping construction) was still partially evident on some high magnification images, despite being removed at 16x magnification during construction in the laboratory.

5.14 Experimental limitations

It should be emphasized that this is an in vitro study, and involves non-validated artificial simulations of the oral environment that do not reflect all variables encountered in vivo. Clinical evidence from randomized controlled trials remains the highest source of evidence.

The range of retention values and standard deviations in the current study were high. This has been noted and discussed in other studies of a similar nature, and may be related to difficulties in study design (including small sample sizes), construction and testing variations and the relative unpredictability and sensitivity of cements (Mansour et al, 2002; Pan et al, 2006; Squier et al, 2001). The results may in some ways correlate to the sometimes unpredictable nature of the oral environment. The standard deviations for KetacCem that received 0 and 192 compressive cycles were larger than the mean value (Table 2 and Figure 17). A greater sample size and new components for each round of testing may reduce the standard deviations.

5.15 Potential clinical relevance

The clinical relevance of the findings from the current study rests on the validation of in vitro conditions accurately simulating the complex oral environment. Should this be confirmed, the following observations may be considered in a clinical sense.

When crown copings cemented to Straumann synOcta abutments decement, failure is by cement adhesion to the coping intaglio. This is a clinically favourable method of cement failure as minimal cement remains attached to the intra-oral abutment surface which may be more difficult to clean without damaging the abutment.

Of the three tested cements, Panavia-F provided superior retention for retaining cast crown copings to Straumann synOcta abutments and appeared the most appropriate cement for permanent non-retrievable cementation. Despite compressive cyclic loading significantly reducing the retention provided by Panavia-F, the reduced mean retention values remained significantly greater than those of both KetacCem and Tempbond NE.

Increased compressive loading cycle quantities of Panavia-F specimens produced no further statistically significant loss of retention. This may imply that following an initial period of in vivo use where crown copings remain cemented to implant abutments, it may be expected that little further loss of retention would result over subsequent time periods. Clinically, crown copings that remain cemented to implant abutments in the short term may be expected to remain cemented in the long term.

KetacCem and TempBond NE provided comparatively low retention and may be used cautiously to cement crown copings to Straumann synOcta abutments where retrievability may be required.

TempBond NE may be indicated in immediate loading situations or where crown retrievability is desired in the short term. However, it should be considered that cemented interim crowns may have a different intaglio surface that is not as micromechanically retentive as permanent crown copings, hence different retention may be achieved.

Caution should be exercised when using TempBond NE to cement crown copings to Straumann synOcta abutments in conditions where exposure to rapidly alternating extreme heat and cold is likely. The current study has shown TempBond NE to provide little resistance to copings lifting off abutments under such conditions.

Predictable cleaning of crown copings can be achieved with sandblasting abrasion using aluminium oxide particles to produce a coping intaglio that allows micromechanical retention of the proposed cement. Loss of crown coping intaglio occurs with repeated cleaning using this method.

Chapter 6 Conclusions

Within the limitations of the current in vitro conditions employed in this study, the retention of cast crown copings cemented to Straumann synOcta implant abutments with Panavia-F, KetacCem, and TempBond NE was significantly affected by cement type but not compressive cyclic loading.

Panavia-F demonstrated significantly greater mean retention values than both KetacCem and TempBond NE at each quantity of compressive cyclic loading. KetacCem and TempBond NE specimens provided relatively low and similar mean retention values at each level of compressive cyclic loading.

Limited validity of the findings relating to TempBond NE is possible as thermocycling had a marked effect on reducing coping retention.

All cement failure was by adhesion to the coping intaglio.

It would be of benefit to further investigate dental cements with various implant systems under validated standardized in vitro conditions. Future research should be mindful that most cements currently used in implant dentistry were initially developed for use with natural teeth. The development of a cement specifically for use in implant dentistry may be warranted. Until this time, clinicians and researchers alike will continue the debate over the ideal cement to retain crowns to implant abutments.

Bibliography

1728 Software systems. Right circular cone calculator and cone frustum calculator. 2006 Available from: http://www.1728.com (Accessed 3 Dec 2006).

3MESPE. 3MESPE KetacCem glass ionomer cement technical product profile. http://www.3mespe.pl/files/infotech/Ketac%20Cem_infotech.pdf (Accessed 26 Nov 2006).

Agar, J.R., Cameron, S.M., Hughbanks, J.C., Parker, M.H. Cement removal from restorations luted to titanium abutments with simulated subgingival margins. J Prosthet Dent 1997; 78(1): 43-47.

Akashia, A.E., Francischone, C.E., Tokutsune, E., da Silva, W. Jr. Effects of different types of temporary cements on the tensile strength and marginal adaptation of crowns on implants. J Adhes Dent. 2002; 4(4): 309-315.

Akca, K., Iplikcioglu, H., Cehreli, M.C. Comparison of uniaxial resistance forces of cements used with implant-supported crowns. Int J Oral Maxillofac Implants 2002; 17(4): 536-542.

Albrektsson, T., Wennerberg, A. The impact of oral implants – past and future, 1966-2042. J Can Dent Assoc 2005; 71(5): 327.

Alfaro, M.A., Papazoglou, E., McGlumphy, E.A., Holloway, J.A. Short-term retention properties of cements for retrievable implant-supported prostheses. Eur J Prosthodont Restor Dent. 2004; 12(1): 33-37.

Anderson D.J. Measurement of stress in mastication II. J Dent Res 1956; 35: 671-674.

Anderson, D.J., Picton, D.C. Masticatory stresses in normal and modified occlusion. J Dent Res 1958; 37: 312-317.

Andersson, B. Odman, P. Carlsson, L. Brånemark, P.I. A new Brånemark single tooth abutment: handling and early clinical experiences. Int J Oral Maxillofac Implants 1992; 7: 105-111.

Andersson, B., Odman, P., Lindvall, A., Brånemark, P.I. Cemented single crowns on osseointegrated implants after 5 years: results from a prospective study on CeraOne. Int J Prosthodont 1998; 11: 212-218.

Armellini, M.S., Bilko, R.D.T., Carmichael, D.M.D., von Fraunhofer, J.A. Screw-retained prosthesis for Straumann implant sites with limited interocclusal clearance. J Prosthodont 2006; 15(3): 198-201.

Ayad, M.F., Rosensteil, S.F., Hassan, M.M. Surface roughness of dentin after tooth preparation with different rotary instrumentation. J Prosthet Dent 1996; 75(2): 122-128.

Ayad, M.F., Rosenstiel, S.F., Salama, M. Influence of tooth surface roughness and type of cement on retention of complete cast crowns. J Prosthet Dent 1997; 77(2): 116-121.

Baldissara, P., Comin, G., Martone, F., Scotti, R. Comparative study of the marginal microleakage of six cements in fixed provisional crowns. J Prosthet Dent 1998; 80(4): 417-422.

Bayindir, F. Akyil, M.S., Bayindir, Y.Z. Effect of eugenol and non-eugenol containing temporary cement on permanent cement retention and microhardness of cured composite resin. Dent Mater J. 2003; 22(4): 592-599.

Becker, W., Becker, B.E. Replacement of maxillary and mandibular molar with single endosseous implant restorations: a retrospective study. J Prosthet Dent 1995; 74(1): 51-55.

Bernal, G., Okamura, M., Munoz, C.A. The effects of abutment taper, length and cement type on resistance to dislodgement of cement-retained, implant-supported restorations. J Prosthodont. 2003; 12(2): 111-5.

Binon, P.P. Evaluation of three slip fit hexagonal implants. Implant Dent 1996; 5: 235-248.

Brånemark, P.I. Introduction to osseointegration In: Brånemark, P.I., Zarb, G.A. Albrektsson, T. Tissue-integrated prostheses. Osseointegration in clinical dentistry. 3rd ed. Chicago, Ill: Quintessence, 1989. pg. 11-76.

Breeding, L.C., Dixon, D.L., Bogacki, M.T., Tietge, J.D. Use of luting agents with an implant system: part I. J Prosthet Dent 1992; 68(5): 737-741.

Bresciano, M., Schierano, G., Manzella, C., Screti, A., Bignardi, C., Preti, G. Retention of luting agents on implant abutments of different height and taper. Clin Oral Implants Res. 2005; 16(5): 594-598.

Carter, G.M., Hunter, K.M., Herbison, P. Factors influencing the retention of cemented implant-supported crowns. NZ Dent J 1997; 93(412): 36-38.

Carter, S.M., Wilson, P.R. The effect of die-spacing on crown retention. Int J Prosthodont 1996; 9(1): 21-29.

Chan, D.C.N., Wilson, A.H., Barbe, P. Cronin, R.J., Chung, C., Chung, K. Effect of preparation convergence on retention and seating discrepancy of complete veneer crowns. J Oral Rehab 2005; 32(1): 58-64.

Chee, W., Jivraj, S. Screw versus cemented implant supported restorations. Brit Dent J 2006; 201: 501-507.

Chee, W.W.L., Torbati, A., Albouy, J.P. Retrievable cemented implant restorations. J Prosthodont 1998; 7(2): 120-125.

Chu, K.M., Tredwin, C.J., Setchell, D.J., Hems, E. Effect of screw hole filling on retention of implant crowns. Eur J Prosthodont Restor Dent 2005; 13(4): 154-158.

Clayton, G.H., Driscoll, C.F., Hondrum, S.O. The effect of luting agents on the retention and marginal adaptation of the CeraOne implant system. Int J Oral Maxillofac Implants 1997; 12(5): 660-665.

Covey, D.A., Kent, D.K., St Germain, H.A Jr., Koka, S. Effects of abutment size and luting cement type on the uniaxial retention force of implant-supported crowns. J Prosthet Dent. 2000; 83(3): 344-348.

Craig, R.C. Craig's restorative dental materials. 12th ed. St Louis, Missouri: Mosby Elsevier; 2006.

Craig, R.G., Powers, J.M. Restorative Dental Materials. 10th ed. St Louis, Mo: Mosby; 2002. pg. 90-91.

Crim, G.A., Franklin, G. Microleakage: the effect of storage and cycling duration. J Prosthet Dent 1987; 57(5): 574-576.

De Gee, A.J., Pallav, P., Davidson, C.L. Effect of abrasion medium on wear of stress-bearing composites and amalgam in vitro. J Dent Res 1986; 65: 654-658.

Diaz-Arnold, A., Williams, W.V., Aguilino, S. Tensile strengths of three luting agents for adhesion fixed partial dentures. Int J Prosthodont 1989; 2: 115-122.

Dickson, G. Physical and chemical properties and wear. J Dent Res 1979; 58: 1535-1543.

Dixon, D., Breeding, L.C., Lily, K. Use of luting agents with an implant system: part II. J Prosthet Dent 1992; 68(6): 885-90.

Eames, W.B., O'Neal, S.J., Monteiro, J., Miller, C., Roan, J.D.,Cohen, K.S. Techniques to improve the seating of castings. J Am Dent Assoc 1978; 96: 432-437.

Eckert, S.E. Wollan, P.C. Retrospective review of 1170 endosseous implants placed in partially edentulous jaws. J Prosthet Dent 1998; 79(4): 415-421.

el Askery, A.S. Meffert, R.M., Griffin, T. Why do dental implants fail? Part I. Implant Dent 1999; 8: 173-185.

Engquist, B., Nilson, H., Astrand, P. Single-tooth replacement by osseointegrated Brånemark implants. A retrospective study of 82 implants. Clin Oral Implants Res 1995; 6: 238-245.

Esposito, M., Coulthard, P., Thomsen, P., Worthington, H.V. Interventions for replacing missing teeth: different types of dental implants. The Cochrane Database of Systemic Reviews 2005. Issue 1. Art. No.: CD003815.pub2. DOI: 10.1002/14651858.CD003815.pub2.

Fusayama, T., Ide, K., Hosoda, H. Relief of resistance of cement of full cast crowns. J Prosthet Dent 1964; 14(1): 95-106.

GaRey, D.J., Tjan, A.H., James, R.A., Caputo, A.A. Effects of thermocycling, load-cycling, and blood contamination on cemented implant abutments. J Prosthet Dent 1994; 71(2): 124-132.

Gilboe, D., Teteruck, W. Fundamentals of extracoronal tooth preparation. Part I. Retention and resistance form. J Prosthet Dent 1974; 32(6): 651-656.

Goodacre, C.J., Kan, J.Y., Rungcharassaeng, K. Clinical complications of osseointegrated implants. J Prosthet Dent 1999; 81(5): 537-552.

Gorodovsky, L., Sergio, E., Zidan, O. Retentive strength, disintegration, and marginal quality of luting cements. J Prosthet Dent 1992; 68(2): 269-274.

Graf, H. Bruxism. Dent Clin North Am. 1969; 13: 659-665.

Graf, H. Occlusal forces during function. In: Rowe, N.H. Occlusion: research on from and function. University of Michigan, Ann Arbor; 1975. pg. 90-111.

Graf, H., Grassl, H., Aeberhard, H.J. A method for the measurement of occlusal forces in three directions. Helv. Odont. Acta 1974; 18: 7-11.

GraphPad software. Post test calculator. Updated Dec 2004. Available from: http://graphpad.com/welcome.htm (Accessed 2 Dec 2006).

Guichet, D.L., Caputo, A.A., Choi, H. et al. Passivity of fit and marginal opening in screw- or cement-retained implant fixed partial denture designs. Int J Oral Maxillofac Implants 2000; 15: 239-246.

Harrison, A., Lewis, T.T. The development of an abrasion testing machine for dental materials. J Biomed Mater Res 1975; 9(3): 341-353.

Helkimo, E., Ingervall, B. Bite force and functional state of the masticatory system in young men. Swed Dent J. 1978; 2: 167-175.

Hernry, P.J., Laney, W.R., Jemt, T. et al. Osseointegrated implants for single-tooth replacement: a prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1996; 11: 450-455.

Jorgensen, K.D. The relationship between retention and convergence angle in cemented veneer crowns. Acta Odontol Scand 1955; 13: 35-40.

Kaar, D., Oshida, Y., Andres, C.J., Barco, M.T., Platt, J.A. The effect of fatigue damage on the force required to remove a restoration in a cement-retained implant system. J Prosthodont 2006; 15: 289-294.

Kaidonis, J.A., Richards, L.C., Townsend, G.C., Tansley, G.D. Wear of human enamel: a quantitative in vitro assessment. J Dent Res 1998; 77(12): 1983-1990.

Kakigawa, H., Yokoyama, Y., Tajima, K. et al. Effect of repeated loading on retention of the crown fixed with adhesive resin cements. In: Okabe, T., Takahashi, S. eds. Transactions of International Congress on Dental Materials. Honolulu: The Academy of Dental Materials and the Japanese Society of Dental Materials and Devices. 1989; 6.

Kanomi, R. Mini-implant for orthodontic anchorage. J Clin Orthod 1997; 31: 763-767.

Kaufman, E., Cohelo, D., Colin, L. Factors influencing the retention of cemented gold castings. J Prosthet Dent 1961; 11(3): 487-502.

Kelly, R. Evidence-based decision making: guide to reading the dental materials literature. J Prosthet Dent 2006; 95(2): 152-160.

Kent, D.K., Koka, S., Banks, S.B., Beatty, M.W. Factors influencing retention of a CeraOne gold cylinder. Implant Dent. 1996; 5(2): 96-99.

Kent, D.K., Koka, S., Froeschle, M.L. Retention of cemented implant-supported restorations. J Prosthodont 1997; 6(3): 193-196.

Kerby, R. McGlumphy, E.A. Holloway, J. Some physical properties of implant abutment luting cements. Int J Prosthodont 1992; 5(4): 321-325.

Kerr International. Temporary materials – TempBond and TempBond NE Product Summary. (3/1/01) Kerr International. Kerr, Romulus, Michigan.

Koka, S., Ewoldsen, N.O., Dana, C.L., Beatty, M.W. The effect of cementing agent and technique on the retention of a CeraOne gold cylinder: a pilot study. Implant Dent 1995; 4: 32-35.

Kuraray Dental. Dental products. Product overview – cements. Available from: http://www.kuraray-dental.de/eng/overview_cements.html (Accessed 26 Nov 2006).

Kuraray Dental. Panavia-F technical information. Panavia-F dual cure dental adhesive system. (03/99) Osaka, Japan.

Leempoel, P., Lemmens, L. Snoek, P. van'tHof, M. The convergence angle of tooth preparations for complete crowns. J Prosthet Dent 1987; 58(4): 414-416.

Leinfelder, K.F., Beaudreau, R.W., Mazer, R.B. An in vitro device for predicting clinical wear. Quintessence International 1989; 20(10): 755-761.

Levine, R.A., Clem D.S. 3rd, Wilson T.G.Jr., et al. Multicenter retrospective analysis of the ITI implant system used for single tooth replacements: result of loading for 2 or more years. Int J Oral Maxillofacial Implants 1999; 14: 516-520.

Lewinstein, I., Fuhrer, N., Gelfand, K. et al. Retention, marginal leakage and cement solubility of provisional crowns cemented with temporary cement containing stannous fluoride. Int J Prosthodont 2003; 16: 189-193.

Lindquist, T.J., Connolly, J. In vitro microleakage of luting cements and crown foundation material. J Prosthet Dent 2001; 85(3): 292-298.

Lugassy, A.A., Greener, E.H. An abrasion resistance study of some dental resins. J Dent Res 1972; 51: 967-972.

Luthra, R. A comparative study on the retention of full coverage cast crowns cemented with zinc phosphate cement with and without die relief agent on prepared human teeth. J Indian Prosthodont Soc 2005; 5: 82-85.

Lutz, F., Phillips, R.W., Roulet, J.F., Setcos, J.C. In vivo and in vitro wear of posterior composites. J Dent Res 1984; 63: 914-920.

Maeyama, H., Sawase, T., Jimbo, R., Kamada, K., Suketa, N., Fukui, J., Atsuta, M. Retentive strength of metal copings on prefabricated abutments with five different cements. Clin Implant Dent Relat Res. 2005; 7(4): 229-34.

Mansour, A., Ercoli, C., Graser, G., Tallents, R., Moss, M. Comparative evaluation of casting retention using the ITI solid abutment with six cements. Clin Oral Impl Res 2002; 13: 343-348.

Markowitz, K., Moynihan, M., Liu, M., Kim, S. Biologic properties of eugenol and zinc oxide eugenol. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1992; 73: 729-737.

Matsumura, H., Yoshida, K., Tanaka, T. Atsuta, M. Adhesive bonding of titanium with a titanite coupler. J Dent Res 1990; 69: 1614-1616.

Matthews, M.F., Breeding, L.C., Dixon, D.L., Aquilino, S.A. The effect of connector design on cement retention in an implant and natural tooth-supported fixed partial denture. J Prosthet Dent 1991; 65(6): 822-827.

McGlumphy, E.A., Papazoglou, E., Riley, R. The combination implant crown: a cement and screw retained restoration. Compend Contin Educ Dent 1992; 13: 34-41.

McGlumpy E.A., Mendel, D.A. Holloway, J.A. Implant screw mechanics. Dent Clin North Am 1998; 42: 71-89.

Michalakis, K.X., Hirayama, H., Garefis, P.D. Cement-retained versus screw-retained implant restorations: a critical review. Int J Oral Maxillofac Implants 2003; 18: 719-728.

Michalakis, K.X., Pissiotis, A.L., Hirayama, H. Cement failure loads of 4 provisional luting agents used for the cementation of implant-supported fixed partial dentures. Int J Oral Maxillofac Implants 2000; 15: 545-549.

Millstein, P.L., Hazan, E., Nathanson, D. Effect of aging on temporary cement retention in vitro. J Prosthet Dent 1991; 65(6): 768-771.

Mount, G.J. Decription of glass-ionomer cements. In: An atlas of glass-ionomer cements: a clinician’s guide. Hong Kong: Imago Publishing Ltd.; 1990. pg. 1-25.

Nakamura, K., Takatsu, T., Hosoda, H. Retentive characteristics and durability of adhesive resin luting cements for internal inlays. In: Okabe, T. Takahashi, S. eds. Transactions of International Congress on Dental Materials. Honolulu: The Academy of Dental Materials and the Japanese Society of Dental Materials and Devices; 1989. pg. 5.

Olin, P.S., Rudney, J.D., Hill, E.M. Retentive strength of six provisional dental cements. Quint Int 1990; 21: 197-200.

Olio, G., Jorgensen, K.D. The influence of surface roughness on the retentive ability of two dental luting cements. J Oral Rehabil 1978; 5: 377-389.

Ongthiemsak, C., Mekayarajjananonth, T., Winkler, S., Boberick, K.G. The effect of compressive cyclic loading on retention of a temporary cement used with implants. J Oral Implantol. 2005; 31(3): 115-20.

Outhwaite, S.W., Twiggs, C.W., Fairhurst, C.W., King, G.E. Slots vs pins: a comparison of retention under simulated chewing stresses. J Dent Res 1982; 61: 400-402.

Pan, Y.H., Lin, C.K. The effect of luting agents on the retention of dental implant-supported crowns. Chang Gung Medical Journal 2005; 28(6): 403-410.

Pan, Y-H., Ramp, L.C., Lin, C-K., Liu, P-R. Retention and leakage of implant-supported restorations luted with provisional cement: a pilot study. J Oral Rehab 2007; 34(3): 206-212.

Parein, A.M., Eckert, S.E., et al. Implant reconstruction in the posterior mandible: a long-term retrospective study. J Prosthet Dent 1997; 78(1): 34-42.

Passon, C., Lambert, R.H., Lambert, R.L., Newman, S. The effect of multiple layers of die spacer on crown retention. Oper Dent 1992; 17: 42-49.

Pauletto, N. Lahiffe, B.J., Walton, J.N. Complications associated with excess cement around crown on osseointegrated implants: a clinical report. Int J Oral Maxillofac Implants 1999; 14(6): 865-868.

Piemjai, M. Effect of seating force, margin design, and cement on marginal seal and retention of complete metal crowns. Int J Prosthodont 2001; 14(5): 412-416.

Piwowarczyk, A., Lauer, H.C., Sorensen, J.A. Microleakage of various cementing agents for full cast crowns. Dent Mater 2005; 21: 445-453.

Rajan, M., Gunaseelan, R. Fabrication of a cement- and screw-retained implant prosthesis. J Prosthet Dent 2004; 92(6): 578-580.

Ramp, M.H., Dixon, D.L., Ramp, L.C., Breeding, L.C., Barber, L.L. Tensile bond strengths of provisional luting agents used with an implant system. J Prosthet Dent 1999; 81(5): 510-514.

Rosensteil, S.F., Land, M.F., Fujimoto, J. Principles of tooth preparation. In: Contemporary fixed prosthodontics. 2nd ed. St Louis, Missouri: Mosby; 2001. pg. 135-167.

Rossomando, K.J., Wendt, S.L.Jr. Thermocycling and dwell times in microleakge evaluation for bonded restorations. Dent Mater 1995; 11: 47-51.

Roulet, J.F. Degradation of dental polymers. Basel, Switzerland, Korger Press; 1987. pg. 114-159.

Schneider, R.L. Evaluation of the retention of castings to endosseous implants. J Prosthet Dent 1987; 58(1): 73-78.

Shabanian, M., Richards, L.C. In vitro wear rates of materials under different loads and varying pH. J Prosthet Dent 2002; 87(6): 650-656.

Singer, A.S., Serfaty, V. Cement-retained implant-supported fixed partial dentures; a 6-month to 3-year follow-up. Int J Oral Maxillofac Implants 1996; 11: 645-649.

Smith, B.H., McCabe, J.F. Three laboratory methods for evaluating wear of restorative materials. J Dent Res 1987; 1: 478 (AADR abstr No. 60).

Soderholm, K.J. Degradation of glass filler in experimental composites. J Dent Res 1981; 60: 1867-1875.

Sorensen, J. The lava all-ceramic system: CAD / CAM zirconia prosthodontics for the 21st century. Australian Dental Practice 2006; Jan / Feb: 168-172.

Squier, R.S., Agar, J.R., Duncan, J.P., Taylor, T.D. Retentiveness of dental cements used with metallic implant components. Int J Oral Maxillofac Implants 2001; 16(6): 793-798.

Straumann International. Straumann Prosthetics. Crown and bridge restorations with the synOcta prosthetic system. 04/05. Available from: http://www.straumann.com (Accessed 15 July 2006).

Suzuki, S., Leinfelder, K.F. Localised wear and marginal integrity of posterior resin composites. Am J Dent 1999; 6: 199-203.

Taylor, T.D., Agar, J.R., Vogiatzi, T. Implant prosthodontics: current perspectives and future directions. Int J Oral Maxillofac Implants 2000; 15: 66-75.

Tillitson, R.G., Craig, R.G., Peyton. Friction and wear of restorative dental materials. J Dent Res 1971; 50: 149-154.

Uchiyama, Y. Clinical study on the retentive force of adhesive resins. J Jpn Prosthodont Soc 1986; 30: 198-204.

Ulrich, R., Műhlbradt, L., et al. Qualitative mechanoperception of natural teeth and endosseous implants. Int J Oral Maxillofac Implants 1993; 8: 173-178.

University of Michigan. Biomaterials Properties Database. (April 1996). Available from: http://www.lib.umich.edu/dentlib/Dental_tables (Accessed 6 April 2006).

Vermilyea, S.G., Kuffler, M.J., Huget, E.F. The effects of die relief agent on the retention of full coverage castings. J Prosthet Dent 1983: 50(2): 207-210.

Vigolo, P., Givani, A., Majzoub, Z., Cordioli, G., Cemented versus screw-retained implant-supported single-tooth crowns: a 4-year prospective clinical study. Int J Oral Maxillofac Implants 2004; 19(2): 260-265.

Vigolo, P., Majzoub, Z., Cordioli, G.P. Measurement of the dimensions and abutment rotational freedom of gold machined 3i UCLA-type abutments in the as-received condition, after casting with a noble metal alloy and porcelain firing. J Prosthet Dent 2000; 84(5): 548-553.

Wacker, D.R., Tjan, A.H.L. Effect of variation in powder-to liquid ratio of zinc phosphate cement on the retention of posts. J Prosthet Dent 1988; 60(1): 49-52.

White, S.N., Furuichi, R., Kyomen, S.M. Microleakage through dentine after crown cementation. J Endod 1995; 21: 9-12.

Wilson, A.D., McLean, J.W. Glass-ionomer cement. London: Quintessence; 1988.

Wilson, A.H., Chan, D.C.N. The relationship between preparation convergence and retention of extracoronal retainers. J Prosthodont 1994; 3(2): 74-78.

Winkler, S., Ring, K., Ring, J., Boberick, K. Implant screw mechanics and the settling effect: overview. J Oral Implantol. 2003; 29: 242-245.

Wu, J.C., Wilson, P.R. Optimal cement space for resin luting cements. Int J Prosthodont 1994; 7(3): 209-215.

Zarb, G., Schmitt, A. Edentulous predicament. I: a prospective study of the effectiveness of implant supported fixed prostheses. J Am Dent Assoc 1996; 127: 59-65.

Zarb, G.A., Schmitt, A. The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study. Part 1: surgical results. J Prosthet Dent 1990; 63(4): 451-457.

SECTION 2

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Retention of cast crown copings cemented to implant abutments

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Abstract

Background

The cementation of crowns to dental implant abutments is an accepted form of crown retention that requires consideration of the properties of available cements within the applied clinical context. Dental luting agents are exposed to a number of stressors that may reduce crown retention in vivo, not the least of which is occlusal loading. This study investigated the influence of compressive cyclic loading on the physical retention of cast crown copings cemented to implant abutments.

Method

Cast crown copings were cemented to Straumann synOcta titanium implant abutments with three different readily used and available cements. Specimens were placed in a humidifier, thermocycled and subjected to one of four quantities of compressive cyclic loading. The uniaxial tensile force required to remove the cast crown copings was then recorded.

Results

The mean retention values for crown copings cemented with Panavia-F cement were statistically significantly greater than both KetacCem and TempBond non–eugenol cements at each compressive cyclic loading quantity. KetacCem and TempBond non–eugenol cements produced relatively low mean retention values that were not statistically significantly different at each quantity

of compressive cyclic loading. Compressive cyclic loading had a statistically significant effect on Panavia-F specimens alone, but increased loading quantities produced no further statistically significant difference in mean retention.

Conclusions

Within the limitations of the current in vitro conditions employed in this study, the retention of cast crown copings cemented to Straumann synOcta implant abutments with a resin, glass-ionomer and temporary cement was significantly affected by cement type but not compressive cyclic loading. Resin cement is the cement of choice for the definitive non-retrievable cementation of cast crown copings to Straumann synOcta implant abutments out of the three cements tested.

Introduction

Dental implants are an effective and popular option for replacing the single missing tooth and form an important part of mainstream dental practice today. Their use often represents a better alternative over traditional options of tooth replacement. The selection of the method of crown retention presents the clinician with a treatment planning challenge that involves recognition of the drivers of the desired treatment outcome. Amid other factors, aspects of retrievability versus aesthetics have largely been considered in deciding whether crowns should be screw-retained or cement-retained.

The option to cement crowns to implant abutments may be elected, or contrastingly forced upon the clinician due to implant positioning. The choice of cement must subsequently be considered. The majority of cements used in implant dentistry at present have been designed for use with crowns luted to natural teeth. In cementing crowns to implant abutments, luting agents are required to act in a different manner to oppose two metallic surfaces whereas with natural teeth one surface normally consists of enamel, dentine or restorative material.

In implant dentistry, careful consideration of the choice of cement should include reference to the abutment and crown specifications, opposing surface characteristics, desired retention and individual properties of the preferred cement. Different types of cements provide different levels of crown retention.[1,2,3]

The degree of crown retrievability has been linked to the use of temporary and permanent cements,[4,5,6,7] although variations exist in the quantity of retention provided by the same types of cements used with different implant systems and under different in vitro conditions.[4,5,6,8,9,10,11,12]

A multitude of factors in the oral environment including temperature changes, salivary pH and occlusal forces affect the properties and retention of dental cements. In vitro conditions may be used to simulate some influential aspects of the oral environment in order to obtain evidence of the potential performance of materials in vivo. Compressive cyclic loading is one such condition that may be employed to simulate occlusal stresses encountered in the oral environment and may affect the retentive properties of dental cements.

Resin, glass-ionomer and zinc oxide cements are some of the more readily available and widely used materials for traditional crown and bridge procedures. These types of cements are now employed clinically in cementing crowns to implant abutments. Subsequently, research into their properties and performance when used with implant systems is required to provide recommendations on their use.

The purpose of this study was to investigate the influence of compressive cyclic loading on the physical retention of cast crown copings cemented to Straumann synOcta implant abutments (Straumann, Basel, Switzerland) using

Panavia-F (Kuraray Medical, Osaka, Japan), KetacCem (3M ESPE, St Paul, Minnesota) and TempBond non-eugenol (TempBond NE) (Kerr, Romulus, Michigan) cements.

Two null hypotheses were tested

$H_0$1: There is no influence of compressive cyclic loading on the physical retention of cast crown copings cemented to Straumann synOcta implant abutments with Panavia-F, KetacCem, and TempBond NE

$H_0$2: There is no difference in the retention provided by Panavia-F, KetacCem, and TempBond NE for cast crown copings cemented to Straumann synOcta implant abutments

Method

Twelve Straumann regular neck synOcta titanium abutments (height 5.5mm and 8º taper) with abutment screws (abutment 048.605) and corresponding stainless steel laboratory implant analogs of length 12mm (analog 048.124) were used (Straumann, Basel, Switzerland) (Figure 1).

<< Insert Figure 1 here >>

Crown copings were constructed by the same operator by initially waxing a flattened 6mm x 6mm occlusal platform of 1.2mm thickness to a prefabricated plastic coping of height 7mm (plastic coping 048.605) (Straumann, Basel, Switzerland). The waxed patterns connected to plastic burnout copings were sprued, invested with Speedvest (Argibond, Germany) and cast with Matticraft-C (Matticraft, Johnson Matthey, United Kingdom), a 51.5% gold / 38.3% palladium alloy, using a vacuum casting machine (Easycast, Zubler, Germany). Using calipers and 16x magnification, all cast copings were confirmed for accuracy and fit. Each coping was numbered 1 to 12 for easy identification during testing and randomly assigned to correspondingly numbered abutments. The occlusal platform was flattened with silicone dioxide points so it aligned parallel to the horizontal bench surface, and finished with rubber wheels. The intaglio of all copings was finally briefly sandblasted with 110µm aluminium oxide particles (Renfert, Hilzingen, Germany) at a pressure of 2 barometers, and dried with compressed air before initial testing.

To facilitate experimental testing, twelve acrylic (Orthoplast, Vertex-Dental, Netherlands) housing bases with hollowed centre sections were constructed using a single split silicone mould and numbered 1 to 12. From the materials readily available, the modulus of elasticity of acrylic (1.6GPa) most closely approximated that of cancellous bone (0.49GPa) in which dental implants would normally function.[13]

Laboratory analogs were randomly paired with numbered abutments (and cast crown copings) and connected via the encased abutment screw with finger pressure only. Using a dental surveyor and a connected prefabricated custom stainless steel aligning tip inserted into the abutment screw access channel, laboratory analogs attached to abutments were aligned vertically and centrally positioned within the hollowed centre section of the acrylic housing base. The acrylic housing base was filled with acrylic (Orthoplast, Vertex-Dental, Netherlands) up to the red line of the laboratory analog and allowed to self cure.

The implant abutment screws were torqued to 35Ncm using the SCS screwdriver and ratchet with torque control device (reference 046.049) (Straumann, Basel, Switzerland) as recommended by the manufacturer. Screws were subsequently retightened to 35Ncm after 10 minutes to compensate for the settling effect.[14] All abutment screw access channels were filled with two compacted cotton pellets and sealed flush with the occlusal surface with softened and compacted modeling wax. Cast crown copings were positioned onto correspondingly numbered mounted laboratory analog / implant abutment complexes (Figure 2).

<< Insert Figure 2 here >>

Three commonly used and readily available luting agents representative of their class were tested: Panavia-F (Kuraray Medical, Osaka, Japan), a dual curing resin based cement system (with fluoride release) for metal, composite and silanated porcelain restorations; KetacCem (3M ESPE, St Paul, Minnesota), a permanent glass ionomer luting cement in powder / liquid form; and TempBond NE (non-eugenol) (Kerr, Romulus, Michigan), a non-eugenol temporary cement for trial cementing restorations or cementing temporary crowns and bridges that will not inhibit the polymerization of resin cements and acrylic temporaries, but with the same retentive properties as TempBond. The cementation protocol for the three cements was in accordance with each manufacturer’s instructions for mixing time, mixing conditions and cement component ratios.

The casting intaglio was completely covered with luting agent and seated onto its paired abutment with firm finger pressure for 10 seconds, followed by a 5kg axial compressive load for 5 minutes. Excess cement was removed using a Hollenback carver. Specimens were examined visually to confirm complete seating of the coping onto the abutment, referenced by marginal integrity and the absence of marginal space.

Immediately after cementation, and in accordance with ISO standard ISO/TR 11405:1994(E) for the testing of dental materials, specimens were placed in a humidifier at 100% humidity and 37ºC for 24 hours, then subjected to 500 cycles of thermocycling between 5ºC (+/- 2ºC) and 55ºC (+/-2ºC) with a 20 second dwell time in each water bath, and 5-10 second interlude between water baths.

Specimens within each cement group were subsequently subjected to one of four quantities of compressive cyclic loading in a tooth wear machine to simulate average human mastication (Figure 3). Specimens received either 0 compressive cycles (baseline), 192 cycles to simulate one week, 5,000 cycles to simulate six months, or 10,000 cycles to simulate one year of average human masticatory function.[15,16] A rounded stainless steel stylus delivered a 5kg total load at 80 cycles / minute at room temperature.

<< Insert Figure 3 here >>

A Universal Testing Machine (Hounsfield H50KM, Hounsfield Testing Equipment, United Kingdom) with a load cell of 2000N was used to apply a uniaxial tensile force to the copings at a cross-head speed of 1mm/min, and the force at which cement failure occurred was recorded in Newtons.

The experimental procedure was repeated eight times for each specimen. The wax seal of the abutment screw access channels was repaired between testing rounds. The same crown coping was used with the same abutment complex within the same cement group to eliminate the possibility of surface cross contaminations from different cements and avoid interactions between material residues.[17] Specimens were rotated between quantities of compressive cyclic loading to ensure even distribution of load cycling over the eight rounds of testing. Abutments and copings were examined under scanning electron microscopy after rounds one, five and eight of testing.

Crown copings were cleaned between rounds of testing by short duration sandblasting with aluminium oxide 110µm particles (Renfert, Hilzingen, Germany) at a pressure of 2.5 barometers and dried using compressed air.[3,9,12,18,19,20,21] Abutments were cleaned using glass bead abrasion (ArgiBond Dental Laboratory Supplies, Cheltenham, Victoria) at a pressure of one barometer for 5-10 seconds, then wiped with gauze and dried using compressed air. Sixteen times magnification was used to ensure the abutment and coping surface was free of residual cement.

A two-way without replication ANOVA test was used to determine the effect of cement type and compressive cyclic loading on crown coping retention. Post tests between all comparable pairs of mean values were conducted using the Bonferroni correction to adjust for multiple comparisons.[22]

A pilot study using one specimen excluded from the main study was conducted to confirm all experimental stages could be completed, the proposed cleaning procedure was effective and specimens could be reused intact.

Results

Table 1 presents summary data for each tested cement (n=8). The surface area of the abutment was calculated[23] (65.9mm^2) and mean values converted to megapascals to permit interexperimental comparison (Table 1). Figure 4 provides a comparison of the mean retention values with standard deviation bars at each quantity of compressive cyclic loading for all cements.

<< Insert Table 1 here >>

<< Insert Figure 4 here>>

Two-way without replication ANOVA analysis of results demonstrated a statistically significant effect of cement type (p=0.0011), but no statistically significant effect of compressive cyclic loading (p=0.6182) (Table 2).

<< Insert Table 2 here >>

Post test analysis (p<0.05) conducted between all comparable pairs of mean values[22] demonstrated a statistically significant difference between Panavia-F loaded and unloaded groups. Increased loading quantities produced no further statistically significant difference of mean retention within the Panavia-F group alone. Panavia-F specimens showed statistically significantly greater mean retention values than both KetacCem and TempBond NE specimens at each quantity of compressive cyclic loading (0, 192, 5000, 10000 cycles). The mean retention values for KetacCem and TempBond NE cements were not statistically significantly different at each quantity of compressive cyclic loading.

Further data analysis revealed that, over the course of testing, five individual retention values lay outside two standard deviations and were subsequently removed form the data set as they were thought to possibly represent deviations from normal distribution probability. With these values removed, new mean values with standard deviations were recalculated but subsequent ANOVA analysis and post tests[22] revealed no further statistically significant effects compared to the initial reported data.

Components remained structurally intact throughout testing and no abutment screw loosening was detected following the completion of testing. Analysis of the round by round total testing values and cement-specific total testing values revealed no obvious effect on retention values of re-using the same components for each round of testing with each cement. Scanning electron microscope analysis revealed no apparent differences in cement appearances between specimen loading regimes.

In considering the results, $H_0 1$ can be accepted and $H_0 2$ rejected.

Discussion

All tested cements demonstrated adhesive failure to the crown coping surface. The rough sandblasted abutment intaglio provided greater micromechanical retention than the smooth machined titanium abutment surface, hence the cement adhered to the abutment. Clinically, cement that adheres to the abutment may be difficult to remove without damaging the abutment surface and therefore this mode of failure is of benefit to the clinician. Of the three tested cements, Panavia-F was the most resistant to remove from crown copings following testing, and this should be considered from the clinical perspective of excess cement removal. In an in vitro study of glass ionomer, resin and zinc phosphate cement removal from restorations luted to titanium abutments with simulated subgingival margins, resin cement was proven to be the most difficult to remove when excess was expelled subgingivally.[24] Periodontal surgery may be required to remove residual excess cement.[25]

Panavia-F specimens demonstrated significantly greater mean retention values than both KetacCem and TempBond NE with each quantity of compressive cyclic loading (Figure 4). Resin cements are regarded as the strongest luting agents among available cements. The results suggested minimal crown coping retention was lost following initial compressive cyclic loading with Panavia-F (Figure 4). Even though alloy primer was not used in the current study, Panavia-F cement itself contains a phosphate monomer, 10-methacryloyloxydecyl dihydrogen phosphate (MDP) (also present in alloy primer), which facilitates chemical bonding to non-precious metals.[26] Panavia-F specimens therefore benefited from chemical adhesion via MDP to the non-precious metal oxide components of both the crown coping (indium 8%, gallium 2%) and the titanium abutment (predominantly titanium dioxide) which KetacCem and TempBond NE specimens lacked.

Although KetacCem specimens provided greater mean retention values than TempBond NE, both cements were not statistically significantly different at each level of compressive cyclic loading. This may come as some surprise to clinicians in considering the widespread use of glass ionomer cements for the cementation of natural tooth crowns. The lack of tooth structure to apply 10% polyacrylic acid for 15 seconds to remove the smear layer and enhance chemical bonding was most definitely a limiting factor in the retentive ability of KetacCem in this study.

On subjecting TempBond NE specimens to thermocycling, crown copings visibly lifted off their abutments but were maintained within the experiment and tested as normal (Figure 5). No detectable marginal gap was detected with Panavia-F and KetacCem specimens.

<< Insert Figure 5 here >>

Different coefficients of thermal expansion of the materials, a poor marginal seal provided by TempBond NE and its high solubility in water may play some role in explaining this observation. It has been established that zinc oxide / eugenol cement (TempBond) has high solubility in direct contact with water and also requires sufficient time for a complete setting reaction in order to maximize its retention,[3,9,27,28] however the same has not been reported for TempBond NE. Further research regarding the precise mechanism responsible for this observation with TempBond NE is required.

Caution should therefore be exercised in interpreting the results obtained with TempBond NE specimens. In each round of testing, the coping that received no compressive cyclic loading and was not compressed back onto its abutment demonstrated the lowest retention value (Table 1). With increased quantities of compressive cyclic loading, increased mean retention values were observed (Table 1). The retention of copings that underwent compressive cyclic loading, although very low, was more likely a measure of the duration of time for which copings were compressed back onto their abutments with compressive cyclic loading.

Previous studies have investigated the retention of various dental cements with various implant systems[3,4,5,6,11,29] but few have looked specifically at the effect of varying compressive cyclic loading within the same context as the current study.[9,10] In one study, compressive cyclic loading resulted in a statistically significant loss of retention of gold castings cemented to Zimmer abutments (Zimmer Dental, Carlsbad, California) with TempBond.[9] Increased loading quantities produced no further significant loss of crown coping retention[9] which is in agreement with the current study's findings for Panavia-F. Contrastingly, in a separate study, compressive cyclic loading demonstrated a statistically insignificant effect on gold cylinders cemented to CeraOne abutments with TempBond.[10]

Studies specific to the investigation of the retentiveness of TempBond NE with implant systems were limited in number.[4,8] The mean retention values for TempBond NE in the current study (4.9N – 20N) were notably lower than those of other comparative studies that investigated the retention of crown copings provided by either TempBond or TempBond NE.[4,5,8,9,11,12,30] In these comparative studies, inconsistent combinations of in vitro conditions were applied to various implant systems. The effect of thermocycling alone appeared to considerably reduce TempBond NE coping retention in the current study, and may be the subject of further investigation.

The differences in retention values between studies can predominantly be explained by different implant systems and components but also different combinations of in vitro experimental conditions, including (where applied) the more severe compressive cyclic loading conditions of comparative studies that may stress and fatigue the cement more resulting in reduced cement retentiveness. Crown coping retention is multifactorial in nature and requires consideration of preparation taper, cervico-occlusal wall height and surface finish of the preparation and casting. In some comparative studies, abutments contained retentive grooves[9] while others provided relatively smooth surfaces.[4] Studies involving various abutment designs have shown greater occluso-cervical dimension and less occlusal convergence provided higher tensile resistance to coping dislodgement.[21,31]

The use of abutments with various dimensions requires the additional expression of cement retention values in universal units of Megapascals (conveying force per unit area). The majority of previous studies conveyed findings in Newtons or kilograms, but further conversion to megapascals was not possible if the crown coping surface area was not provided. Standardized experimental conditions and reporting are required for cement testing with implant components if more than individual experimental results are to be considered and more accurate and meaningful interexperimental comparisons permitted.

Previous studies found different cements responded in different manners to filled or unfilled abutment screw access channels.[8,32,33] The recommendation provided by Straumann was to seal the abutment screw access channel with wax or gutta percha prior to crown cementation.[34] It may be possible that filling abutment screw access channels with composite resin, and indeed some other materials, affects crown coping retention. Filling the abutment screw access channel with a rigid material may prevent cement escape into the internal abutment cavity, thus creating a greater internal cement pressure between the coping intaglio and abutment forcing cement into the micromechanical irregularities of the crown coping intaglio under greater pressure.[32] There may also be potential for a chemical bond between the abutment screw access channel filling material (eg. composite resin) and compatible luting cement that may aid in crown coping retention.

This in vitro study used non-validated simulations of the oral environment that were not able to accurately reproduce all oral factors such as temperature changes, salivary pH, salivary buffering capacity and saliva flow rate. Clinical evidence from randomized controlled trials remains the highest source of evidence. The clinical relevance of the findings from the current study rests on the validation of in vitro conditions accurately simulating the complex oral environment.

The number of compressive cycles and applied load used in this study were smaller than other studies,[6,9,10] although great variation in the estimation of numbers of cycles that equate to average human daily, weekly and yearly masticatory function exists.[15,16,35] Chewing rate is subjective and varies from person to person and may be related to the type of food; it also varies within the same person. No known study has validated this due to apparent difficulties in ethics and measurement.

Uniaxial tensile testing was employed in the current study as it permitted comparison with previous investigations of a similar nature.[4] A purely tensile test may not represent the clinical stresses where other non-axial forces may contribute to crown de-cementation.[10]

The range of retention values and standard deviations in the current study were high. This has been noted and discussed in other studies of this nature and may be related to difficulties in study design (including small sample sizes), construction and testing variations and the relative unpredictability and sensitivity of cements.[4,7,29] The standard deviations for KetacCem specimens that received 0 and 192 compressive cycles were larger than the mean value (Table 1, Figure 4). A greater sample size and new components for each round of testing may reduce the standard deviations.

Further research regarding cemented implant abutment-retained crowns may investigate dental cements with various implant systems under validated, standardized in vitro conditions. Future research should be mindful that most cements currently used in implant dentistry were initially intended for use with natural teeth. The development of cements specifically for use in implant dentistry may be warranted. Alternatively, dental cements may continue to be selected on a case-by-case basis according to individual cement advantages and the anticipated requirement for crown retrievability.

Conclusions

Within the limitations of the current in vitro conditions employed in this study, the retention of cast crown copings cemented to Straumann synOcta implant abutments with a resin, glass-ionomer and temporary cement was significantly affected by cement type but not compressive cyclic loading. Somewhat surprisingly, glass-ionomer cement provided only marginally more retention than the temporary cement. Resin cement is the cement of choice for the definitive non-retrievable cementation of crown copings to Straumann synOcta implant abutments out of the three cements tested.

Acknowledgement

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References

1. Clayton GH, Driscoll CF, Hondrum SO. The effect of luting agents on the retention and marginal adaptation of the CeraOne implant system. Int J Oral Maxillofac Implants 1997;12:660-665.

2. Carter GM, Hunter KM, Herbison P. Factors influencing the retention of cemented implant-supported crowns. NZ Dent J 1997;93:36-38.

3. Alfaro MA, Papazoglou E, McGlumphy EA, Holloway JA. Short-term retention properties of cements for retrievable implant-supported prostheses. Eur J Prosthodont Restor Dent 2004;12:33-37.

4. Mansour A, Ercoli C, Graser G, Tallents R, Moss M. Comparative evaluation of casting retention using the ITI solid abutment with six cements. Clin Oral Impl Res 2002;13:343-348.

5. Akca K, I·plikçiog˘lu H, Cehreli MC. Comparison of uniaxial resistance forces of cements used with implant-supported crowns. Int J Oral Maxillofac Implants 2002;17:536-542.

6. Pan YH, Lin CK. The effect of luting agents on the retention of dental implant-supported crowns. Chang Gung Medical Journal 2005;28:403-410.

7. Squier RS, Agar JR, Duncan JP, Taylor TD. Retentiveness of dental cements used with metallic implant components. Int J Oral Maxillofac Implants 2001;16:793-798.

8. Kent DK, Koka S, Froeschle ML. Retention of cemented implant-supported restorations. J Prosthodont 1997;6:193-196.

9. Ongthiemsak C, Mekayarajjananonth T, Winkler S, Boberick KG. The effect of compressive cyclic loading on retention of a temporary cement used with implants. J Oral Implantol. 2005;31:115-20.

10. Kaar D, Oshida Y, Andres CJ, Barco MT, Platt JA. The effect of fatigue damage on the force required to remove a restoration in a cement-retained implant system. J Prosthodont 2006;15:289-294.

11. Ramp MH, Dixon DL, Ramp LC, Breeding LC, Barber LL. Tensile bond strengths of provisional luting agents used with an implant system. J Prosthet Dent 1999;81:510-514.

12. Clayton GH, Driscoll CF, Hondrum SO. The effect of luting agents on the retention and marginal adaptation of the CeraOne implant system. Int J Oral Maxillofac Implants 1997;12:660-665.

13. University of Michigan. Biomaterials Properties Database. (April 1996). Available from: http://www.lib.umich.edu/dentlib/Dental_tables (Accessed 6 April 2006).

14. Winkler S, Ring K, Ring J, Boberick K. Implant screw mechanics and the settling effect: overview. J Oral Implantol 2003;29:242-245.

15. Kaidonis JA, Richards LC, Townsend GC, Tansley GD. Wear of human enamel: a quantitative in vitro assessment. J Dent Res 1998;77:1983-1990.

16. Graf H, Grassl H, Aeberhard HJ. A method for the measurement of occlusal forces in three directions. Helv Odont. Acta 1974;18:7-11.

17. Schneider RL. Evaluation of the retention of castings to endosseous implants. J Prosthet Dent 1987;58:73-78.

18. Breeding LC, Dixon DL, Bogacki MT, Tietge JD. Use of luting agents with an implant system: part I. J Prosthet Dent 1992;68:737-741.

19. Chee W, Jivraj S. Screw versus cemented implant supported restorations. Brit Dent J 2006;201:501-507.

20. GaRey DJ, Tjan AH, James RA, Caputo AA. Effects of thermocycling, load-cycling, and blood contamination on cemented implant abutments. J Prosthet Dent 1994;71:124-132.

21. Bresciano M, Schierano G, Manzella C, Screti A, Bignardi C, Preti G. Retention of luting agents on implant abutments of different height and taper. Clin Oral Implants Res. 2005;16:594-598.

22. GraphPad software. Post test calculator. Updated Dec 2004. Available from: http://graphpad.com/welcome.htm (Accessed 2 Dec 2006).

23. 1728 Software systems. Right circular cone calculator and cone frustum calculator. 2006. Available from: http://www.1728.com (Accessed 3 Dec 2006).

24. Agar JR, Cameron SM, Hughbanks JC, Parker MH. Cement removal from restorations luted to titanium abutments with simulated subgingival margins. J Prosthet Dent 1997;78:43-47.

25. Pauletto N, Lahiffe BJ, Walton JN. Complications associated with excess cement around crown on osseointegrated implants: a clinical report. Int J Oral Maxillofac Implants 1999;14:865-868.

26. Kuraray Dental. Panavia-F technical information. Panavia-F dual cure dental adhesive system. (03/99) Osaka, Japan.

27. Millstein PL, Hazan E, Nathanson D. Effect of aging on temporary cement retention in vitro. J Prosthet Dent 1991;65:768-771.

28. Markowitz K, Moynihan M, Liu M, Kim S. Biologic properties of eugenol and zinc oxide eugenol. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1992;73:729-737.

29. Pan Y-H, Ramp LC, Lin C-K, Liu P-R. Retention and leakage of implant-supported restorations luted with provisional cement: a pilot study. J Oral Rehab 2007;34:206-212.

30. Kent DK, Koka S, Banks SB, Beatty MW. Factors influencing retention of a CeraOne gold cylinder. Implant Dent. 1996;5:96-99.

31. Bernal G, Okamura M, Munoz CA. The effects of abutment taper, length and cement type on resistance to dislodgement of cement-retained, implant-supported restorations. J Prosthodont 2003;12:111-5.

32. Koka S, Ewoldsen NO, Dana CL, Beatty MW. The effect of cementing agent and technique on the retention of a CeraOne gold cylinder: a pilot study. Implant Dent 1995;4:32-35.

33. Chu KM, Tredwin CJ, Setchell DJ, Hems E. Effect of screw hole filling on retention of implant crowns. Eur J Prosthodont Restor Dent 2005;13:154-158.

34. Straumann International. Straumann Prosthetics. Crown and bridge restorations with the synOcta prosthetic system. 04/05. Available from: http://www.straumann.com (Accessed 15 July 2006).

35. Leinfelder KF, Beaudreau RW, Mazer RB. An in vitro device for predicting clinical wear. Quintessence International 1989;20:755-761.

Figures

Figure 1. Straumann synOcta components (laboratory analog; implant abutment; plastic burnout coping)

Figure 2. Completed mounted laboratory analog / implant abutment with coping

Figure 3. Tooth wear machine

Figure 4. Comparison of mean retention values for all specimens

Figure 5. Comparison of marginal gap after thermocycling (Panavia-F (2), KetacCem (7), TempBond NE (11))

Figure 1. Straumann synOcta components (laboratory analog (left); implant abutment (centre); plastic burnout coping (right))

Figure 2. Completed mounted laboratory analog / implant abutment with coping

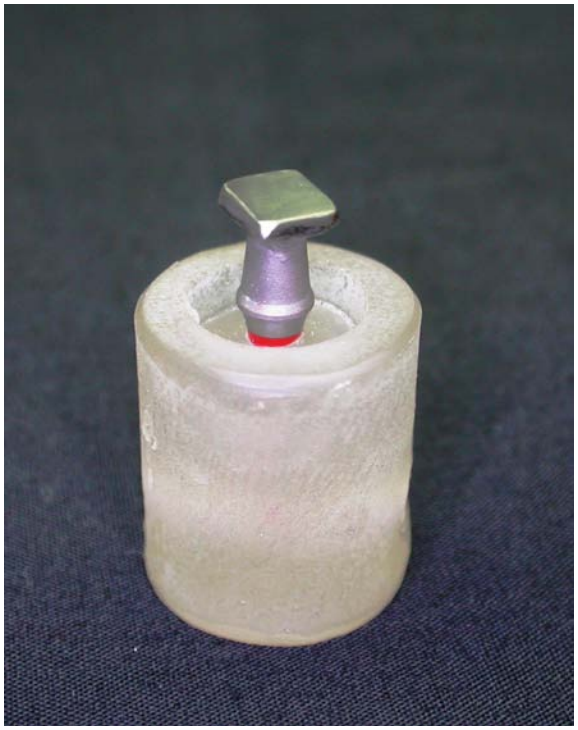

Figure 3. Tooth wear machine

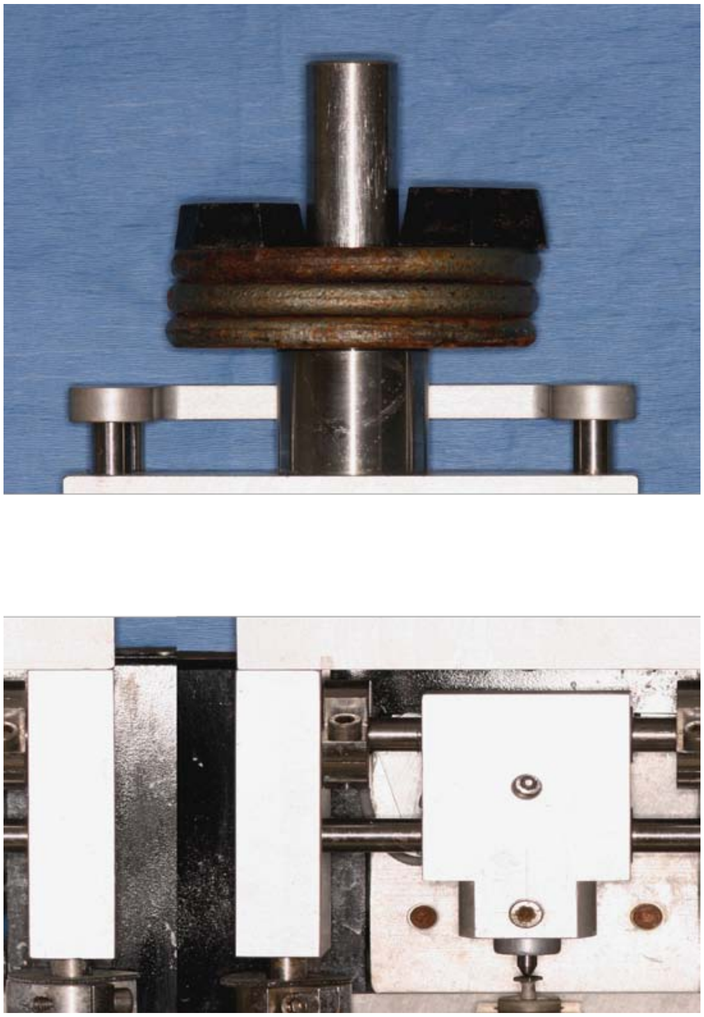

Figure 4. Comparison of mean retention values for all specimens

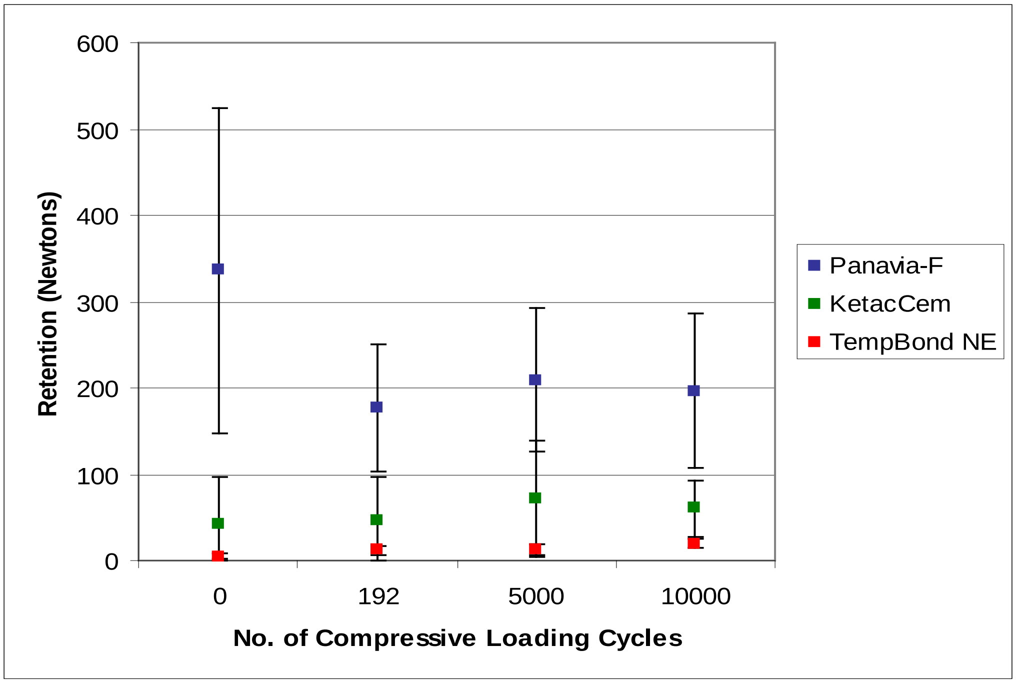

Figure 5. Comparison of marginal gap after thermocycling (Panavia-F (2), KetacCem (7), TempBond NE (11))

Tables

Table 1. Summary data for all tested cements (in Newtons unless otherwise specified) n=8

Table 2. Two-way without replication ANOVA analysis

Table 1. Summary data for all tested cements (in Newtons unless otherwise specified) n=8

Cycles	0	192	5000	10000
Cement				
Panavia-F				
Mean (N)	336.3	176.7	209.4	196.8
Median	219.3	160.5	204.5	190
SD	188.1	72.8	82.7	90.1
Minimum	137	72.5	78	79
Maximum	697	283.5	335	350
Mean (MPa)	5.103	2.681	3.178	2.986
Ketac Cem				
Mean (N)	42.6	46.2	71.4	60.2
Median	23.5	29.8	50.7	43
SD	53.3	51.3	66.5	32.7
Minimum	10	17	17	30
Maximum	172	171	223	108.5
Mean (MPa)	0.646	0.701	1.083	0.914
TempBond NE				
Mean (N)	4.9	11.9	12.5	20
Median	5.2	10.3	10.8	21.3
SD	2.5	5	5.5	5.7
Minimum	1.4	6.2	7	12.1
Maximum	8.5	22.8	25	28.6
Mean (MPa)	0.074	0.181	0.19	0.303

Table 2. Two-way without replication ANOVA analysis

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Panavia-F	4	919.2	229.8	5222.34
KetacCem	4	220.4	55.1	175.72
TempBond NE	4	49.3	12.325	38.0825
0 cycles	3	383.8	127.933	32917.8
192 cycles	3	234.8	78.2667	7560.96
5000 cycles	3	293.3	97.7667	10213.8
10000 cycles	3	277	92.3333	8588.97

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Cement	106194	2	53096.8	25.7552	0.00114	5.14325
Loading	3938.86	3	1312.95	0.63686	0.61823	4.75706
Error	12369.6	6	2061.6			
Total	122502	11				