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Retentiveness of Dental Cements Used with Metallic Implant Components

Rachel Schultz Squier

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RETENTIVENESS OF DENTAL CEMENTS USED WITH METALLIC
IMPLANT COMPONENTS

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B.A., Harvard University, 1993
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RETENTIVENESS OF DENTAL CEMENTS USED WITH METALLIC IMPLANT COMPONENTS

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DEDICATION

The completion of this chapter in my life is dedicated to my husband and best friend, Gregory Chase Squier. He has been my support and source of sanity over the past few years and during this thesis project.
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I. INTRODUCTION

The use of screw-retained versus cement-retained implant restorations has been the subject of controversy in the literature. The main advantage of a screw-retained restoration is retrievability. However, loosening and/or fracture of occlusal or abutment screws remains a complication and concern. Cemented restorations have become a popular alternative and exhibit potential advantages over screw-retained restorations. These advantages include elimination of prosthesis screw loosening, better esthetics, easier control of occlusion, simplicity, lower cost, more equitable stress distribution, and passivity of fit. Because of the desire to reduce the cost and maintenance associated with screw-retained restorations, cement-retained restorations have gained favor among many practitioners.

While cementation may have advantages over screw retention, lack of retrievability remains problematic for some practitioners. Controversy exists as to whether a provisional or a permanent luting agent should be used. There is very little evidence to support the selection of one luting agent over another when retrievability versus “permanent cementation” is the goal in a metal-to-metal situation. Some authors advocate the use of a provisional cement to maintain retrievability. These authors base their use of provisional luting agents on the assumption that provisional cements are less retentive than permanent ones, thus ensuring retrievability of the restorations. Data on the retentive values of cements used between metal components is sparse, however, and the cementation of metal castings to titanium abutments of varying tapers may not correlate with established data on the retentive strengths of luting agents to natural teeth, or to a metal or composite resin core in an endodontically-treated tooth.
The choice of cement for an implant-supported restoration should be based on the need or
desire for retrievability, the anticipated amount of retention needed, the ease of cement
manipulation and removal,\textsuperscript{18,19} and cost.

Several authors have provided what little information exists on luting agents as they
relate either to cementing implant abutments into implants or cementing cast restorations to
implant abutments. The studies examining luting agents used to cement implant abutments into
implants have been inconclusive as to which cement to use because the protocols vary and the
dimensions of the implant systems used have not been the same.\textsuperscript{15,16,20-22} In addition, the
majority of the implant systems used today utilize either a screw to attach an abutment externally
to an implant or use an abutment that is screwed internally into the implant.

Other authors have examined the issue of retention of luting agents used between metal
castings and machined titanium abutments.\textsuperscript{14,15,17,23-27} Again, the results of these studies
revealed no standardized guidelines for cementation because each author used different cements,
protocols, and implant systems.

While these studies have provided some relevant information, most were conducted with
an external implant-abutment connection using parallel-sided abutments. The results of these
studies to implant systems that use an internal connection and/or tapered abutments may not
apply. In addition, anodized or coated titanium components have become increasingly
commonplace. The effect of anodization on cement retentiveness has not been described in the
literature.

The aim of this study was to provide data on the relative retentive characteristics of five
commonly used dental cements when cementing cast noble metal alloy crowns to 8° tapered
machined titanium abutments with anodized and non-anodized surfaces.
II. OBJECTIVES

Implant practitioners have historically favored retrievable implant restorations in order to be able to remove these prostheses in the event of component and/or material failure. In more recent years, cemented restorations have become a popular alternative to screw-retained restorations. Little data exists to support the selection of one luting agent over another when cementing metal to metal. In the past, parallel-sided abutments were the only abutment configuration available. Today, most implant manufacturers provide pre-fabricated tapered implant abutments, but there is little, if any, research on cementing implant prostheses to these tapered abutments.

The two main objectives of this research were: 1) to provide data on the relative retentive characteristics of five commonly used dental cements when cementing metal crowns to tapered titanium abutments with different surface preparations, and 2) to provide relevant clinical information to the implant practitioner to aid in the selection of a luting agent when cementing implant prostheses to tapered machined titanium abutments.

The Null Hypotheses tested were:

1. There is no difference between the retentiveness of different luting agents when used between metal restorations and metal substructures (abutments).
2. There is no difference between the retentiveness of different luting agents when used with the standard surface treatment of the solid abutments (non-anodized) and the anodized (coated) solid abutments.
3. There is no difference between retentiveness of different luting agents when subjected to thermocycling.
III. LITERATURE REVIEW

Cement Retention

The amount of retention in cement-retained restorations, whether they exist on natural teeth or implant abutments, is influenced by several factors. These factors have been well-documented in the literature and include 1) taper or parallelism, 2) surface area and height, 3) surface finish or roughness, and 4) type of cement.\textsuperscript{28,29}

The retention of cement-retained prostheses is greatly influenced by taper. Jorgensen\textsuperscript{28} demonstrated an inverse relationship between taper and retention with a 6° ideal taper (12° total taper) in crown preparations. He showed that as the taper increased, the retention of a prosthesis on natural teeth decreased. However, the literature suggests that for conventional fixed prosthodontics, most practitioners prepare natural teeth with between 15° and 25° of taper. Therefore, when cemented to natural teeth, crowns have one third to one fourth the retention when compared with the results of the ideal taper of 6 degrees.\textsuperscript{30} Hebel and Gajjar\textsuperscript{13} conclude that when this theory is applied to implant prosthodontics, machined implant abutments of 6° taper provide ideal retention that is three to four times the retention achieved on natural tooth preparations. The authors did not consider, however, whether these taper values are applicable to the two very different situations of metal-to-metal cementation versus metal-to-tooth cementation.

Kaufman\textsuperscript{29} showed that an increase in surface area and height increases retention and resistance form. Comparison of his findings on natural teeth with those on implant abutments is problematic because it is difficult to consistently correlate surface area similarities between natural teeth and implant abutments. Implant abutments replacing teeth have traditionally been placed subgingivally and therefore can often have longer walls and more surface area than
natural teeth. Therefore, machined implant abutments may provide better retention than can be routinely prepared on natural teeth with a handpiece when comparing height and surface area.  

Roughened axial walls of prepared teeth have been advocated to increase mechanical retention for the cementing agent and improve retention. Implant abutments can also be roughened, but the majority of practitioners do not routinely perform this step prior to cementation of their prostheses. Thus, no conclusions can be abstracted from the literature on natural teeth with regard to this principle of retention in implant dentistry.

The final factor related to retention is the type of cement. As was discussed in the introduction, cementation may be provisional or permanent, depending on the desire for retrievability of a prosthesis. In conventional fixed prosthodontics, certain permanent cements such as composite resin, glass ionomer, and resin-modified glass ionomer have been advocated to overcome the lack of retention on tooth preparations due to overtapering. The concern with cement failure on natural teeth is washout and the potential for recurrent decay and possible tooth loss. The same does not hold true in implant prosthodontics, where cement washout may occur, but there is no risk of decay to the metal abutment. Therefore, any discussion concerning the use of a permanent versus provisional cement with implants is solely an issue of retrievability, arbitrarily decided upon by an individual practitioner.

As was discussed in the introduction, the argument over retrievability of implant restorations is unresolved to date. The choice of cement for an implant-supported restoration should be based on the need or desire for retrievability, the anticipated amount of retention needed, the ease of cement removal, and overall cost. The following literature review will show that there is very little data on the retentive capacity of cements used between metal components to support the selection of one luting agent over another when retrievability versus permanent
cementation is desired in a metal-to-metal situation. In addition, and most importantly, the cementation of metal castings to machined titanium implant abutments of varying tapers may not correlate with established data on the retentive strengths of luting agents to natural teeth, metal dies or between metal components.

Crown retention on natural teeth

There is not an abundant amount of dental literature on the retention of crowns cemented to natural teeth. Most studies have used metal\textsuperscript{29} or other prefabricated dies\textsuperscript{32} that do not duplicate the characteristics of natural tooth structure. Evaluating crown retention using standardized preparations on natural extracted teeth provides valuable data that serves as a historical control from which cementation of crowns to metal abutments can be compared.

Pameijer and Jeffries\textsuperscript{31} evaluated the retentive forces of 18 luting agents and adhesive systems on virgin premolars prepared to a 33° taper. Of note were retentive values of the glass ionomer cement (Ketac Cem) which were two times that of zinc phosphate cement (13.1 kg) and three times that of polycarboxylate cement (Durelon). The authors surmise that the ability of glass ionomer cements to bond to dentin and enamel is the main reason for glass ionomer’s higher retentive values. In that study, Panavia, a composite resin cement, and Advance, a resin-modified glass ionomer, were responsible for the fracture of many of the test specimens inside the fabricated crowns as their retentive capacity exceeded the inherent strength of tooth structure.

The retention of cast gold crowns using glass ionomer (Ketac Cem), compomer (Dyract Cem), and resin cement (F21) were investigated by Ernst et al.\textsuperscript{33} The glass ionomer and compomer cements showed significantly higher retention (2.36 ± 0.69 N/mm\textsuperscript{2} and 1.85 ± 0.94
N/mm$^2$ respectively) than the resin cement (0.60 ± 0.28 N/mm$^2$); however, no significant difference was found in retention between the glass ionomer and compomer cement.

Reddy et al.$^{34}$ compared the retention of zinc phosphate, polycarboxylate, and glass ionomer cements used with stainless steel crowns cemented onto extracted human primary molars. Results showed zinc phosphate and glass ionomer cements were more retentive when compared with the polycarboxylate cement on natural teeth.

Gorodovsky and Zidan$^{35}$ evaluated the retention of high noble metal crowns cemented to extracted human molars using 5 methods (zinc phosphate cement, glass ionomer cement, composite resin cement, composite resin cement with a dentin bonding agent, and an adhesive resin cement). The authors classify composite resin cements into 2 categories: the older generation resin cement with no adhesive properties (Comspan), and the newer “adhesive” resin cement with adhesive properties (Superbond). Molars were prepared with a total taper of 8° and the samples were stored for 6 to 8 weeks after cementation. The retention of zinc phosphate cement ($3.08 \pm 0.9$ MPa) and glass ionomer cement ($3.12 \pm 1.2$ MPa) was significantly different than that of the adhesive resin group ($>6.40 \pm 1.8$ MPa). The retention of the adhesive resin cement was 65% greater than that of the composite resin ($4.21 \pm 1.8$ MPa) and the composite resin with dentin bonding agent ($4.01 \pm 1.8$ MPa) groups, but the difference was not significant.

The crown retention on natural teeth with a resin cement and zinc phosphate was studied by Brukl et al.$^{36}$ Maxillary and mandibular molar teeth were prepared with a 5° axial wall taper and vented and non-vented crowns were cemented with resin cement (Den Mat) or zinc phosphate cement. The authors found that the tensile forces required to dislodge 5° taper vented cemented crowns were significantly higher for resin cement (490 N) than for zinc phosphate (300 N) cement.
Maxwell et al.\textsuperscript{37} compared the effect of crown preparation height on the retention and resistance of gold castings. Single-rooted teeth were prepared to a 6° axial wall taper and varying height of 1 mm, 2 mm, 3 mm, and 5 mm. Type III gold castings were cemented with zinc phosphate. The retention forces ranged from $7.4 \pm 2.3$ kg (1 mm group) to $85.4 \pm 15.9$ kg (5 mm group), with an approximate doubling between each millimeter increase in height up to 3 mm.

Michelini et al.\textsuperscript{38} looked at the tensile bonds of gold and porcelain inlays to extracted teeth in standardized cavities using three cements (zinc phosphate, glass ionomer, and composite resin). Gold inlays were cemented using zinc phosphate or glass ionomer, and the porcelain inlays were cemented using composite resin or glass ionomer. The porcelain inlays bonded with resin composite cement to tooth structure (8.0 MPa) showed tensile bonds three to four times higher than glass ionomer (2.2 MPa) and two to three times higher than conventional gold inlays cemented with zinc phosphate (3.6 MPa).

A comparative study of the retentive capacity of three glass ionomer cements, zinc phosphate, and zinc polycarboxylate cement was performed by Omar.\textsuperscript{39} Crown preparations were performed on extracted premolar teeth with an axial wall taper of 5 degrees. The glass ionomer cements were significantly superior in retention (255 to 299 N) to zinc phosphate cement (178 N) and polycarboxylate cement (222 N).

Tjan and Li\textsuperscript{40} evaluated and compared the retention of cast gold crowns cemented with an adhesive resin cement (Panavia EX), a conventional resin cement (Comspan), and zinc phosphate cement. Extracted human maxillary premolars were prepared to an axial wall taper of 6° and crowns were cemented and then stored in water for 21 days before testing. After 7 days of storage, provisional crowns were cemented with non-eugenol temporary cement onto the
samples prior to final cementation. After storage, the preparations were cleaned with pumice and the crowns were then cemented with one of the test cements. Crowns cemented with Panavia EX showed significantly higher retention (83.7 kgf) than zinc phosphate cement (48 kgf) or the conventional resin cement (53 kgf).

In an experiment that directly compared the retention of cements onto a natural tooth or implants, Breeding et al.\textsuperscript{15} examined three different factors: 1) the retentiveness of cast metal 9° tapered implant abutments cemented with resin and glass ionomer luting agents into Core-Vent titanium alloy implants (Core-Vent Corp., Encino, Calif.), 2) the retentiveness of provisional cements between metal castings and machined titanium implant abutments, and 3) the comparison of luting retention data with values obtained by using the same luting agents for cementation of a cast crown to an extracted human premolar with a 9° taper. The authors found no significant difference between retentive values for the natural tooth abutment and the machined metal implant abutments for any of the luting agents tested.

In an experiment incorporating amalgam and natural tooth structure in order to better simulate clinical conditions, Caughman et al.\textsuperscript{41} examined the retention of high noble and base metal castings luted with adhesive resin cements (Panavia and C&B Metabond) and zinc phosphate cement to prepared extracted molars having received MOD amalgam restorations. The crown preparations were standardized on the extracted teeth to produce an 8° axial wall taper. Results showed that the resin luting agents were significantly more retentive (761 Newtons (N) and 609 N) than zinc phosphate cement (326 N). In addition, for each cement, the choice of casting alloys did not significantly affect the retentiveness.
Cement retentiveness with amalgam or metal alloy

Mojon et al.\textsuperscript{42} looked at the bond between dental luting agents and dental amalgam. Amalgam alloy was condensed in a mold to fabricate cylinders, which were luted together with either a zinc phosphate, glass ionomer (Aqua Cem), or an adhesive resin (Super-bond) cement. The adhesive resin was almost six times more retentive (4.17 ± 0.79 MPa) than zinc phosphate (1.98 ± 1.40 MPa) and twice as retentive as glass ionomer cement (3.18 ± 1.03 MPa).

A second paper by Mojon et al.\textsuperscript{43} examined early retentiveness of luting agents to a precious alloy. Cylinders were fabricated in a high-noble alloy and luted in pairs with zinc phosphate cement, glass ionomer cement (Aqua Cem), or an adhesive resin cement (Super-bond). The most retentive combinations were achieved with the adhesive resin cement (16.3 MPa), intermediate values with glass ionomer (approximately 9.0 MPa) and the least retentive with zinc phosphate (5.0 MPa).

Diaz-Arnold et al.\textsuperscript{44} compared the tensile bonding of three luting agents for adhesion fixed partial dentures. Rexillium (Ni-Cr-Be alloy) cast metal cylinders were fabricated and cemented end-to-end with an adhesive resin cement (Panavia Opaque, Comspan, or Super-bond). The samples were stored for either 2 or 30 days and then half were thermocycled before tensile testing. The values for retention were statistically significantly different and ranged from a low of 29.7 MPa for the Super-bond group (non-thermocycled and 30-day storage) to a high of 54.3 MPa for the Panavia group (thermocycled and 2 day storage).

Use of die spacer with natural teeth

Paint applied to the surfaces of dies to achieve relief of castings is advocated to provide enough space for cement thickness, ensuring improved marginal adaptation of a casting to natural teeth. In his classic 1964 article, Fusayama et al.\textsuperscript{45} prepared extracted maxillary molars
for full crown coverage with a shoulder margin preparation design. Relief spaces were produced in the crowns with either nail polish or tin foil in order to reduce resistance to cementation with zinc phosphate cement. The authors found that relief spaces for cement effectively reduced the degree of lack of seating of the crowns by reducing the cement thickness on the shoulders of the preparation. These results were superior to those achieved with an occlusal perforation technique.

Eames et al.\textsuperscript{30} similarly found that, in human molars prepared to an average $18^\circ$ axial wall angle, die relief was the most suitable casting compensation technique. Crowns cemented without die relief could not be satisfactorily seated with either polycarboxylate cement (Durelon) or zinc phosphate cement when the taper of the preparation was 10 degrees. When the taper was increased to $20^\circ$, seating of the crowns improved significantly. The authors concluded that die spacer provides relief of internal stresses, more space for cement, and improved retention of castings by as much as 25%.

Additional studies have determined the influence of cementing variables on crowns made for metal and plastic test dies rather than for natural teeth. However, a recent article\textsuperscript{46} evaluated the influence of die relief on the seating of cast gold crowns constructed for natural human teeth. Crowns were cemented with zinc phosphate cement onto crown preparations relieved with die spacer. Results showed that die relief significantly reduced the vertical seating discrepancy associated with cementation.

**Use of die spacer and crown retention on natural teeth**

The retention of cast restorations on dies or prepared tooth surfaces is a complex combination of variables, including preparation taper, surface finish of the preparation, and the
number of coats of die spacer. The experiments to date\textsuperscript{46-50} have differing methodology, making comparisons of their results difficult. Crown retention has been shown to increase or decrease, depending on the study design and the reuse of dies and/or teeth in the methodology. The use of this data is limited in its applicability to an implant situation, although cement film thickness may in actuality play a very important role in the long-term retention of castings onto metal abutments.

**Use of die spacer on teeth and implants**

The only reference available which examines the use of die spacer with implants was conducted by Dixon et al.\textsuperscript{23} The authors examined the use of die spacer on implant abutments to reduce seating discrepancies of implant crowns caused by varying cement film thicknesses. Their conclusions indicated that the use of a 0.001 to 0.003 inch die spacer decreased seating discrepancies (below 25\textmu) and increased retentive values of the cements used. In their study, resin cement exhibited the highest retentive values, followed by zinc phosphate cement.

Currently, some of the implant manufacturers provide plastic copings from which metal castings are fabricated. The data on the amount of relief provided with these copings between the plastic and the metal abutment is sparse. Straumann (Straumann USA, Waltham, MA) provides 110\mu of relief in their plastic copings for cement space. Long-term data is required to make a definite determination as to the amount of relief needed to provide the optimal casting retention. In the meantime, clinical experience has shown that the cement film thickness produced from the relief of the plastic copings appears to be adequate for successful cementation to castings to metal abutments.
Cementation of superstructures onto implant abutments

The retentive values of provisional cements used with the Steri-Oss implant system abutments (Steri-Oss Corp., Anaheim, Calif.) were evaluated by Ramp et al. Ten castings were fabricated, cemented onto 3° tapered implant abutments, and stored in water for 48 hours. Retentive values were recorded for 6 provisional luting agents. The 10 castings were used multiple times during the study and after retentive tests were performed with one cement, the castings were then cleaned and reused with the next cements. Neo-Temp luting agent exhibited the greatest retentiveness of the cements tested, more then three times that of TempBond or Provilink luting agents.

Several authors have examined luting agents used with parallel-sided abutments. Clayton et al. evaluated the retention of various luting agents used with the CeraOne single-tooth abutment system (Nobel Biocare AB, Göteborg, Sweden). Five different luting agents (zinc oxide-eugenol cement, glass ionomer cement, hybrid glass-ionomer cement, composite resin cement, and zinc phosphate cement) were tested for retentiveness of CeraOne gold cylinders to the CeraOne abutment. The results showed zinc phosphate cement to have the highest retentive value of the cements studied on this non-tapered abutment.

Koka et al. evaluated the retention of the CeraOne gold cylinder to a CeraOne titanium abutment in a pilot study using TempBond NE and zinc phosphate cement. The results showed that the gold cylinder was significantly more retentive when cemented with zinc phosphate cement compared to TempBond NE. The follow-up study showed similar results, with zinc phosphate cement being significantly more retentive than TempBond or TempBond NE when used with the parallel-sided CeraOne abutment.
Schneider\textsuperscript{27} utilized eight different implant and abutment materials, including titanium, aluminum oxide, single-crystal sapphire, and polysulfone, with varying head designs and tested the retention of gold castings with four different cements to the different abutment head shapes. Glass ionomer cement was the most retentive, followed by zinc phosphate, zinc silicophosphate, and polycarboxylate cements. The author indicated that, in general, the more parallel the abutment heads, the more tensile force was required for casting removal.

Michalakis et al.\textsuperscript{17} examined the retention of 4 provisional luting agents used to cement restorations supported by 2 or 4 Brånemark implants (Nobel Biocare AB, Göteborg, Sweden). Plastic UCLA hex abutments (Nobel Biocare AB, Göteborg, Sweden) were cast and screwed to the implants. A 2-unit or 4-unit fixed partial denture (FPD) was cast and cemented with Improv, Nogenol, TempBond, or TempBond NE. Improv cement showed the highest mean retention for both the 2- and 4-unit FPDs (24.60 kg and 43.67 kg, respectively), and Nogenol showed the lowest values for both situations (12.46 kg and 29.51 kg, respectively). The authors state that in order to maintain retrievability, Nogenol provisional cement seems to be the most appropriate for implant-supported FPDs.

In a retrospective analysis of the factors influencing the retention of cemented implant-supported crowns, Carter et al.\textsuperscript{14} found that crowns constructed with the CeraOne milled gold cylinder or cemented with a temporary cement (TempBond) were more likely to be associated with a cement failure than those cemented with zinc phosphate or constructed with cast metal or ceramic copings. The authors conclude that to reduce the initial cost and maintenance associated with recementing implant-supported crowns, the use of a milled-gold cylinder should be discontinued in favor of a cast cylinder and a permanent cement.
Covey et al.\textsuperscript{26} examined the retention of a permanent and a provisional luting agent used to cement CeraOne gold cylinders onto CeraOne titanium abutments of varying dimensions, including standard 4.8 mm abutments and 6.0 mm wide platform abutments. Their results showed that 1) zinc phosphate cement produced uniaxial retention forces approximately 3 times greater than TempBond cement, 2) the increase in surface area provided by a wide CeraOne abutment did not result in an improvement in retention over the standard abutment, and 3) abutment height and height to width ratio were positively related to retention, whereas an abutment’s total surface area and width were not. The authors conclude that the relationship between the height and width of the abutment is more important than the total surface area of the abutment in determining crown retention.

Breeding et al.\textsuperscript{15} examined the retentiveness of provisional cements used between metal castings and machined titanium implant abutments. The machined cementable implant abutments used had an axial taper of 9 degrees. The castings were cemented onto the implant abutments with either TempBond luting agent or IRM luting agent. TempBond produced the lowest retentive values and IRM the highest values.

**Cementation of implant abutments into implants**

Kerby et al.\textsuperscript{20} studied the axial force necessary to dislodge cemented 0° abutments from internally threaded Steri-Oss implants (Steri-Oss Corp., Anaheim, Calif.). The dislodging force of four composite resin luting agents (UDA, UDA with fluoride, Panavia OP, and DenMat) and a conventional glass-ionomer cement (Shofu Type I) were compared. The straight titanium alloy abutments were cemented into the implants, then thermocycled for 1000 cycles after a 24-hour storage in water. The results demonstrated that there was no significant difference between
dislodging forces in abutments luted with UDA with fluoride, Panavia OP, or Shofu Type I cements. The authors suggest, however, that a glass ionomer cement may be indicated for cementation of 0° implant abutments into Steri-Oss internally threaded implants due to its low coefficient of thermal expansion and its ability to bond chemically to metal oxides.

Breeding et al.\textsuperscript{15} examined the retention of 9° tapered cast metal implant abutments cemented with resin composite and glass ionomer luting agents into Core-Vent titanium alloy implants (Core-Vent Corp., Encino, Calif.). The authors found that the abutment/implant combinations cemented with glass ionomer cement (Ketac Cem) had higher retentive values than for the two resin cements used (Resiment and Core Paste).

GaRey et al.\textsuperscript{22} attempted to more closely mimic the oral environment. They studied the effects of thermocycling, load-cycling, and blood contamination on the retention of castings on straight cemented commercially-pure titanium implant abutments. Four resin cements (C&B Metabond, Panavia EX, Resiment with fluoride, and DenMat Thin Film) and zinc phosphate cement were used to lute implant abutments into internally threaded Steri-Oss implants. After the combination of thermocycling and compressive loading, the tensile strengths of Panavia, Resiment, and zinc phosphate cement were significantly stronger than the other cements. Blood contamination weakened the retention of all of the cements more than either thermocycling or compressive loading, and in combination with both, was found to dramatically weaken all of the cements. Resiment cement had the greatest mean retentive value of all the cements with blood contamination, but it was significantly less that that of the Resiment control.
Composition and mechanical properties of the cements used in this investigation

Zinc phosphate cement

Zinc phosphate cement has been used for well over one hundred years. The cement is supplied as a powder and as a liquid, which are mixed together to form a mass of cement. The powder consists of zinc oxide (90%) and magnesium oxide (10%). The liquid is a solution of approximately 67% phosphoric acid buffered with aluminum and zinc, and 33% water.\(^{51-53}\)

When the powder and liquid are mixed together, the zinc oxide is dissolved by the phosphoric acid in an acid-base reaction. It is the significant water content that controls the ionization of the acid and, therefore, the rate of the acid-base or setting reaction. The final structure of the set zinc phosphate cement is essentially a hydrated amorphous network of zinc phosphate surrounding incompletely dissolved particles of zinc oxide.\(^\text{51}\)

When used to cement metal castings to natural teeth, the retention of zinc phosphate cement is due to mechanical interlocking between the surface irregularities of the tooth and the restoration. Zinc phosphate cement does not chemically bond to tooth structure nor to any restorative material and provides a retentive seal by mechanical means only. Therefore, the taper, length, and surface area of the tooth preparation (or metal abutment) are critical to its success.\(^\text{53}\)

When properly mixed, the compressive strength of zinc phosphate cement is in the range of 96 to 133 MPa. The tensile strength is in the range of only 3.1 to 4.5 MPa.\(^\text{51}\)

Resin composite cement

Most resin cements have a composition similar to composite resin filling materials.\(^\text{51,52}\)

The resin cements are made up of a BIS-GMA (from bisphenol-A and glycidyl methacrylate)
resin matrix and are filled, 50% to 70% by weight, with inorganic fillers such as silica or glass particles. The matrix is generally composed of monomers with functional groups that have been used to induce bonding to dentin. Some of these include organophosphonates, hydroxyethyl methacrylate (HEMA) and the 4-methacrylethyl trimellitic anhydride (4-META) system. Resin cements polymerize through chemically initiated mechanisms, photopolymerization, or a combination of both.

Adhesion of resin to enamel occurs through the micromechanical interlocking of resin to the hydroxyapatite crystals and rods of etched enamel. Adhesion to dentin is a more complex process that depends upon penetration of hydrophilic resin monomers into etched dentin, thus producing a micromechanical interlock with partially demineralized dentin underlying the hybrid layer. Adhesion of resins to dentin requires multiple steps, including application of an acid or dentin conditioner to remove the smear layer, smear plugs, open and widen tubules, and demineralize the top 2 to 5 um of dentin. After demineralization, a primer containing hydrophilic monomers dissolved in organic solvents such as acetone or ethanol (i.e.- HEMA), is used to penetrate the exposed collagen network, thus forming a hybrid layer. Adhesive resin, or bonding agent, is then applied. It consists primarily of hydrophobic unfilled resin monomers that penetrate and plug the dentinal tubules.

Resin composite cements bond chemically to resin composite restorative materials and to silanated porcelain. Resin cements also demonstrate good bond strengths to etched or sandblasted base metal alloys as a result of micromechanical retention, and the 4-META resin cements show strong adhesion as a result of chemical interaction of the resin with an oxide layer on the metal surface. Noble metals can be electroplated with tin to increase the surface area
for bonding and therefore can adhere to the metal via a chemical bond to the deposited tin oxide.\textsuperscript{57-59}

Most resin cements exhibit high compressive strength, resistance to tensile fatigue, and are virtually insoluble in the oral environment.\textsuperscript{52,56} White and Yu\textsuperscript{60} examined the physical properties of some of the more commonly used resin composite luting agents. They found compressive strengths ranging from approximately 125 to 205 MPa, while tensile strengths were in the range of 25 to 50 MPa.

\textbf{Glass ionomer cement}

Glass ionomer cements were first introduced in the early 1970s. Like zinc phosphate cement, the glass ionomer cements are supplied as a powder and a liquid. The cement sets by an acid-base reaction between the acid-soluble calcium fluoroaluminosilicate glass powder and a liquid, consisting of copolymers of polyacrylic acid, itaconic, maleic, or tricarballylic acids in water.\textsuperscript{52}

When the powder and liquid are mixed to form a paste, the acid attacks the surface of the glass particles. The polyacrylic acid chains are cross-linked by the calcium ions and form a solid mass. Within the next 24 hours a new phase forms with aluminum ions bound within the cement mix.\textsuperscript{52} The set cement is an agglomeration of unreacted powder particles surrounded by a silica gel in an amorphous matrix of hydrated calcium and aluminum polysalts. Fluorite crystals are contained within the silica gel of the matrix.\textsuperscript{51,52}

Glass ionomer cements bond chemically to enamel and dentin. The mechanism of bonding primarily involves an ionic interaction with calcium and/or phosphate ions from the surface of the enamel or dentin.\textsuperscript{51,52}
The compressive strength of glass ionomer cements is greater than that for zinc phosphate and ranges from 90 to 230 MPa at 24 hours. The tensile strength is similar to zinc phosphate, ranging from 4.2 to 5.3 MPa.\textsuperscript{51}

**Resin-modified glass ionomer cement**

The resin-modified glass ionomer cements were developed over the past decade to reduce the inherent problems of moisture sensitivity and low early strength caused by a slow acid-base setting reaction of traditional glass ionomer cements. To achieve this, polymerizable functional groups have been added to the glass ionomer cements to impart additional curing processes which allow for maturation of the bulk of the material through the acid-base reaction.\textsuperscript{52} Polymerization of the added functional groups occurs through chemically initiated mechanisms, photopolymerization, or both.

The powder component of the resin-modified glass ionomer cement consists of ion-leachable fluoroaluminosilicate glass and initiators for light or chemical curing, or both. The liquid component usually contains water, polyacrylic acid, or polyacrylic acid with some carboxylic groups modified with methacrylate or HEMA monomers.\textsuperscript{52} Because of this chemistry, the cements are termed *resin-modified or hybrid glass ionomers*. The initial setting reaction is due to free radical polymerization of the methacrylate groups either via photo or chemical initiation. The slow acid-base reaction is ultimately responsible for the maturing process and the final strength.

The resin-modified glass ionomer cements bond chemically to enamel and dentin, as well as to resin composite. Their compressive and tensile strengths are better than the glass ionomer cements due to the addition of polymerizable resin. Fracture toughness values for the resin-
modified glass ionomer cements range from 0.88 to 1.37 MN/m². Other authors have reported values in the range of 0.4 to 0.8 MPa·m¹/².

**Zinc oxide non-eugenol cement**

Zinc oxide mixed with eugenol (ZOE) has served as a temporary cement used in dentistry since the 1890s. Its record has been excellent historically, until the more recent advent of widespread use of composite resins and the composite resin luting agents. There have been mixed published reports concerning the fact that eugenol may inhibit resin polymerization, and this has been one reason that has led to the development of non-eugenol containing formulas. A typical zinc oxide-eugenol cement is dispensed in the form of a powder and liquid, or especially today, as two pastes. The powder contains zinc oxide (69%) with the addition of white rosin to reduce brittleness, zinc stearate as a plasticizer, and zinc acetate to improve strength. The liquid contains eugenol (85%) with olive oil as a plasticizer. Zinc oxide non-eugenol cements contain zinc oxide and have the eugenol replaced by an aromatic oil. Other ingredients may include olive oil, petroleum jelly, oleic acid, and beeswax.

The compressive strength of zinc oxide non-eugenol temporary cements ranges from 2.7 to 4.8 MPa and its tensile strength ranges from 0.39 to 0.94 MPa.
IV. MATERIALS AND METHODS

Implant/abutment assembly preparation

Sixty implant/abutment assemblies were used for this study. Standard 5.5 mm long, 8° tapered (16° total convergence), machined abutments were torque-tightened to 35 Ncm into standard 4.1 mm solid screw ITI implants (Straumann USA, Waltham, MA) at the Institute Straumann AG (Waldenburg, Switzerland). Half (30) of the abutments retained the “as machined” surface, while the other half was anodized with a green coating to simulate the color coding of abutments prepared by implant manufacturers to indicate various lengths and sizes of their respective abutments (Figure 1).

Fabrication of castings

Using prefabricated plastic burn-out copings and analogs of the solid abutments, 60 wax copings with occlusal wax rings were formed (Figures 2 and 3). The wax rings were added to the occlusal portion of the waxed coping for retentive testing (Figures 4 and 5). The wax patterns were sprued (Figure 6), invested in a phosphate-bound investment (GC VEST-G; GC Corporation, Tokyo, Japan; Batch No. L072996), and cast in a metal ceramic alloy (JP-I; Jensen Industries, North Haven, CT). After divestment and ultrasonic cleaning, the internal aspect of the castings was inspected under a microscope and surface irregularities removed with a small round bur (Figures 7 and 8). The shoulders of the castings were milled with a beveled internal reamer according to the manufacturer’s recommendations (Figure 9). Castings were numbered and arbitrarily paired to one of the 60 implant/abutment assemblies. All castings were ultrasonically cleaned in mild detergent for 30 minutes, air abraded with aluminum oxide (50
micron particle size; Ivoclar North America, Inc., Amherst, NY) to remove investment and steam-cleaned prior to the cementation procedure.

**Cementation of castings to implant/abutment assemblies**

Five cements were evaluated in this study (Table 1). A detailed description for each cement will follow; however, the general methodology was applicable to all systems. Each of the 60 metal castings was cemented with one of the cements, allowing for 6 castings cemented to the anodized surface and 6 castings to the non-anodized surface for each of the five cements.

When available, single unit dosing of the cement was used for ease of manipulation and for optimal consistency in mixing of the cement (cements 3,4,5). The castings and implant/abutment assemblies were thoroughly dried prior to cementation. One examiner mixed all cements, and all of the samples were cemented onto the implant abutments by the same examiner. A thin layer of cement was painted on the inner surface of each casting with a disposable brush (Figure 10), seated with finger pressure until hydraulic pressure was fully relieved, then placed under a 10 kg weight for 10 minutes at room temperature (Figures 11 and 12). After 10 minutes, the excess cement was removed. After cementation, samples were placed in a humidor at room temperature for at least 24 hours prior to thermocycling and tensile testing.

**Thermocycling and retentive testing in the Instron**

In order to simulate the oral environment, all 60 samples were thermocycled for approximately 1000 cycles between 5.1º C and 56.1º C with a 34 second dwell time for 24 hours before tensile testing was performed. After thermocycling, each specimen was placed in a Universal testing machine (Instron Corp, Canton, MA) using a jig made specifically to ensure the
application of vertical forces only. The lower jig base fit precisely into the lower member of the Instron and the implant was securely tightened into this base. The upper jig base also fit precisely into the upper member of the Instron and was attached to the casting through the ring. The jig thus allowed complete alignment of all components along the long axis of the samples (Figure 13).

Using a 50 kg load cell at a crosshead speed of 0.5 cm/minute, each casting was pulled by its ring from the abutment and the force (in kilograms) at which retentive failure occurred was recorded on a paper chart recorder.

Statistical analysis

The data was recorded and the mean and standard deviation for each cement was calculated. An analysis of variance (ANOVA) was used to determine any differences among the groups. Pairwise comparisons were tested at the $p \leq 0.05$ level using Scheffe’s multiple comparisons test.

Procedures for each cement system tested

Zinc phosphate cement (Mizzy, Cherry Hill, NJ)

The zinc phosphate cement used, Fleck’s, was the only cement unavailable in unit dosing. However, as described below, it was carefully measured and mixed by a single examiner precisely to manufacturer’s instructions.

The cap to the zinc phosphate powder bottle was filled to the shoulder of the powder cap dome with zinc phosphate powder (0.4 grams) and the powder was then placed on a clean, dry, room temperature glass slab. The powder was then formed into a flat rectangular shape with a
metal spatula and divided into quarters. One of the quarters was further divided into two eighth segments. One of these eighth segments was then divided into two sixteenths, so that there were six portions total; three quarters, one eighth, and two sixteenths. Twelve drops of liquid (0.30 ml) were dispensed from the completely inverted bottle of liquid and placed on the glass slab. The first sixteenth of powder was added to the liquid and spatulated for 15 seconds, followed by the second sixteenth which was also spatulated for 15 seconds. Then a one-eighth portion was added and mixed for 15 seconds. Two of the three remaining quarters were each added individually and spatulated for 20 seconds. The final quarter was added and mixed for 35 seconds. The total mixing time was approximately 2 minutes and resulted in a mixture that would draw up one inch from the glass slab with the flat end of the spatula.

A thin layer of cement was painted on the inner surface of each casting with a disposable brush. The implant/abutment assembly was supported up to the polished implant surface in a wooden board. The casting was seated onto the implant/abutment assembly with finger pressure until hydraulic pressure was fully relieved, then placed under a 10 kg weight for ten minutes at room temperature. After 10 minutes, the excess cement was removed with a metal scaler.

**Resin composite cement** (J. Morita USA, Tustin, CA)

The resin cement used, Panavia 21, has a special dispensing system and was chosen specifically for its unit dosing, which allowed repeatable and consistent mixing. Prior to cementation with Panavia 21, the inner surfaces of the castings used to evaluate this resin cement were tinplated according to the manufacturer’s instructions using the Micro-tin Dental Plating System (Danville Engineering, Inc., Danville, CA).
Equal amounts of Panavia 21 Universal base and catalyst were dispensed onto a mixing pad using one full turn of the dispensing unit until a click was heard. The two components were mixed for 20 to 30 seconds until a smooth, uniform paste was formed. Because of Panavia 21’s anaerobic properties, the mix was then spread into a thin layer on the mixing pad until ready to use. One drop of ED Primer Liquid A and Liquid B were dispensed into a mixing well and mixed for 3 to 5 seconds. With a disposable brush, the implant abutment was coated with the Primer A/Primer B mixture. After 60 seconds, the volatiles were evaporated with a gentle stream of air. The mixed Panavia 21 paste was then placed into the tin-plated casting using a new disposable brush. The casting was seated onto the implant/abutment assembly with finger pressure and held for 60 seconds. The casting/abutment/implant assembly was placed under a 10 kg weight, and the excess Panavia 21 paste removed at the casting/implant margin with a new disposable brush. Next, Oxyguard II, the oxygen barrier provided with Panavia 21, was applied with another disposable brush to the casting/implant margin to avoid an oxygen-inhibited layer. After 3 minutes, the Oxyguard II was wiped off with wet gauze. Any hardened excess cement was finally removed with a metal scaler only after a total of ten minutes had passed.

**Glass ionomer cement** (GC America, Alsip, IL)

The glass ionomer cement used, Fuji I, is available in a single dose capsule form and was chosen for its ease of use and for optimal consistency in mixing of the cement. Before activation, the capsule was shaken and tapped against a hard surface to loosen the powder. The pre-measured capsule was activated by compressing the plunger on the capsule until flush with the main body. The capsule was then mixed in an amalgamator set at high speed for 10 seconds. The mixed capsule was loaded into the manufacturer-supplied capsule applier and the cement
dispensed onto a mixing pad. The cement was placed into the casting using a disposable brush, and the casting seated onto the implant/abutment assembly with finger pressure until hydraulic pressure was fully relieved. It was then placed under a 10 kg weight for ten minutes at room temperature. After 10 minutes, the hardened excess cement was removed with a metal scaler.

**Resin-modified glass ionomer cement** (GC America, Alsip, IL)

The resin-modified glass ionomer cement used, Fuji Plus, is also available in a single dose capsule form and was also chosen for its ease of use and for optimal consistency in mixing of the cement. Before activation, the capsule was shaken and tapped against a hard surface to loosen the powder. The pre-measured capsule was activated by compressing the plunger on the capsule until flush with the main body. The capsule was mixed in an amalgamator set at high speed for 10 seconds. The mixed capsule was loaded into the manufacturer-supplied capsule applier and the cement dispensed onto a mixing pad. The cement was placed into the casting using a disposable brush, and the casting seated onto the implant/abutment assembly with finger pressure until hydraulic pressure was fully relieved. It was then placed under a 10 kg weight for ten minutes at room temperature. After 10 minutes, the hardened excess cement was removed with a metal scaler.

**Zinc oxide non-eugenol cement** (Cadco, Oxnard, CA)

The zinc oxide non-eugenol cement used, ZONE, is available in a single dose form and was chosen for its ease of use and for optimal consistency in mixing of the cement. The single dose packets are pre-measured with an equal amount of catalyst and base in separate pouches (net weight = 0.75 grams). The packet was opened at the indicated dotted line, and with an
orangewood stick, the complete contents of both pouches were extruded out of the packet and onto a mixing pad. The two components were mixed together for 10 seconds until the cement had a creamy consistency and uniform color. The cement was applied to the internal surface of the casting using a disposable brush. The casting was seated onto the implant/abutment assembly with finger pressure until hydraulic pressure was fully relieved and placed under a 10 kg weight for ten minutes at room temperature. After 10 minutes, the hardened excess cement was removed with a metal scaler.
V. RESULTS

Cementation of the castings as described in the Materials and Methods section resulted in 60 samples suitable for testing. One sample was omitted from the Panavia 21 group cemented onto the anodized abutment because the metal occlusal ring fractured during retentive testing in the Instron, and the casting was unable to be pulled from the abutment/implant assembly.

Data was collected from the remaining 59 samples and the raw data for the 5 cements and 2 surfaces is presented in ascending order within each group in Table 2. Tables 3 and 4 and Figures 14 and 15 present the mean retentive readings in kilograms that resulted in catastrophic failure for each of the cement systems for the anodized and non-anodized abutments, as well as their standard deviations and standard errors.

The ANOVA results demonstrated a statistically significant difference between the 5 cements at \( p \leq 0.001 \). However, there was no statistically significant difference (\( p=0.7185 \)) observed in retention with the addition of the anodized surface treatment. Multiple comparison analyses suggested that of the cements used, the resin cement demonstrated the highest mean retention (\( p \leq 0.05 \)) with both anodized and non-anodized abutment surfaces. The next most retentive cements were zinc phosphate and resin-modified glass ionomer, which were different from all other cements (\( p \leq 0.05 \)) but not from each other for both the anodized and non-anodized surfaces. Glass ionomer had retentive characteristics similar to zinc oxide non-eugenol for both the anodized and non-anodized surfaces. These cements had the lowest retention values recorded (Figures 14 and 15).

An analysis of the interaction of the cements and the surface preparation of the abutments was also performed. The findings showed that the cements did not respond in the same way to the anodized surface (\( p \leq 0.002 \) for the interaction term). While the retention may have decreased
for one of the cements, they increased for the others with no specific or consistent trend. It appears, therefore, that retention overall was not altered by the use of anodized abutment surfaces.

The mode of failure of the cement was further investigated visually at the time of retentive testing. Cement failure in the resin cement and resin-modified glass ionomer cement occurred within the cement itself. Cement was found to remain partly on the abutment and partly in the metal casting after tensile testing. This was true for both anodized and non-anodized abutments. The zinc phosphate, glass ionomer, and zinc oxide non-eugenol cements all failed at the cement-abutment interface, and all of the cement remained inside the metal casting, leaving the abutment surface clean.
VI. DISCUSSION

This study examined the use of cements with an 8° tapered titanium abutment. Clayton et al.\textsuperscript{21} used a similar selection of permanent and provisional cements with the CeraOne abutment and recorded higher retentive values for zinc phosphate than for resin cement. The differing results between that study and this one may be related to the difference between a 0° taper in the CeraOne abutment and an 8° taper (total convergence of 16°) in the ITI abutment. With a parallel-sided abutment, compressive strength of the cement may play a more important role than in a situation with a tapered abutment, where the effect of adhesion, shear, and tensile strength become increasingly important.

The ITI implant abutment has an 8° taper that differs from the implant abutments used in other studies to date. With human teeth, a decrease in cement retention has been demonstrated with increasing preparation taper.\textsuperscript{28, 29, 68} Whether this holds true for cementation between metal components may be assumed, but is still unknown. There are presently no studies evaluating the change in retention when cementing metal castings to implant abutments of varying taper.

The question arises, then, as to how much retention is necessary when cementing implant restorations. Retention is based not only on the cement used, but also on the roughness of the inner surface of the casting, the taper, the surface texture of the abutment, the overall abutment height, and the surface area available to the cement.\textsuperscript{16} The decision to use provisional versus permanent cement should be based on how retentive a given cement is and the degree of retention needed.

The retentive values of the luting agents used in this investigation can be compared only loosely to those obtained with retentive testing of conventional fixed restorations to natural teeth. First, the metal abutment cannot be precisely compared with dentin as a surface to cement
castings to. In addition, while the implant abutment taper and height was fixed in this study, the studies comparing retention of cements on natural teeth each use natural tooth preparations of different tapers, heights, and surface areas. Depending on the study design, the values for retention reported for the different classes of dental luting agents in the literature were similar to those obtained in this study, except for the glass ionomer cement.

In this study, the zinc oxide non-eugenol cement performed as predicted for natural teeth and was minimally retentive. The composite resin, resin-modified glass ionomer, and zinc phosphate cements also performed as expected and were highly retentive. Surprisingly, though, the glass ionomer cement, which is used routinely as a permanent luting agent for natural tooth structure, did not perform as anticipated and was minimally retentive with metal implant abutments.

The location and manner of cement failure may be another important consideration in the selection of a cement when retrievability is desired. A cement that adheres to the implant or abutment may be difficult to remove and attempts to do so may damage the surfaces. Furthermore, decreased retention may result after recementing to that abutment if cement remains permanently attached to the abutment. In this study, failure in the resin cement and resin-modified glass ionomer cement occurred within the cement itself (cohesive failure). Thus, these two cements may prove difficult to use clinically for these reasons.

In two studies investigating the use of luting agents with metal-to-metal cementation, the results were similar to those obtained in this study. Imbery et al. found that cohesive failure occurred in the two resin cements (Panavia EX and C&B Metabond) used in their study, suggesting the alloy-resin bond exceeded the cohesiveness of the two resin cements. Diaz-
Arnold et al.\textsuperscript{44} also found both cohesive and adhesive fractures with the resin cement, Panavia Opaque, after storage in water prior to retentive testing. Mojon et al.\textsuperscript{43} found on SEM examination of their adhesive resin samples cemented to amalgam that separation occurred within the cement itself. In their study using provisional luting agents with the Steri-Oss implant system, Ramp et al.\textsuperscript{16} found that for 5 of the 6 provisional cements used, failure occurred at the abutment/luting agent interface and was primarily adhesive in nature. Only one cement failed at the casting/luting agent interface, and in general, minimal cohesive failure was recorded.

In a study using luting agents to cement crowns to natural teeth, Caughman et al.\textsuperscript{41} used the same two resin cements (Panavia EX and C&B Metabond) and observed that some luting cement remained on both the tooth and the internal casting surface after tensile testing. In contrast, Ernst et al.\textsuperscript{33} found that with the resin-reinforced glass ionomer used in their study (Dyract Cem), most of the remaining cement failed adhesively and was found inside the crowns. The comparison, though, of adhesive versus cohesive failure of cements may not be valid when comparing a metal-to-tooth situation with a metal-to-metal situation.

It is unlikely that the alloy type used in this investigation was as important as the surface treatment of the metal. That is, the surface roughness caused by sandblasting of the internal aspects of the castings, rather than type of metal, was more likely to be the critical factor in retention of the castings to the abutments. In this investigation, cast noble metal alloy was used to simulate the castings routinely used for implant restorations.

The retrievability issue and the possible need for re-cementation of loosened crowns demonstrate the difference between new, clean surfaces versus re-cementing previously cemented components. Previous studies\textsuperscript{15, 16, 20, 22, 23, 25, 26} included the reuse of paired abutments and castings for retentive testing. The effect of repeated use of components on retentive values
of cements is unknown, but there is a possibility that changes occur on the inner surface of the metal castings or on the machined abutment surfaces after cementation, removal, and cleaning that alter subsequent retention between the same components. This study examined only initial retention as each casting and abutment pair was used only once.

The effect of thermocycling of test specimens on retention of luting agents used with metal implant components has been examined once previously. GaRey et al.\textsuperscript{22} found that thermocycling had minimal effect on retention when cementing abutments into internally threaded implants. Clayton et al.\textsuperscript{21} thermocycled samples between 5°C and 55°C for 1000 cycles before performing tensile testing of gold cylinders cemented onto CeraOne abutments. Zinc phosphate cement was found to be the most retentive cement for the 0° tapered CeraOne abutment. All specimens in their study, however, were subjected to thermocycling, and thus, the effect of this procedure could not be examined. The present study followed a similar protocol that subjected all specimens to thermocycling, and as a result, did not examine this effect either.

Finally, the results of this investigation found that anodization, or coating, of the abutment surface was not a factor in cement retention. To the author’s knowledge, this is the first study to report on this feature, and future studies will be needed to determine conclusively if this finding is reproducible.

The variation of the results with regard to the large standard deviations seen here is most likely due to the variations in cements and film thicknesses. Another factor could have been the inclusion of voids in the cement layer at the time of seating. Because the abutments and castings were all uniform with a 5.5 mm height and an 8° taper, variations of retentiveness were probably due to cement variables and not to the metal components.
Statistical analysis of the data was performed using an ANOVA. Because of the small sample number in this study, there is no question that there was an exaggeration of the assumptions used to perform this statistical test. Another approach, given the scarcity of the data, would be to have used a non-parametric ANOVA (i.e.- the Kruskal-Wallis one-way ANOVA). The use of this test would have helped to eliminate the assumptions that the traditional ANOVA makes: 1) a normal distribution of the data within each group, 2) the same variance within each group, and 3) the observations are random and independent. The first two assumptions were most violated in this study, where sample size did not approach needed numbers for these assumptions to be made. The downside to the use of the Kruskal-Wallis test, however, is that it is a less powerful and versatile tool than a traditional ANOVA, and therefore may not have provided the results that the ANOVA revealed.

The use of the ANOVA in this exploratory study was broad, and certainly less conservative than using a non-parametric ANOVA. However, because in actuality this investigation resembled more of a pilot study in sample size, the use of the ANOVA allowed a look into possible leads and new directions for future research.
VII. CONCLUSIONS

The following conclusions were made:

1. Resin cement demonstrated the highest mean retention.

2. Glass ionomer and zinc oxide non-eugenol cements exhibited the lowest mean retention.

3. Zinc phosphate and resin-modified glass ionomer showed intermediate mean retention.

4. Use of an anodized abutment surface does not appear to affect retention.

5. Resin and resin-modified glass ionomer cements failed cohesively, leaving residual cement on the abutment and the implant shoulder.
VIII. FUTURE RESEARCH

The results of this study provide some of the first data on cementing crowns to machined tapered titanium implant abutments. As such, this research provides a methodology with which further studies can expand upon.

This study covered only 5 cements and cement systems. These cement systems represent the most generally used cement types in private practice. Other cements should be considered for future studies, including those which some implant manufacturers recommend to be used with their systems (i.e.- Nobel Biocare and Improv® cement).

Variables that simulate clinical conditions can also be further evaluated. Force application to the crowns prior to retentive testing and different thermocycling conditions might be clinically relevant variables to consider.
IX. SUMMARY

This study compared the retention of 5 different types of luting agents used to cement cast noble metal alloy crowns to 8° machined titanium cementable implant abutments. A zinc phosphate cement, a composite resin cement, a glass ionomer cement, a resin-modified glass ionomer cement, and a zinc oxide non-eugenol cement were examined.

Sixty prefabricated 5.5 mm solid titanium implant abutments and implants were used; 30 with the standard surface preparation and the other 30 with an anodized surface preparation. Anodized implant components were used to reflect current implant marketing. Sixty castings were fabricated and randomly paired with an abutment and implant. A total of 12 castings were cemented onto the implant-abutment assemblies for each of the 5 different luting agents. After cementation, the assemblies were stored in a humidor at room temperature prior to thermocycling for 24 hours. Each casting was pulled from its respective abutment and the force at which failure occurred was recorded as retentiveness in kilograms.

A statistically significant difference was found between the 5 cements at p≤0.001. Of the cements used, resin cement demonstrated the highest mean retentive capability. Zinc phosphate and resin-modified glass ionomer cements were the next most retentive, while glass ionomer and zinc oxide non-eugenol cements demonstrated minimal retention. In addition, retention was not altered by the use of an anodized abutment surface.
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<tr>
<th>Cement Type</th>
<th>Brand</th>
<th>Company</th>
<th>Lot number</th>
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<tbody>
<tr>
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<td>Mizzy, Inc. Cherry Hill, NJ</td>
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<tr>
<td>resin composite</td>
<td>Panavia 21</td>
<td>J. Morita USA Inc. Tustin, CA</td>
<td>61213</td>
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<tr>
<td>glass ionomer</td>
<td>Fuji I</td>
<td>GC America Inc. Alsip, IL</td>
<td>270584</td>
</tr>
<tr>
<td>resin-modified glass ionomer</td>
<td>Fuji Plus</td>
<td>GC America Inc. Alsip, IL</td>
<td>261277</td>
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<tr>
<td>zinc oxide non-eugenol</td>
<td>ZONE</td>
<td>Cadco Oxnard, CA</td>
<td>52180</td>
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Table 2. Raw data for the 5 luting agents tested. Values represent the force in kilograms at catastrophic failure of the cement.

<table>
<thead>
<tr>
<th></th>
<th>Zinc phosphate</th>
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<tr>
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<td>35.00</td>
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<tr>
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</tr>
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Table 3. Mean retentive values in kilograms with anodized abutments.

<table>
<thead>
<tr>
<th>Luting agents</th>
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<th>Mean</th>
<th>SD</th>
<th>Standard Error</th>
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<td>27.58</td>
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<td>composite resin</td>
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<td>2.11</td>
<td>0.86</td>
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</tbody>
</table>

Table 4. Mean retentive values in kilograms with non-anodized abutments.

<table>
<thead>
<tr>
<th>Luting agents</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>zinc phosphate</td>
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<td>29.71</td>
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<tr>
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<td>42.29</td>
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<td>6</td>
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<td>0.63</td>
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Figure 1. ITI implants with non-anodized abutment (A) and anodized abutment (B).
Figure 2. Prefabricated plastic burn-out coping and solid abutment analog used to fabricate metal castings.
Figure 3. Plastic coping seated onto abutment analog. Coping “snaps” over implant shoulder with an extended plastic lip.
Figure 4. Wax ring added to occlusal portion of waxed coping for retentive testing.
Figure 5. Final wax-up for metal casting before investment and casting.
Figure 6. Sprued wax patterns ready for casting.
Figure 7. Metal ceramic alloy castings after divestment.
Figure 8. Internal surface of castings before removal of metal lip past implant shoulder.
Figure 9. Internal surface of castings showing flat side and milled beveled shoulder.
Figure 10. Cementation technique. A thin layer of cement was applied to the inner surface of each casting with a disposable brush.
Figure 11. Standardized pressure jig used to cement castings.
Figure 12. Close-up of castings used for cementation showing ring added for retentive testing.
Figure 13. Jig used for retentive testing in Instron universal testing machine.
Figure 14. Retentive values with anodized abutments.
Figure 15. Retentive values with non-anodized abutments.
X. BIBLIOGRAPHY


