COMPARATIVE EVALUATION OF TENSILE BOND STRENGTH OF LUTING CEMENTS WITH EFFECT OF ABUTMENT ANGULATION ON RETENTION OF CEMENT-RETAINED IMPLANT SUPPORTED RESTORATIONS - AN IN VITRO STUDY

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In partial fulfillment for the Degree of

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BRANCH I

PROSTHODONTICS AND CROWN & BRIDGE

APRIL 2013

CERTIFICATE

This is to certify that the dissertation titled **"COMPARATIVE EVALUATION OF TENSILE BOND STRENGTH OF LUTING CEMENTS WITH EFFECT OF ABUTMENT ANGULATION ON RETENTION OF CEMENT-RETAINED IMPLANT SUPPORTED RESTORATIONS- AN IN VITRO STUDY"** is a bonafide record work done by **Dr. Parvez Ahmad Khan** under our guidance and to our satisfaction during his post graduate study period between 2010 – 2013.

This dissertation is submitted to **THE TAMILNADU DR. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the Degree of **MASTER OF DENTAL SURGERY – PROSTHODONTICS AND CROWN & BRIDGE, BRANCH I.** It has not been submitted (partial or full) for the award of any other degree or diploma.

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ABSTRACT

Purpose: The objective of this in vitro study was to compare the tensile bond strength of three different luting cements on retention of cement retained implant-supported cast copings cemented on straight and 15° angulated titanium implant abutments.

Material and Methods: A total of sixty (n-60) implant analogs, straight and 15°angulated titanium implant abutments of thirty (n-30) each were selected. The implant analogs were embedded vertically in autopolymerizing acrylic resin blocks. The abutments were fixed to the implant analogs. The cast copings with a loop on the occlusal surface were fabricated with Ni-Cr alloy. The cast copings were luted to implant abutments with three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement. All the test samples were kept in distilled water at 37°C for 24 hours for aging. Tensile force was applied to separate the cast copings from the abutments and peak load to dislodgement was recorded, using universal testing machine. Statistical analyses were performed using One-wayANOVA test and multiple range Tukey- HSD procedure.

Results: The mean tensile bond strength of dual cure resin cement was significantly higher in both straight and 15°angulated titanium implant abutments (3.75±0.21, 3.35±0.07) respectively, followed by glass ionomer cement (2.34±0.04, 1.97±0.08) and the least value with zinc phosphate cement (2.08±0.12, 1.75±0.11).

Conclusion: Dual cure resin cement exhibited the highest retentive value compared to glass ionomer cement and zinc phosphate cement with both types of abutments in this study. The cast copings cemented with the cements used in this study on straight titanium implant abutments exhibited higher retention compared to 15° angulated titanium implant abutments. The retention of cast copings are influenced by the type of luting cement and the type of implant abutment.

Key words: Implant abutments, luting cements, retention, tensile bond strength.

INTRODUCTION

Implant therapy is a well-documented treatment for replacement of missing teeth in completely or partially edentulous patients.[23] Implant supported prosthesis are an established treatment option for those patients with long term success. The success of the oral rehabilitation of implant patient depends not only on osseointegration of the implant fixtures but on maintaining the integrity of the connection of the prosthetic superstructure to these fixtures.[4] Currently, there are many options for prosthetic designs that differ from those proposed by Branemark et al. These options are related not only to the materials used, but also to the method of fixation of the restorations to the implant.[30]

Retention of implant-supported restorations plays an important role in success of the treatment.[38] The factors that influence the selection mode of retention of implant-supported fixed prosthesis include passivity of fit, interarch space, occlusion, esthetics, and retrievability of prosthesis.[36] Implant restorations can be screw-retained, cement-retained, or a combination of both.[36,38] 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 material or abutment screws remain 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, and easier control of occlusion, simplicity, lower cost, 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.[53]

Implant designs, surface modifications and successful osseointegration of implant materials and soft tissue management techniques have allowed the single tooth implant procedure to become a viable treatment option.[51] Since it is difficult to achieve a passive-fit of frame-work for screw-retained implant restorations, cement-retained implant prostheses have become increasingly popular for single tooth replacement.[19,41] The success of cement-retained designs depends largely on adequate retention and resistance. The factors that influence retention of the cement-retained implant restorations are well documented, and are basically the same as those on natural teeth, such as convergence of axial walls, surface area and height, roughness of the surface, and type of cement.[3, 29, 51]

Although cement-retained prostheses are the restorations of choice for many of the implant patients, it is a fact that, in comparison to screw retained restorations, these prostheses have limited scientific documentation.[36] The type of cement used is also an important consideration because it affects the retention characteristics of the restoration.[14,36] 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.[14]

The ideal cement would provide sufficient retention to prevent loosening during normal service but allow the restoration to be removed without damaging to the tissue interface, abutment, or the restoration.[42] Cement that is too retentive may lead to damage of implant, implant abutment, abutment screw and the prosthesis if an aggressive removal technique is used. However, cement that is not retentive enough could be a potential source of failure of retention of the restoration.[52]

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 cost.[36] Cements used for luting cast coping to the implant abutment are either provisional or definitive. The definitive cements are used to increase retention and provide good marginal seal for the restorations. Provisional cements are used primarily for interim restorations to facilitate their removal. Although the retention values of provisional luting agents are lesser than those of permanent luting agents, implant abutments are not at risk for caries.[36] Therefore, the use of provisional cements may be considered to facilitate the removal procedures without damaging the restoration or the implant or its abutment. However the physical properties of provisional cements, like low tensile strength and high solubility might result in high risk for loss.[60]

The various definitive cements like zinc phosphate, glass ionomer, zinc polycarboxylate, resin composite and resin modified glass-ionomer are used on implant abutments to increase retention, provide good marginal seal and to significantly enhance the cement failure loads of the prosthesis luted to titanium abutment in comparison to provisional luting agent.[14]

The use of different cements, protocols, and implant systems may alter the retentive strength of implant supported restorations. In addition different aging process can also affect the retentive strength of the cement.[38] Many types of cements in use today were developed to provide bonding to natural tooth surfaces. However, subsequent to the success of dental implants, they have also been used for cementation of interim and definitive prostheses (metal or ceramic) to implants.[41] Although there is some published material on the retentive strength of both definitive and provisional cements when used with natural teeth and crowns, there is not a large volume of information regarding the generalizability of these results to metal implant components.[37]

Dental implants have been proven to be active way of restoring the function, esthetics in edentulous patients. But in some real clinical situations, severely resorbed bone may result in inappropriate implant alignment, which can cause disparities between the implant and the abutment long axes. Under such circumstances, difficulties will be encountered in future prosthesis fabrication. In these conditions an angled abutment is often the treatment of choice for prosthodontic restoration.[23] The use of angled abutments also facilitates paralleling of nonaligned implants, thereby making prosthesis fabrication easier, and can aid the clinician in avoiding anatomical structures when placing the implants. In addition, use of angled abutments can also reduce treatment time, fees and the need to perform guided bone regeneration procedures.[6] The angulation of these abutments varies from 15^o to 35^o.[9] The clinical performances of angled abutments have mostly been satisfactory.[9,23] In the literature, more studies have reported on the retentive characteristics of luting cements on straight implant abutments, but studies regarding the effect of abutment angulation on the retention of cement-retained implant supported restorations are lacking.

Thus the determination of the relative retentive strengths of different cements on straight and angulated implant abutments is therefore of clinical significance. Static tensile loading is commonly used for testing crown retention provided by cements because it provides an estimation of the bond strength of the crown during mastication and the force required to remove the restoration.

In view of the above, the present in-vitro study was conducted for the comparative evaluation of the tensile bond strength of three different luting cements, namely, zinc phosphate cement, glass ionomer cement and dual cure resin cement on retention of implant supported cast copings cemented on straight titanium implant abutments and 15^{o} angulated titanium implant abutments.

The objectives of the present in-vitro study included the following:

1. To evaluate the tensile bond strength of zinc phosphate cement for luting cast copings on straight titanium implant abutments.

2. To evaluate the tensile bond strength of glass ionomer cement for luting cast copings on straight titanium implant abutments.

3. To evaluate the tensile bond strength of dual cure resin cement for luting cast copings on straight titanium implant abutments.

4. To evaluate the tensile bond strength of zinc phosphate cement for luting cast copings on 15^{o} angulated titanium implant abutments.

5. To evaluate the tensile bond strength of glass ionomer cement for luting cast copings on 15^{o} angulated titanium implant abutments.

6. To evaluate the tensile bond strength of dual cure resin cement for luting cast copings on 15^{o} angulated titanium implant abutments.

7. To comparatively evaluate the tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure

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8. To comparatively evaluate the tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on 15^{o} angulated titanium implant abutments.

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11. To comparatively evaluate the tensile bond strength of dual cure resin cement for luting cast copings on straight titanium implant abutments and on 15^{o} angulated titanium implant abutments.

12. To comparatively evaluate the tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on straight titanium implant abutments and on 15^{o} angulated titanium implant abutments.

REVIEW OF LITERATURE

KAUFMAN EDWARD G. (1961)[26] studied to evaluate the factors which influences retention was, tooth preparation, casting and the cementing media. The tests were made on metal dies with controlled variation in height and angle of convergence, diameter and was found that there is not much effect of height on retention with reduced diameter and increased angle of convergence, but had a significant increase in retention with the increase in diameter and decrease in angle of convergence.

Richter William A. et al (1975)[47] in this study it was evaluated that dental cements suffer dissolution in the mouth is of considerable concern while restoring teeth with cast restoration. In this study, the in-vivo degradation of dental cements was evaluated. Four different cements such as zinc phosphate, zinc silicophosphate, ZOE-EBA with alumina and zinc polycarboxylate cements were placed in cavities prepared in the pontics of temporarily cemented fixed partial dentures and found that the zinc silicophosphate cement was the most impervious to wear then zinc phosphate, ZOE-EBA or zinc polycarboxylate cement.

Shillingburg HT Jr, Potts RG, Duncanson MG Jr. (1980)[49] Compared the relationship between degree of taper, surface area, preparation length and the force necessary to remove cemented castings from machined dies. Five preparation designs were tested for retention and resistance. Retention values for all partial veener crowns were significantly lower than those for the complete veener crown. Resistance values increased significantly with the addition of grooves and or extension of axial surface coverage produced small increase in retention values but marked increases in resistance values.

Weed, R.M, et al (1984)[58] Author in his studies evaluated the factors which are responsible for the contribution of resistance form to dislodge the complete cast crown. Before crown preparations are made, factors such as length, diameter, and occlusal convergence angle must be evaluated. The result was noted that as the convergence angle increases, the resistance to displacement decreased.

Schneider RL. (1987)[50] **s**tudied to evaluate the comparative retentive values of various dental cements to the gold castings, the four cements used in the studies were zinc phosphate cement, polycarboxylate cement, glass ionomer cement, and zinc silicophosphate cement to various dental implants manufactured in different materials and with varying head design. In the retention a significant difference was found between these four cements, among the most retentive was glass ionomer and the then followed by zinc phosphate cement, zinc silicophosphate cement, and polycarboxylate cement.

Breeding Larry C. et al (1992)[4] compared the retentive strength of castings cemented on machined titanium implant abutments and on human premolar with three provisional luting agents. A comparison between the retentive strengths of cast noble metal implant abutments cemented on fixtures with three permanent luting agents both dry and after storage in 0.9% physiological saline for 30 days at 37° C. Author concluded that no significant difference were noted in retentive values between the castings cemented on the titanium abutment and the natural tooth. The

Temp Bond zinc oxide-eugenol luting agent exhibited a lower mean retentive strength than IRM reinforced zinc oxide-eugenol and life calcium hydroxide luting agent. Castings cemented with Ketac Cem glass-ionomer cement on abutments that were stored in saline, exhibited a significantly higher mean retentive strength than casting cemented on abutment either with Core Paste or Resiment resin luting agents.

Dixon DL et al (1992)[11] studied to determine the amount of die spacer necessary to reduce seating discrepancies of casting cemented onto implant abutments and to determine the effect of this on the luting-agent for the crown retention. Noble metal castings were made with 0.001 inch, 0.002 inch, and 0.003 inch spacing for pre-manufactured titanium implant abutments. The castings were cemented onto the abutment with three permanent luting agents Core Paste, Resin cement, and zinc phosphate. Seating discrepancies of each casting and abutment combination were measured, and the castings were pulled from the abutments by using tensile force. The results of this study concluded that: (1) Spacing did not reduce retentive values for any of the specimen group. The resin luting agent groups exhibited consistently higher retentive strength than the zinc phosphate cement specimens. (2) Zinc phosphate cement and Resinment luting agents exhibited seating discrepancy values below 25 μm with 0.001 inch luting agent spacing. Core Paste cemented specimens required 0.003 inch spacing to show values below 25μm.

Cleland Nancy L., Gilat Amos (1992)[9] The purpose of this study was to compare the effect of abutment angulation on stress transfer to an implant. In this study five abutment angulations of a specific implant system was used. Photoelastic resin was cast directly to a 3.75 × 10mm Branemark fixture in a 50 × 70 × 13 mm mold. A strain gauge rosette was also incorporated in the resin to allow precise determination of normal stresses at a specific point. Each 4mm abutment with 15^o, 25^o, and 35^o from implant innovations was assembled on the fixture and subjected to 178N load, and viewed with a circular polariscope. Observed fringes were photographed and strain indicator reading were recorded and it was concluded that (1) the stress distribution is more favorable for abutments of less angulations (2) All of the five abutment angulations evaluated produced strains at the location of the rosettes that were within the physiological zone for bone as reported by Martin and Burr; (3) higher stress and strain can be expected closer to the fixture.

Lorey RE et al (1993)[32] in this study, the potential for bonding titanium was evaluated by cementing with various adhesives: (A) metal to metal, (B) metal to enamel, and (C) comparing with a known procedure of bonding nickel-chromium. The resin-metal adhesives used were: (1) Infinity, (2) Metabond, (3) All-Bond 2, and (4) Panavia. It was concluded that titanium bonded restorations with certain adhesive cements were a definite possibility.

GaRey DJ et al (1994)[18] This study compared the effects of thermocycling, load cycling, and human blood contamination on the retentive strength of five different cements for luting posts to root-form implants. In this study an Instron machine used indicate that thermocycling did not significantly reduce retentive strength of the test cements. The combination of thermocycling, cyclical load-stressing, and blood contamination substantially reduced the retentive strengths for all the cements. This suggests that blood adversely affects the retentive strength of the cements tested more than other variables.

Agar JR et al (1997)[1] compared the surfaces of abutments after removal of three cements (glass ionomer, resin, and zinc phosphate) by use of three instruments (gold coated scaler, rigid plastic scaler and stainless steel explorer). The stainless steel explorer appeared to produce the deepest scratches. The stainless steel explorers had sharp tips and they were hard compared with the relatively soft titanium of the abutment. These characteristics favored deep gouges with the tip or swaging of the metal when the side of the explorer was used aggressively during cement removal. Gold scaler appeared to produce multiple shallow scratches per stroke. When the tips of the gold scaler were used, they produce some gouges, but these appeared broader and shallower than those made with the stainless steel explorer. The plastic scaler created multiple scratches per stroke that were shallower than the stainless steel explorer. The tips of the plastic scaler did not appear to cause gouging as deep as the other instruments. Author concluded that clinicians should be aware of potential problems when cementing restorations with subgingival margins. They may be leaving more cement remnants and/or causing more scratches and gouges on restorations and abutments than they realize. Clinicians should be particularly careful when using resin cements. Stainless steel explorers probably should not be used to remove cement from subgingival abutment margins.

Keith Scott E and Miller Barbara H et al (1999)[27] This in vitro study quantified the marginal discrepancy of the implant-to-prosthetic-crown interface on submerged dental implants restored with either a cemented or screw-retained prostheses. Two cements used in this study were zinc phosphate cement and glass ionomer cement. It was concluded that the marginal discrepancy of screw-retained metal ceramic crowns on implant abutments were significantly smaller than that of cemented metal-ceramic crowns. The mean marginal discrepancy of metal-ceramic crowns cemented on implant abutments with glass-ionomer was significantly smaller than those cemented with zinc phosphate cement.

Covey David A., Kent Dennis K (2000)[10] this study was done to evaluate the effect of abutment size and luting cement type on the uniaxial retention force of implant-supported crowns. In this study the wide Cera One titanium implant abutments and matching Cera One gold cylinders were used. Three sizes of implant abutments and two types of cement were also evaluated like (1) zinc phosphate cement (2) zinc oxide eugenol cement. Dimensions of the abutments were recorded. With respective cements the cylinders were seated onto the abutment and loaded in compression at 20N for 10 minutes. Specimens were tested in tension using a universal testing machine. This study tested the hypothesis that implant abutment dimensions caused different failure stresses with Cera One components and 2 luting agents. The results support this hypothesis because of permanent cement led to significantly greater retention than use of provisional luting agent but implant abutment size is also a significant factor in crown retention.

Michalakis Konstantinos X (2000)[35] in this study the author evaluated the cement failure loads of 4 provisional luting agents used for the cementation of FPDs supported by 2 implants or 4 implants. It was concluded from the study that Nogenol luting agent exhibited the lowest retentive values in both types of FPD. ImProv proved to be the most retentive cement of all the tested cement. It was also concluded from this study that the Nogenol appears to be more appropriate for cementation of both 2 and 4 implant-supported FPDs when removal of the provisionally cemented superstructure is anticipated.

Guichet David L, Caputo Angelo A (2000)[21] This study compares the passivity of fit and stress generation upon the placement of screw-retained or cement retained implant restorations on a Photoelastic model. It was concluded in this study that the marginal openings were not significantly different prior to placement but following placement; marginal openings of screw-retained FPDs were significantly smaller than cement-retained FPDs. The screw-retained design exhibited variability in the intensity and location of stress, with instances of high apical stress concentrations. The cement-retained FPDs produced similar, low-level stresses, with a tendency towards coronal location. There was a decreased marginal opening with screw tightening and was associated with higher stress in the screw-retained restorations. While as the cemented restoration was associated with less stress generation in the bone model.

Squier RS et al (2001)[53] compared retentiveness of dental cements used with metallic implant components. The cements used for this study were zinc phosphate cement, resin composite cement, glass ionomer cement, resin-reinforced glass ionomer cement and zinc oxide-non-eugenol cement. Author has concluded that (1) Resin cement demonstrated the highest mean retentive strength.(2) Glass-ionomer and zinc oxide-non-eugenol cement exhibited the lowest mean retentive strengths.(3) Zinc phosphate and resin-reinforced glass ionomer showed intermediate mean retentive strengths.(4) Use of an anodized abutments surface does not appear to affect retentive strength.(5) Resin and resin-modified glass-ionomer cement failed cohesively, leaving residual cement on the abutment and implant shoulder.

Okamato M et al (2002)[40] describes a technique for removing a cemented superstructure from implant abutments. A cylindrical guide hole on the lingual surface of the abutment is prepared and an access hole on the lingual side of the superstructure. To remove the superstructure from the abutment, insert a removing driver into the guide hole through the access hole. Turn the removing driver to generate a shear force to raise the superstructure. The shear force will cause the temporary cement layer to fracture and enable removal of superstructure from the abutment. This technique is easy and reliable.

Ergin Sule and Gemalmaz Deniz (2002)[15] The aim of this study was to evaluate the retentive properties of 5 different luting cements on base and noble metal copings to short and over-tapered preparations. Eighty extracted mandibular premolars were prepared to receive full cast copings with a flat occlusal surfaces, 33^o taper and 3mm axial length. Half of the Copings were made in Au-Ag-Pd alloy, while the other half in Ni-Cr alloy. Cementation was done with five cements like phosphate cement (Zinc phosphate), Meron (Glass ionomer cement), Principle (Resin-modified glass ionomer cement), Fuji plus (Resin modified glass ionomer cement) and Avanto (Resin cement). The results showed that the mean dislodgement forces for AuAgPd crowns and Ni-Cr crowns were 120.88N and 143.09N. The retentive strength of Fuji Plus was significantly higher than the retentive strength of the other cements tested on Ni-Cr alloy. It was concluded that all 5 cements can be used satisfactorily when they are prepared according to the manufactures recommendation. However resin and resin-modified glass ionomer cement seem to be better choices for non-retentive coping preparation.

Bernal Guillermo, Okmura Mitsunobu (2003)[3] The purpose of this study was to compare the effect of 20^o and 30^o of total occlusal convergence, the occlusocervical dimension, and the type of cement on the tensile resistance of cement-retained, implant-supported restorations. In this study custom made titanium abutments were selected with TOC angle of 20 degree and 30 degree and occlusal heights of 4.0mm(S) and 8.0mm (L). The cylinders had a 1.0mm shoulder finish line. Two cements were used Fleck's cement (zinc phosphate) and IMProv (zinc oxide eugenol cement). Eight poly vinyl siloxane impressions were made of each abutment, so total of 32 dies were made. Two coats of die spacer were applied. A master wax pattern coping was made. The copings were cemented. A uniaxial tensile force was applied to debond the copings. Preparations with 20 degrees of TOC and 8 mm of occlusocervical dimension had significantly higher mean retentive values for all cements tested. Significant differences in mean strength were observed, the highest tensile resistance was seen with IMProv, followed by Fleck's cement, and the lowest with Temp-Bond plus Vaseline.

Michalakis KX et al (2003)[36] reviewed on Cement-Retained versus Screw-Retained implant restorations. The advantages, disadvantage, and limitations have been discussed on both the types of restorations. Several factors are essential for the long-term success of any implant were reviewed with regards to the both method of fixation. These factors include (1) ease of fabrication and cost, (2) passivity of the framework, (3) retention, (4) occlusion, (5) esthetics, (6) Delivery, and (7) retrievability.

Retrievability is advantageous for servicing, replacement, or salvaging of the restorations and implants necessitated by (1) the need for periodic replacement of prosthodontic components; (2) loosening or fracture of the fastening screws; (3) fracture of abutments; (4) modification of the prosthesis after loss of an implant; and (5) surgical re-intervention. The main disadvantage of cemented prostheses is the difficulty of their retrievability. Although retrieval is needed less often because of the dramatically increased in survival rates for dental implants, the need for future removal of FPDs should not be overlooked. For this reason, provisional luting agents are widely used for the cementation of cement-retained restorations. From various laboratory researches it was concluded that there is a statistically significant difference in the tensile strength of provisional cements. Clinicians are encouraged to use the least retentive cements so that prostheses can retrieve if necessary.

Zidan Omar and Ferguson Gary C. (2003)[61] This study was regarding the evaluation of retention of full crowns prepared with 3 different tapers cemented with 2 conventional and 2 adhesive resin cements. In this study 120 human sound molar teeth were assigned randomly between 12 groups. Four cements used were zinc phosphate cement, conventional glass ionomer cement and 2 adhesive resins cement with three tapers 6^o, 12^o, and $24^o$with each cement. Crowns were casted with a high noble alloy. The 6^o tapper was considered the control within each group. There was a significant difference in the effect of cement and tapper. The retention of crowns prepared with 6^{o} tapper was not significant from 12^{0} taper but was significant with 24^{o} tapper. The type of failure was adhesive in cement (65%) cohesive in the tooth (31%) and assembly failure (fracture of embedding resin) (4%). In the conclusion of this study the type of failure was dependent on the degree of taper and type of cement.

Tomson.P.L.M. et al (2004)[56] reported a patient who developed peri-implant bone loss around 2 maxillary endosseous root-form implants after restoration with cement-retained single crown. Significant localized bone loss around 1 of the implants was due to retained excess cement. Reparative treatment consisted of a guided bone regeneration technique. Following a 9 month period of submerged healing, the implants were re-exposed and restored to complete function.

Bresciano M. et al (2005)[5] studied to evaluate the retention of four cements such as zinc-phosphate cement, zinc oxide-eugenol cement, polyurethane resin cement with and without Vaseline cemented on Procera titanium abutments of 5, 7, and 9 mm of height, with 0 degree, and 8 degrees of convergence angle. Author concluded that the most retentive cement was zinc-phosphate cement, followed by polyurethane cement, polyurethane plus Vaseline, and zinc oxide-eugenol cement.

Hsu Ming-Lun, Chung Tai-Foong, Kao Hung-Chan (2005)[23] this is literature review regarding the clinical application of angled abutments. On the basis of literature reviewed, it was concluded that the clinical performance of angled abutment is comparable to that of straight abutment. The stress/strain generated through off-axis loading increase as the abutment angulation increases, but there is no consensus as to what extent of angle increase will cause implant or bone failure. The data from mechanostat theory were used in the literature as a certain threshold reference to predict possible bone failure. Off-axis loads are said to be detrimental to the surrounding bone. However the clinical performances of angled abutments have mostly satisfactory.

Kaar Darian, Oshida Yoshiki, Andres Carl J, Barco M. Thomas and Platt Jeffery A (2006)[25] The purpose of this study was to evaluate the luting agents and their retentive forces before and after mechanical streeing. Twelve regular Platform Branemark fixtures were used on Cera-One abutments luted with three types of cement ImProv (eugenol free acrylic/urethane polymer based), Ultra Temp (non-eugenol polycarboxylate), and Temp Bond (zinc-oxide) after cycling loading it was concluded that ImProv was most retentive before and after cycling loading, TempBond was the least retentive.

Lawson Nathaniel C., Burgess John O, and Mercante Donald (2007)[29] The purpose of this study was to measure the retention of base metal alloy castings to dentin provided by provisional cement (3 resin-based and 5 zincoxide) and correlate the retention to their flexural strength. Significant differences were found in the flexural strength and retention provided by the various cements. Flexure strength was correlated with cement retention for resin-based cements but not zinc-oxide noneugenol cements. The study concluded that a 20-degree preparation, stronger cements provide increased retention. Therefore, the desired amount of retention should be based on both cement and a clinical evaluation of the preparation.

Markarian Roberto Adrian and Ueda Cristiane et al. (2007)[34] The objective of this study was to compare by photoelastic analysis the stress distribution along a fixed framework placed over angled or parallel implants with different gap values between the framework and the implants. The photoelastic analysis indicated that in the model with parallel implants, stress distribution followed the implant axis, and in the model with an angled implant, a higher and nonhomogeneous stress concentration was observed around the apical region of the lateral implants.

Dudley JE, Richards LC (2008)[14] This study was done for the retention of cast crown copings cemented on implant abutments. Cast crown copings were cemented on Straumann synocta titanium abutments with three different cements like Panavia-F (Resin cement), Ketac Cem (Glass ionomer cement) and TempBond NE (temporary cement). It was concluded that the retention of cast crown copings cemented to Straumann synocta implant abutments with a resin cement, glass ionomer and temporary cement was significantly affected by cement type but not with compressive cyclic loading. Glass ionomer cement provided marginally more retention than 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.

Sheets Jmaes L. et al (2008)[52] The purpose of this study was to assess and compare the retentive nature of common dental cements used in the implant supported cement-retained crown (CRC). It was concluded that the retention values of castings to natural teeth versus metallic implants may be totally different for the same cement and cannot be always compared.

Tarica Diane Yoshinobu et al (2010)[54] The purpose of this survey was to determine what dental cementation protocols are taught and recommended by 62 US dental schools and postgraduate programs. From February to September 2008, 96 questionnaires consisting of 8 questions were sent to the chairperson or director of restorative departments, advanced prosthodontics programs, and implant programs. The questionnaire asked recipients which implant manufacturers provided the products used at their dental schools. Additionally, recipients were queried as to the choice of material and techniques for abutment and restoration preparations prior to definitive cementation. Data were analyzed with descriptive statistics. It was concluded that there are a wide range of implant cementation protocols and materials used however; some common trends were identified among predoctoral and postgraduate programs. The 5 most commonly used materials to fill screw access openings are cotton pellets, composite resin, rubber-based material, gutta-percha, and light-polymerized provisional composite resin.

Tan Kian M. et al (2012)[55] The purpose of this was to evaluate the effect of 5 implant abutment designs on the retention of cement-retained crowns by varying the number and position of the axial walls. It was found the abutment with 2 opposing axial walls had significantly higher retention. The abutment with 3 walls exhibited the second highest retention and was significantly greater than abutments with 2 adjacent walls, 1, and 4 walls. Abutments with 2 adjacent walls and 1 wall were not significantly different from each other. The unmodified abutment with 4 walls exhibited the lowest retention despite having a large retentive surface area.

The author concluded that the retention of cemented crowns on implant abutments is influenced by the number and position of axial walls.

Saber Saleh Fariba, Abolfazli Nader (2012)[51] The aim of this study was to evaluate the effect of abutment height on retention of single casting, cemented on wide-and narrow-platform implant abutments. Thirty–six parallel-sided abutments (Bio horizon Straight Abutment) of narrow platform and wide platform sizes with their analogs were used. In each group the axial wall height of the abutment were 5,4,3,2 mm and the castings were cemented with Temp Bond. A tensile force was applied. The result showed that the mean peak removal force for corresponding abutment was significantly different with platform size and with alteration of axial wall height. It was conclude that the retention of narrow platform with longer abutment exhibited higher tensile resistance to dislodgement.

Nejatidanesh Farahnaz et al (2012)[39] The aim of this study was to evaluate the retention values of implant-supported metal copings using different luting agents. Twenty ITI implant analogs and solid abutments of 5.5-mm height were used. The copings were luted using eight cements with different retention mechanisms (Panavia F2.0, Fuji Plus, Fleck's, Poly F, Fuji I, Temp Bond, GC-free eugenol, and TempSpan). Within the conditions of this study, the resin modified glass ionomer cement, zinc phosphate cement, zinc polycarboxylate cement, and Panavia F2.0 had statistically the same retentive quality and are recommended for definitive cementation of single implant-supported restorations. The provisional cements and glass ionomer may allow retrievability of these restorations.

MATERIALS AND METHODS

The present in-vitro study was conducted for comparative evaluation of the tensile bond strength of three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement on retention of implant- supported metal copings with effect of abutment angulation.

The following materials and equipments were used for the study

Materials Employed:

1. Straight titanium implant abutment (RS-3802, ADIN Dental Implant System Ltd., Israel (Fig.1a)
2. 15^{o} angulated titanium implant abutment (RS-4115, ADIN Dental Implant System Ltd., Israel) (Fig.1b)
3. Implant Analog (RS-5737, ADIN Dental Implant System Ltd., Israel) (Fig.2)
4. Hand hex driver (ADIN Dental Implant System Ltd., Israel) (Fig.3a)
5. Rachet hex driver (ADIN Dental Implant System Ltd., Israel) (Fig.3b)
6. Torque ratchet (Fig.3c)
7. Clear autopolymerizing acrylic resin (DPI, India) (Fig.4)
8. Milling bur(Bredent, Germany) (Fig.5)

9. Polyvinyl Siloxane (PVS) impression material (Aquasil Dentsply-Germany) (Fig.6)

    a) Soft putty /regular set (Fig.6a)
    b) Light body consistency (Fig.6b)

10. Mixing spiral (Yellow-70 mm, Adenta, USA). (Fig.6c)
11. Auto mixing gun (Dispensing Gun 2, Heraeus Kulzer, Dormagen, Switzerland) (Fig.6d)
12. Die stone (Type-IV, Ultra rock, Kalabhai, Mumbai, India) (Fig.6e)
13. Die spacer (Yeti Dental, Germany) (Fig.7a)
14. Die lubricant (Yeti Dental , Germany) (Fig.7b)
15. Inlay casting wax(GC Corporation, Tokyo, Japan) (Fig.7c)
16. PKT instruments (Delta labs, Chennai, India) (Fig.8)
17. Sprue wax (Bego, Germany) (Fig.9a)
18. Surfactant sparay (Uni Coat, Delta, India) (Fig.9b)
19. Silicone investment ring and crucible former (Siliring, Delta labs, Chennai, India) (Fig.9c)
20. Phosphate bonded investment material (Belasm , Bego,Germany) (Fig.9d)
21. Colloidal silica (Bego Sol, Bego, Germany) (Fig.9e)

22. Carborundum separating discs (Dentorium, New York, U.S.A.) (Fig.9f)
23. Ni-Cr alloy pellets (Bellabond Plus, Bego, Germany) (Fig.9g)
24. Distilled water (Nirma Ltd., Gujarat, India) (Fig.10)
25. Aluminum oxide powder, 100 μm (Delta labs, Chennai, India) (Fig.11)
26. Zinc Phosphate cement (GC CORPORATION TOKYO,JAPAN) (Fig.12a)
27. Glass ionomer cement (DENTSPY Detrey GmbH-Germany) (Fig.12b)
28. Dual cure resin cement (RelyX luting U2000, 3M ESPE AG, Seefeld, Germany) (Fig.12c)
29. Agate plastic spatula (GC Corporation, Tokyo, Japan) (Fig.13a)
30. Plastic instrument (API, Manipal, India) (Fig.13b)
31. Hand scaler, anterior (API, Manipal, India) (Fig.13c)
32. Mixing pad (GC Corporation, Tokyo, Japan) (Fig.13d)
33. Two kg weight cast iron (Lakshmi steels, Chennai) (Fig.14a)
34. Custom-made autopolymerizing acrylic resin table (Fig.14b)

Equipments used for this study:

1. Milling machine (Bredent, Germany) (Fig.15)
2. Scanning Electron Microscope (Model S-3400N, Hitachi, Japan) (Fig.16)
3. Dental Surveyor (Paraflex, Bego Germany) (Fig.17)
4. Vacuum mixer (Technico, Technico Laborarty Products Pvt Ltd., Chennai) (Fig.18)
5. Burnout furnace(Technico, Technico Laborarty Products Pvt Ltd., Chennai) (Fig.19)
6. Induction casting machine (Fornax Bego, Germany) (Fig.20)
7. Sandblaster (Delta labs. Chennai, India) (Fig.21)
8. Alloy grinder (Demco, California, U.S.A) (Fig.22)
9. Universal Testing Machine (Lloyd instruments, Farnham, U.K.) (Fig.23)

Description of Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) (Model S-3400N, Hitachi, Japan) (Fig.16) was used to know the surface dimensions of the straight titanium implant abutments and 15^{o} angulated titanium implant abutments. It is an instrument similar to an electron microscope in this beams of electrons are used to scan the surface of a specimen. The beam is moved in a point-to-point manner over the surface of the specimen. The specimen is placed inside the chamber for scanning which is controlled by the computer.

Description of Universal Testing Machine

To obtain the tensile bond strength of zinc phosphate cement, glass ionomer cement, and dual cure resin cement used for luting metal copings on straight titanium implant abutments and 15^o angulated titanium implant abutments with universal mechanical testing machine (Lloyd instruments, Farnham, U.K.) (Fig.23) was used.

Components:

Load frame - usually consisting of two strong supports for the machine.

Cross head - A movable cross head is controlled to move up or down.

Test fixtures- Test samples holding jaws.

It consists of two members, the upper and the lower, which is controlled by the computer. The upper member houses the hydraulic pressure machine and also bears a fixture to hold the metal hook. The lower portion has a bench vice test sample fixture to hold the test samples. Once the machine is started it begins to apply an increasing load on test samples. Throughout the test the control system and its associated software records the load applied for the test samples to debond the copings.

Methodology

The following methodology was adapted for preparation of samples to be tested to evaluate the tensile bond strength of three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement on retention of implant-supported cast copings with effect of abutment angulation.

1. Selection of titanium implant abutments.
   a) Straight titanium implant abutment.
   b) 15^{o} Angulated titanium implant abutment.
2. Milling of straight titanium implant abutment.
3. Measurements of the surface area of the titanium implant abutments.
4. Preparation of silicone mold for resin block.
5. Placement of the implant analog for straight titanium implant abutment in the silicone mold.
6. Placement of the implant analog for 15^{o} angulated titanium implant abutment in the silicone mold.
7. Stabilization of the implant analogs in the mold with clear autopolymerizing resin.
8. Fixation of titanium implant abutments to implant analogs.
9. Fabrication of Ni-Cr alloy cast copings.
   a. Closure of abutment screw access hole.

b. Impression procedure for straight titanium implant abutment and 15^{o} angulated titanium implant abutment.
c. Preparation of master dies with type-IV dental stone.
d. Application of die spacer.
e. Preparation of wax patterns with inlay casting wax.
f. Attachment of loop.
g. Sprue former attachment.
h. Investment procedure.
i. Burn out procedure.
j. Casting procedure.
k. Divesting and finishing of the cast copings.

10. Cementation of Ni-Cr alloy cast copings on straight titanium implant abutments and on 15^{o}angulated titanium implant abutments with three different cements.
11. Grouping of test samples
12. Aging of all the test samples.
13. Testing of test samples for tensile bond strength with universal testing machine.

1. Selection of titanium implants abutments (Fig.24)

Two types of titanium implant abutments were selected for this study.

a. Straight titanium implant abutment. (Fig.24a)
b. 15^{o} Angulated titanium implant abutment. (Fig.24b)

2. **Milling of straight titanium implant abutments (Fig.25)**

Straight titanium implant abutments were kept on surveying table of milling machine. A Micromotor with a milling bur (Bredent, Germany) (Fig.5) was attached to the milling machine (Bredent, Germany) (Fig.25). The surface of the straight titanium implant abutment was milled to eliminate the grooves and to get similar surface as of 15^{o}angulated titanium implant abutment. The same procedure was followed for all thirty (30) straight titanium implant abutments.

3. Measurement of the surface area of the titanium implant abutments (Fig.26)

The surface dimensions of both the straight titanium implant abutments and 15^{o} angulated titanium implant abutments were measured with scanning electron microscope (SEM-Model S-3400N, Hitachi, Japan) (Fig.16) and with the help of mathematical formula (Surface area=$\pi \times d \times h$)surface area was calculated.

4. Preparation of silicone mold for resin block (Fig.27)

The square form of silicone mold was obtained with polyvinyl siloxane and the internal space was kept 20 mm in all dimensions. This mold was used for the placement of implant analogs with the surveyor

5. Placement of implant analog for straight titanium implant abutment in the silicone mold (Fig.29a)

The silicone mold was positioned on the surveying table of Dental surveyor (Bego, Germany) (Fig.17) with its base kept parallel to the floor with the help of spirit level indicators (Fig.28). Straight titanium implant abutment (ADIN Dental Implant System Ltd., Israel) (Fig.24a) was attached to the implant analog (Fig.2) with a hand hex driver (ADIN Dental Implant System Ltd., Israel) (Fig.3a). With the help of straight mandrel an implant analog with straight titanium implant abutment (Fig.1a) was attached to long axis of the surveying arm of the dental surveyor, so that the abutment analog assembly will be parallel to the long axis of the surveying arm of dental surveyor. The surveying arm was adjusted at such a position so that the implant analog will be in the center of the silicone mold, and the platform of the implant abutment was kept 1 mm above the surface of silicone mold (Fig.29a).

6. Placement of implant analog for 15^{o} angulated titanium implant abutment in the silicone mold (Fig.29b)

The silicone mold (Fig.27) was positioned on the surveying table of Dental Surveyor (Bego, Germany) (Fig.17) with its base kept parallel to the floor with the help of spirit level indicators (Fig.28). 15^{o} angulated titanium implant abutment was screwed to the implant analog (Fig.2) with a hand hex driver (ADIN Dental Implant System Ltd., Israel) (Fig.3a). With the help of straight mandrel, 15^{o}angulated titanium implant abutment (Fig.1b) and implant analog assembly was attached to long axis of the surveying arm of the dental surveyor in such a way so that 15^o angulated titanium implant abutment is parallel to long axis of the surveyor arm, which let the implant analog to be at 15^o angulation to the long axis of the surveyor arm. The surveying arm was adjusted at such a position so that the implant analog is in the center of the silicone mold and the platform of 15^o angulated titanium implant abutment was 1 mm above the surface of silicone mold (Fig.29b). This was done for testing the 15^o angulated titanium implant abutment, as universal testing machine can pull samples which are parallel to long axis of the machine to obtain tensile bond strength.

7. Stabilization of the implant analogs in the silicone mold with clear autopolymerizing resin (Fig.29)

After positioning the implant analog (Fig.2) in the silicone mold (Fig.27) in its center, the space around the analog was filled with clear autopolymerizing acrylic resin (DPI, India) (Fig.4). The silicone mold space was filled completely in such a way so that the platform of the titanium implant abutment was 1 mm above the surface of the resin block. The resin was allowed to polymerize and the resin block containing the implant analog was removed from silicone mold. Sixty (60) clear acrylic blocks with implant analogs were made, thirty (30) consists of straight titanium implant abutments and other thirty (30) consists of 15° angulated titanium implant abutments. After stabilizing the implant analog for straight titanium implant abutments, and 15^{o} angulated titanium implant abutments, the abutments were then removed from the implant analog. In this way now the implant analog for straight titanium implant abutment will be parallel to the long axis of the block and for 15^{o} angulated titanium implant abutment the analog will be at an angle of 15^{o} to the long axis of the acrylic block.

8. Fixation of titanium implant abutments to implant analogs (Fig.30)

The titanium implant abutment was placed on the implant analog and the abutment screw was first tightened with hand hex driver (ADIN Dental Implant System Ltd., Israel) (Fig.3a) and followed by tightening the screw to 35 Ncm of torque with a rachet hex driver and torque rachet (ADIN Dental Implant System Ltd., Israel) (Fig.3c). Sixty (60) such samples were obtained in the same way, thirty (30) for straight titanium implant abutments and thirty (30) for 15^{o} angulated titanium implant abutments.

9. Fabrication of Ni-Cr alloy cast copings

a) Closure of the abutment screw access hole (Fig.31)

The screw access hole of the straight titanium implant abutments (Fig.31a) and 15^{o} angulated titanium implant abutments (Fig.31b) were filled and sealed off with polyvinyl siloxane (Aquasil Dentsply-Germany) (Fig.6)

b) Impression procedure for straight titanium implant abutment and 15^{o} angulated titanium implant abutment (Fig.32)

The impression of straight titanium implant abutment and 15^{o} angulated titanium implant abutment were made with single stage putty wash impression technique with a custom made acrylic resin tray (Fig.32a). The light body consistency of polyvinyl siloxane (Aquasil, Dentsply, Germany) (Fig.6b) was syringed on the titanium implant abutment surface, meanwhile the putty consistency of polyvinyl siloxane (Aquasil, Dentsply, Germany) (Fig.6a) was mixed by another operator and the impression was made.

c) Preparation of master dies with type-IV dental stone (Fig.33)

The impression made was then poured with the type-IV dental stone (Ultrarock, Kalabhai, and Mumbai, India) (Fig.6e). The stone was mixed with the water as per the instructions of the manufacturer. The dies were removed from the impression within 1 hour, and the dies were allowed to dry for at least 48 hours before application of die spacer.

d) Application of die spacer (Fig.34)

The master dies were treated with master die hardener and 3 coats of die spacer (Yeti Dental, Germany) (Fig.7a). Each coat will create a space of 10 microns, so three coats will create a space of 30 micron on the die, which simulates the luting cement space, 1mm short of the margin. A fine coat of die lubricant (Yeti Dental, Germany) (Fig.7b) was applied on to the die which allowed easy removal of the wax pattern from the die and prevented the pattern from adhering to the stone die.

e) Preparation of wax patterns with inlay casting wax (Fig.35)

A master wax pattern coping was designed on master dies for straight titanium implant abutment (Fig.35a) and for 15^o angulated titanium implant abutment (Fig.35b). A silicone mold (Fig.36a) was obtained from this wax pattern to allow for multiple wax pattern replications, so that standardized wax patterns could be formed. The inlay casting wax (GC Corporation, Tokyo, Japan) (Fig.7c) was melted and filled in the mold and was pressed on with the type IV die stone master die. The master die and the mold were held together for 1 minute with finger pressure (Fig.36b). The die was then separated from the mold with the wax pattern on the die and after then the wax pattern margins were readapted. The excess wax below the margins was trimmed using PKT carver (Fig.8). Thus thirty (30) wax patterns from straight abutment and thirty (30) wax patterns from 15^o angulated abutment master dies were made.

f) Attachment of loop (Fig.37)

A small loop was made from sprue wax (Fig.9a) and was attached to the occlusal surfaces of the wax patterns to hold it in a hook of the universal testing machine.

g) Sprue former attachment

Wax pattern were connected to a manifold sprue (Bego, Germany) (Fig.9a) of 2.5 mm thick at their thickest portion which is the bevel region, in turn were connected to horizontal runner bar of 3.5 mm preformed round wax sprue. The horizontal runner bar was connected to a feeder sprue of 5 mm diameter which was bent to semicircular in shape. The open arms were connected to runner bar and the bent portion to the base of the crucible former.

h) Investment procedure (Fig.38b)

All the wax patterns were invested using phosphate bonded investment material (Bellosum, Bego, Germany) (Fig.9d). A 6mm distance was provided between the margin of pattern and top of the ring (Siliring, Delta, India) (Fig.9c). The patterns were sprayed with surfactant spray (Uni Coat, Delta, India) (Fig.9b) to obtain a clean pattern and to reduce surface tension and therefore improve wettability. As per the manufacture's recommendation, 160gms of phosphate bonded investment requires 30ml of colloidal silica mixed with 8ml of distilled water. Initially the investment was hand mixed until wetted the powder thoroughly and then vacuum mixing for 30 seconds. The pattern was invested and the invest ring was allowed to bench set for 30 minutes, siliring and crucible former was removed from the invested mold after 30 minutes.

i) Burn out procedure. (Fig.38c)

After 20 minutes of bench time, the set investment mold was placed in the burnout furnace (Technico Laboratory Pvt., Ltd., and Chennai, India) (Fig.19). Burn out of the wax pattern was done using a programmed preheating technique. The investment mold was kept in to the furnace at room temperature and was heated continuously up to the temperature of 950^{O} C at the rate of 8^{o}C/min. The investment mold was kept in such a way in the furnace so that the crucible end was in contact with the floor of the furnace for the escape of melting wax. The investment mold was reversed later near the end of the burn out cycle with the space hole facing upwards to enable the escape of the entrapped gases and allow oxygen contact to ensure complete burnout of the wax pattern and allow mold expansion. Same was repeated with all the sixty (60) patterns.

j) Casting procedure (Fig.38d)

Casting was done in induction casting machine (FornaxGenu, Germany) (Fig.20). Casting procedure was performed quickly to prevent heat loss from the mold resulting in the thermal contraction of the mold. After the mold was transferred from the burnout furnace to induction casting machine, the Ni-Cr alloy (Bellabond plus, Bego, Germany) (Fig.9g) was heated sufficiently till the alloy ingot turned into the molten state and the crucible was released and the centrifugal force ensured the completion of the casting procedure. This was repeated for all the sixty (60) patterns.

k) Divesting and finishing of the cast copings (Fig.38e)

Following casting, the hot casting ring was left for bench cooling at room temperature. This procedure was done in order to retrieve the cast coping from the investment. The investment mold was cleaved along its long axis and the casting was left free. After this the adherent investment was removed from the casting by sandblasting with 110 microns alumina (Delta, India) (Fig.11) at 80lb psi pressure. The sprue was cut and removed with the help of a thin carborundum disc (Fig.9f) and the area was recontoured. Castings were inspected for any surface irregularities, if present were removed with round bur. They were steam cleaned, air dried and seated on respective abutments. Castings with poor marginal adaptation and poor fit were not included in this study. New castings were made according to the previously described procedures. Thus a total of sixty (60) Ni-Cr alloy copings were fabricated.

10. Cementation of Ni-Cr alloy cast copings on straight titanium implant abutments and on 15^{o} angulated titanium implant abutments with three different cements (Fig.39,40,41)

A custom-made autopolymerizing acrylic resin table (Fig.14b) was fabricated and was attached to the surveying arm of the surveyor (Bego, Germany) (Fig.17). A 2kg cast iron weight (Lakshmi Steels, Chennai) (Fig.14a) was placed on this custom-made table. Zinc phosphate cement (GC CORPORATION TOKYO, JAPAN) (Fig.12a) which is available as powder and liquid system was mixed as per the manufactures directions (Fig.39a). The mixed cement was carried to the intaglio surface of the cast copings with the plastic instrument and painted on to the walls (Fig.39b). The cast copings were then seated on titanium implant abutments and pressed down with finger pressure for 10 seconds (39c). Excess cement was removed carefully using a hand scaler (API, Manipal, India) (Fig.13c) without scratching the surface of the abutments. Later the samples were placed on the surveying table under the surveying arm with the weight of 2kg (Fig.39d) for 10 minutes. A total of twenty (20) Ni-Cr alloy cast copings were cemented. Ten (10) cast copings for straight titanium implant abutments were labeled as Group I (GI) (Fig.42a) and ten (10) for 15^{o} angulated titanium implant abutments were labeled as GroupIV (GIV) (Fig.42d).

Same procedure was used for glass ionomer cement (Aqua Cem Dentsply, Germany) (Fig.12b) which is available as powder/ liquid in bottles and mixed as per the manufactures recommendation (Fig40a). The mixed cement was carried to the intaglio surface of the cast copings with the plastic instrument and painted on to the walls (Fig.40b). The cast copings were then seated on titanium implant abutments and pressed down with finger pressure for 10 seconds (40c). Excess cement was removed carefully using a hand scaler (API, Manipal, India) (Fig.13c) without scratching the surface of the abutments. Later the samples were placed on the surveying table under the surveying arm with the weight of 2kg (Fig.40d) for 10 minutes. The copings luted with glass ionomer on straight titanium implant abutments were labeled as GroupII (GII) (Fig.42b), and the cast copings luted with glass ionomer on

15^o angulated titanium implant abutments were labeled as GroupV (GV) (Fig.42e), each group with ten (10) test samples.

Dual cure resin cement (RelyX U200, 3M ESPE AG, Seefeld, Germany) (Fig.12c), which is available as a two-paste system in clicker were used for cementation of the cast copings to the straight titanium implant abutments and 15^o angulated titanium implant abutments. Both the pastes were mixed with folding technique using an agate plastic spatula (GC Corporation, Tokyo, Japan) (Fig.13a) for 30 seconds. The mixed cement was carried to the intaglio surface of the cast copings with the plastic instrument and painted on the walls (Fig.41a). The cast copings were then seated on the titanium implant abutments and pressed down with finger pressure for 10 seconds (Fig.41b). Excess cement was removed carefully using a hand scaler (API, Manipal, India) (Fig.13c) without scratching the surface of the abutments. Later the samples were placed on the surveying table under the surveying arm with the weight of 2kg (Fig.41c) for 10 minutes, meanwhile the margins of the copings were light cured with the UV gun (Fig.41d) on all the sides. Straight titanium implant abutments with cemented cast copings were labeled as Group III (Fig.42c) and 15^o angulated titanium abutment with cemented cast copings were labeled as Group VI (GVI) (Fig.42f), each group with ten (10) test samples. Total of sixty (60) test samples were made and grouped as follows.

11. Grouping of test samples (Fig.42)

Group I (GI): Cast copings luted with zinc phosphate cement on straight titanium implant abutments (Fig.42a).

Group II (GII): Cast copings luted with glass ionomer cement on straight titanium implant abutments (Fig.42b).

Group III (GIII): Cast copings luted with dual cure resin cement on straight titanium implant abutments (Fig.42c).

Group IV (GIV): Cast copings luted with zinc phosphate cement on 15^{o} angulated titanium implant abutments (Fig.43d).

Group V (GV): Cast copings luted with glass ionomer cement on 15^{o}angulated titanium implant abutments (Fig.42e).

Group VI (GVI): Cast copings luted with dual cure resin cement on 15^{o}angulated titanium implant abutments (Fig.42f).

12. Aging of all the test samples (Fig.43)

The test samples of Groups GI, GII, GIII, GIV, GV, and GVI after one hour of cementation were kept in distilled water (Nirma Ltd., Gujarat-India) (Fig.10) for 24 hours at 37^{o} for aging before testing. Aging was done to simulate of the oral environment.

13. Testing of the test samples for tensile bond strength with universal testing machine (Fig.44)

To obtain the tensile bond strength of groups GI, GII, GIII, GIV, GV, and GVI, Universal mechanical testing machine (Lloyd instruments, Farnham, U.K.) (Fig.23) was used to determine the tensile bond strength of all the sixty (60) test samples. The testing samples were fixed to the sample fixture at bench vice of the lower chamber. The straight end of the metal hook was attached to the upper chamber and the curved end of the hook was attached to the loop of the test sample. The test samples were subjected to tensile test. Each coping cemented on the titanium implant abutment was pulled from the titanium implant abutment in the universal testing machine at a crosshead speed of 5mm/minute, until the coping deboned from the titanium implant abutment. The computer attached to the testing machine recorded the force at which this debonding occurred. All the values were obtained in Newton and were converted into MPa by the formula

$$\text{Tensile Strength MPa} = \frac{\text{Force applied}}{\text{Surface area}}.$$

Thus the tensile bond strength (MPa) was obtained for all the 60 (sixty) test samples and tabulated for statistical analysis.

METHODOLOGY – OVERVIEW

Milling of straight titanium implant abutment

Measurement of the surface area of straight titanium implant abutment and 15^{o} angulated titanium implant abutment with Scanning Electron Microscope (SEM)

Placement of the implant analog in the mold parallel to long the axes with surveyor

Placement of the implant analog in the mold at 15^{o} angulation with surveyor

Stabilization of the implant analogs with clear autopolymerising resin

Fixation of the straight titanium implant abutment to implant analog. (No.of Samples=30)

Fixation of 15^{o} angulated titanium implant abutment to implant analog. (No. of Samples=30)

Filling the screw access opening with silicone for straight titanium implant abutment and 15^{o} angulated titanium implant abutment

Making of an impression of straight titanium implant abutment and 15^{o} angulated titanium implant abutment with polyvinyl siloxane impression material and master die obtained using type IV die stone

Preparation of wax pattern with inlay casting wax from master die and attachment of loop on occlusal surface of pattern

Fabrication of Ni-Cr alloy cast copings for straight titanium implant abutment by investment and casting procedures (No. of samples=30)

Fabrication of Ni-Cr alloy cast copings for 15^{o} angulated titanium implant abutment by investment and casting procedures (No. of samples=30)

Cementation of Ni-Cr alloy cast copings on straight titanium implant abutment and 15^{o} angulated titanium implant abutment with three different cements

Grouping of test samples

Cast copings luted with zinc phosphate cement on straight titanium implant abutments **(GI)**
Cast copings luted with glass ionomer cement on straight titanium implant abutments **(GII)**
Cast copings luted with dual cure resin cement on straight titanium implant abutments **(GIII)**
(10 samples of each)

Cast copings luted with zinc phosphate cement on 15^{o} angulated titanium implant abutments **(IV)**
Cast copings luted with glass ionomer cement on 15^{o} angulated titanium implant abutments (**V**)
Cast copings luted with dual cure resin cement on 15^{o} angulated titanium implant abutments **(VI)**
(10 samples of each)

After one hour of cementation, Aging of 60 Nos. of test samples in distilled water at 37^{0} for 24 hours

Testing of 60 Nos. of test samples with six groups GI, GI, GIII, GIV, GV, GVI each group with 10 samples for tensile bond strength with Universal testing machine

Basic data tabulated and mean obtained for all test samples

Statistical Analysis

MATERIALS

Fig.1: Titanium Implant Abutments

a: Straight titanium implant abutment

b:15^{o} angulated titanium implant abutment

Fig.2: Implant Analog

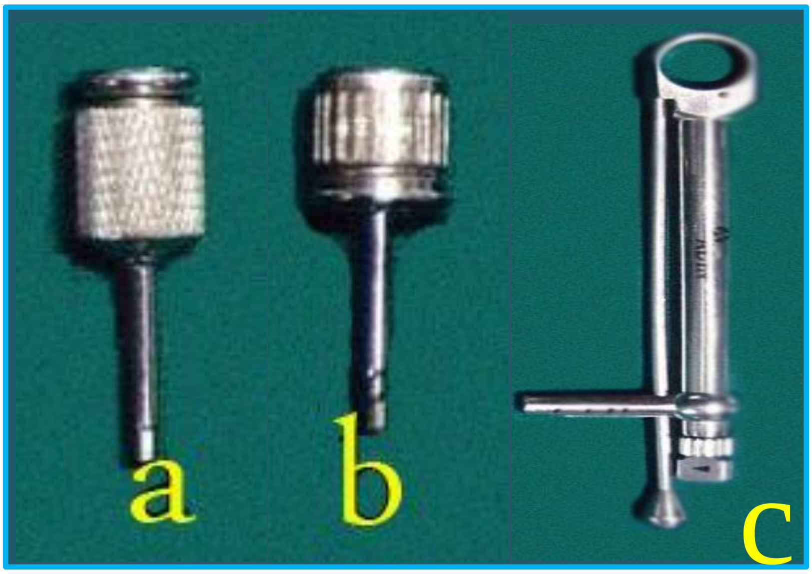

Fig.3: Tools for Fixation of Abutments

a: Hand Hex Driver

b: Ratchet Hex Driver

c: Torque Ratchet

Fig.4: Clear Autopolymerising Acrylic Resin

Fig.5: Milling Bur

Fig.6: Impression and Die Materials

a: Soft Putty, Polyvinyl Siloxane (PVS) impression material

b: Light Body, Polyvinyl Siloxane (PVS) impression material

c: Mixing spiral

d: Automixing gun

e: Type IV die stone

Fig.7: Materials for Wax Pattern Preparation

a: Die Lubricant

b: Die spacer

c: Inlay casting wax

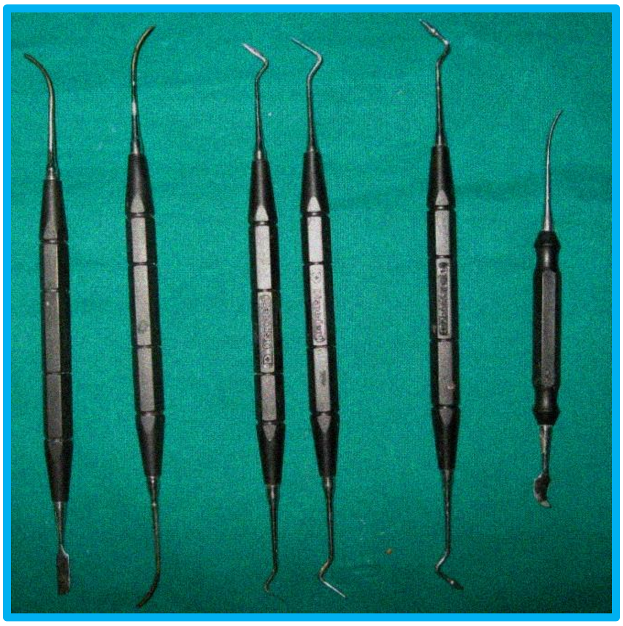

Fig.8: PKT Instruments

Fig.9: Materials for Casting Procedure

a: Sprue wax

b: Surfactant spray

c: Silicone investment ring and crucible former

d: Phosphate bonded investment material

e: Colloidal silica

f: Carborundum separating discs

g: Ni-Cr alloy pellets

Fig.10: Distilled Water

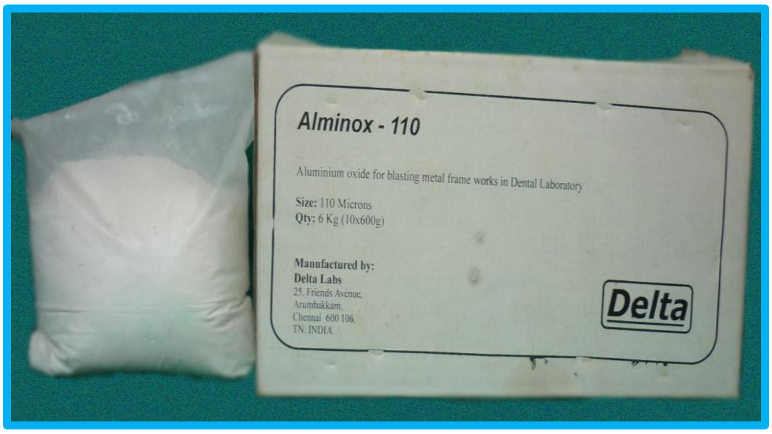

Fig.11: Aluminum Oxide Powder – 110 µm

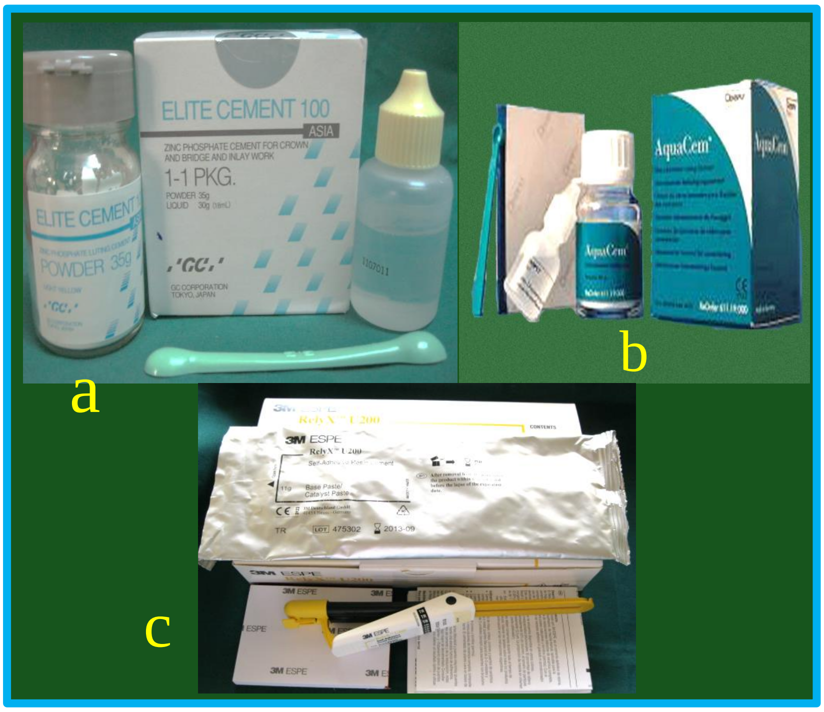

Fig.12: Luting Cements

a: Zinc phosphate cement

b: Glass ionomer cement

c: Dual cure resin cement

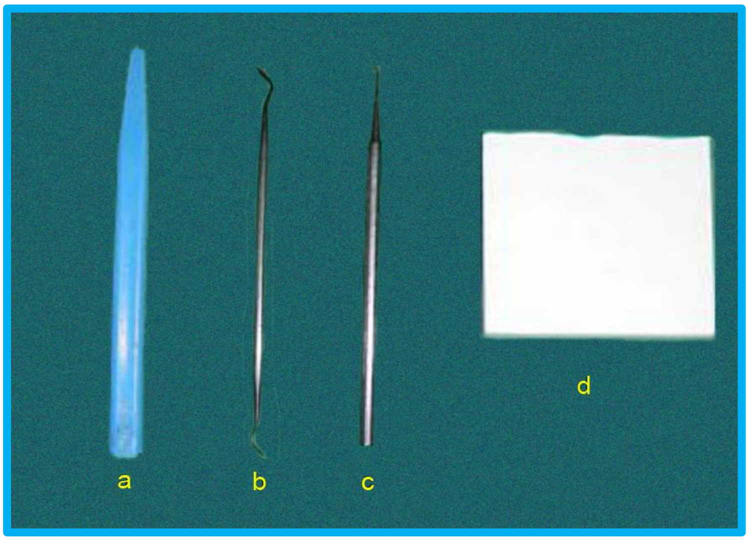

Fig.13: Instruments for Cementation

a: Agate plastic spatula

b: Plastic Instrument

c: Hand scaler

d: Mixing pad

Fig. 14: Materials for load application to cemented cast copings

a: Two kg weight cast iron

b: Custom-made autopolymerizing acrylic resin table

EQUIPMENTS

Fig.15: Milling Machine

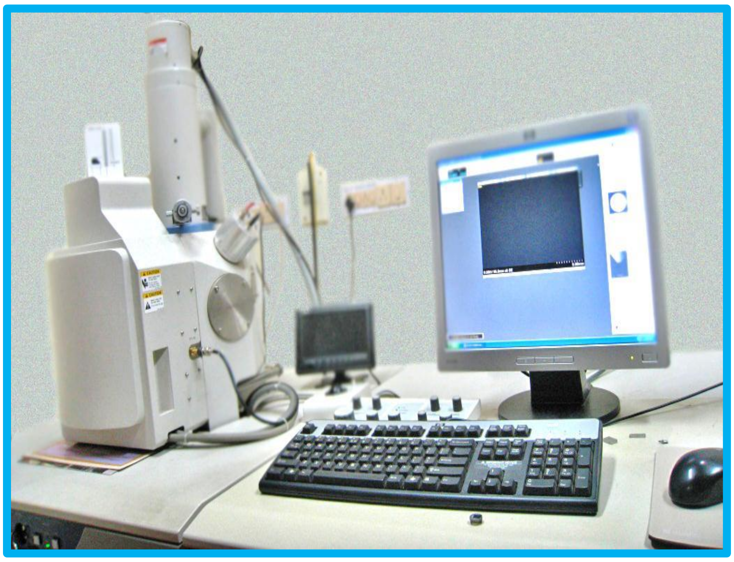

Fig.16: Scanning Electron Microscope

Fig.17: Dental Surveyor

Fig.18: Vacuum Mixer

Fig.19: Burnout Furnace

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Fig.20: Induction Casting Machine

Fig.21: Sandblaster

Fig.22: Alloy Grinder

Fig.23: Universal Testing Machine

Fig.24: Titanium Implant Abutments

a: Straight titanium implant abutment

b: 15^{o}angulated titanium implant abutment

Fig.25: Milling of straight titanium implant abutment

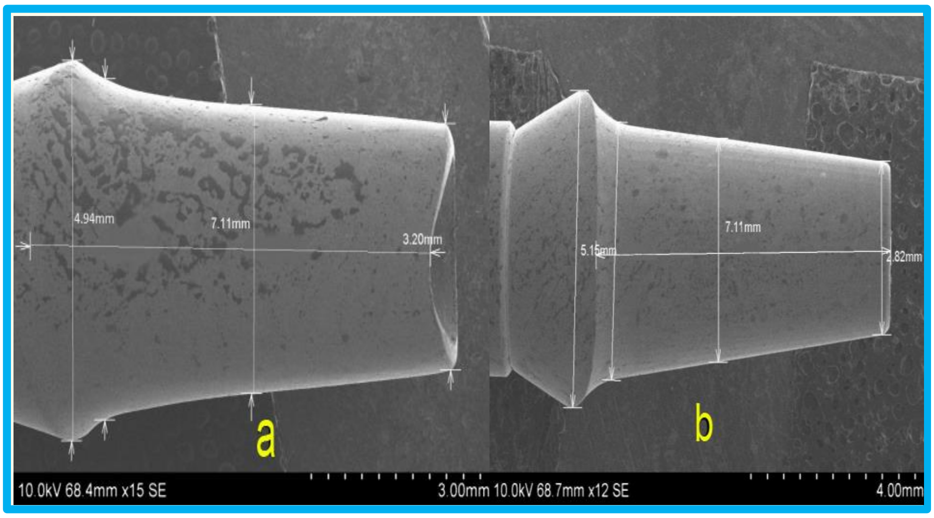


Fig. 26: Measurement of the surface area of the titanium implant abutments

a: Measurement of Straight titanium implant abutment

b: Measurement of 15^{o}angulated titanium implant abutment

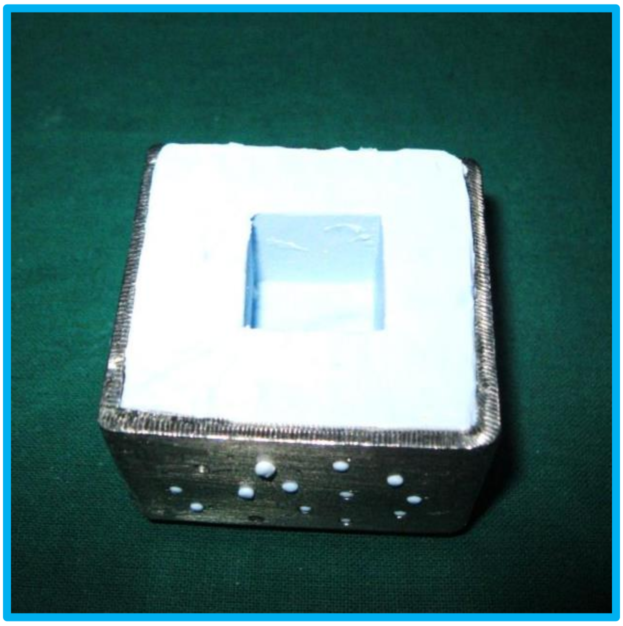


Fig.27: Silicone mold for Preparation of resin block

Fig.28: Making surveyor table parallel to floor with Spirit level indicators

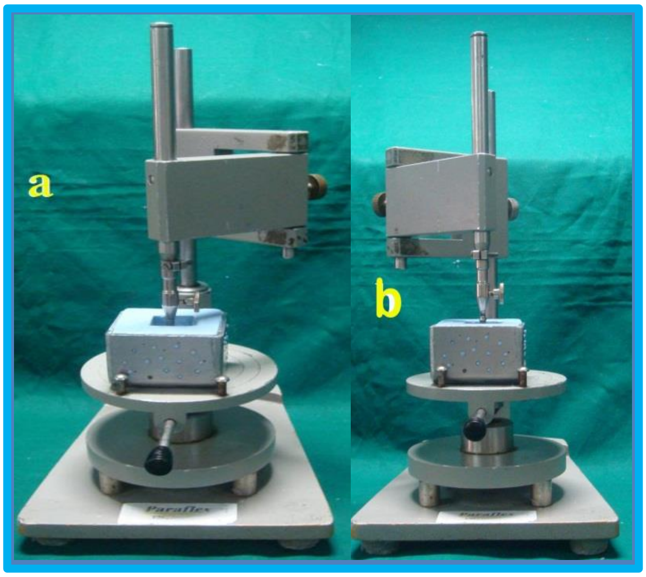


Fig.29: Placement of implant analog in the silicone mold

a: Positioning of implant analog for straight titanium implant abutment in the silicone mold

b: Positioning of implant analog for15^{o}angulated titanium implant abutment in the silicone mold

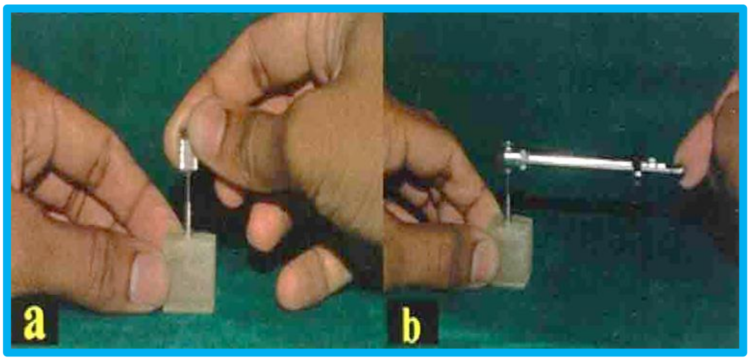


Fig.30: Fixation of titanium implant abutment to implant analog

a: Fastening the titanium implant abutment to implant analog with Hand Hex Driver

b: Fastening the titanium implant abutment to implant analog with Torque Rachet and Rachet Hex Driver

FABRICATION OF Ni-Cr ALLOY CAST COPINGS

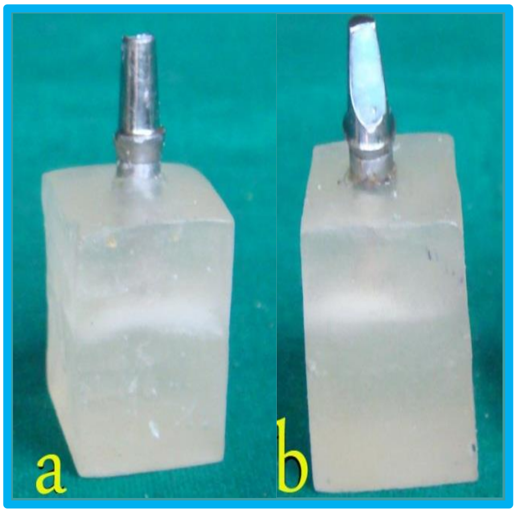


Fig.31: Closure of Abutment Screw Access Hole

a: Straight titanium implant abutment

b: 15^{o} Angulated titanium implant abutment

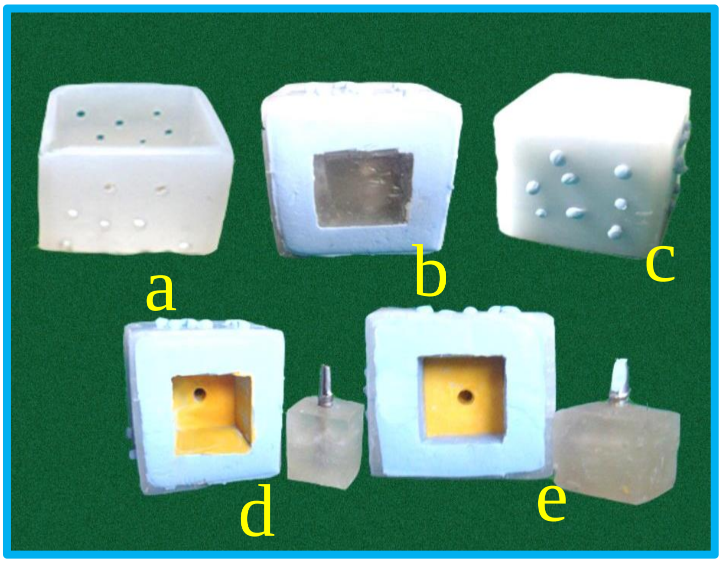


Fig.32: Impression procedure for straight and 15^{o}angulated titanium implant abutments

a: Custom made impression tray

b & c: Impression tray with titanium implant abutment

d: Impression of straight titanium implant abutment

e: Impression of 15^{o}angulated titanium implant abutment

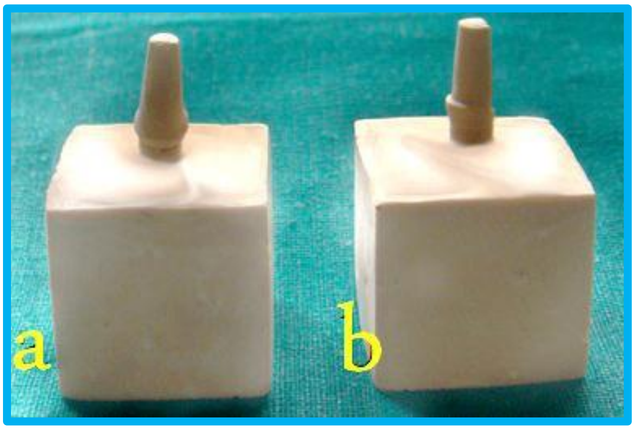


Fig.33: Preparation of Master Dies with type-IV Dental Stone

a: Die of straight implant abutment

b: Die of 15^{o} angulated implant abutment

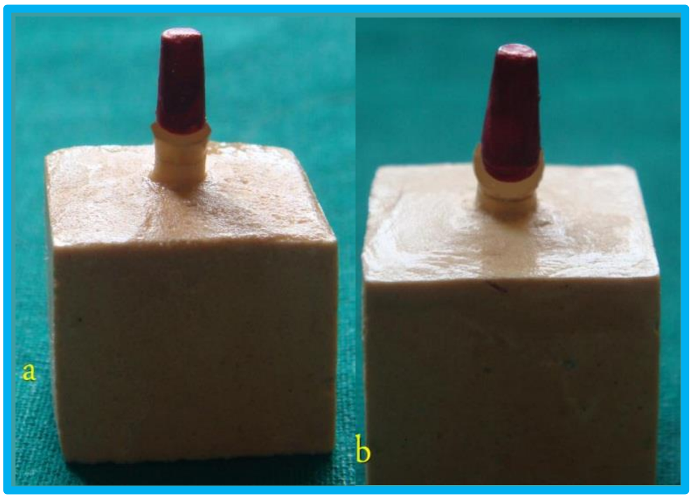


Fig.34: Application of Die Spacer

a: Die spacer on the die of straight titanium implant abutment

b: Die spacer on the die of 15^{o} angulated titanium implant abutment

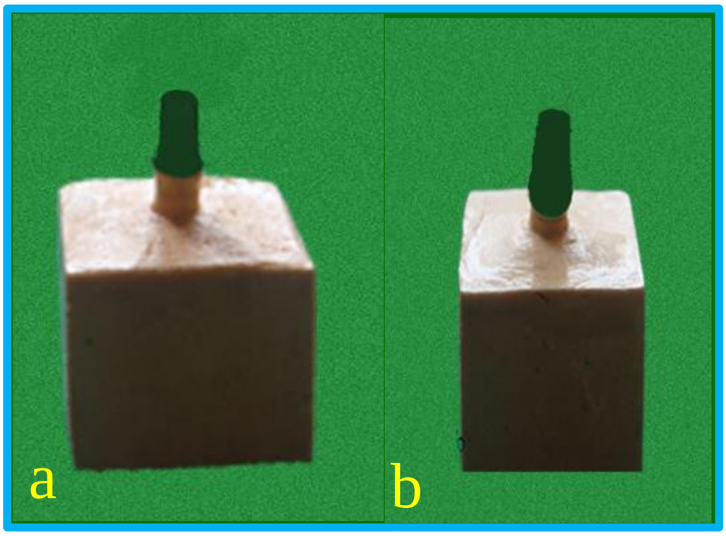


Fig.35: Wax Pattern on Master Die

a: Master die of Straight abutment

b: Master die of 15^{o} angulated abutment

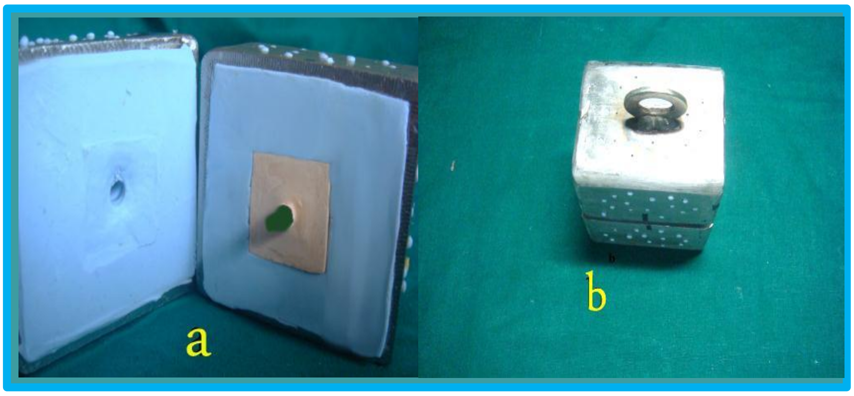


Fig.36: Preparation of Wax Pattern

a: Duplication of wax pattern prepared on the master dies

b: Preparation of the Wax Patterns from the duplicating mold

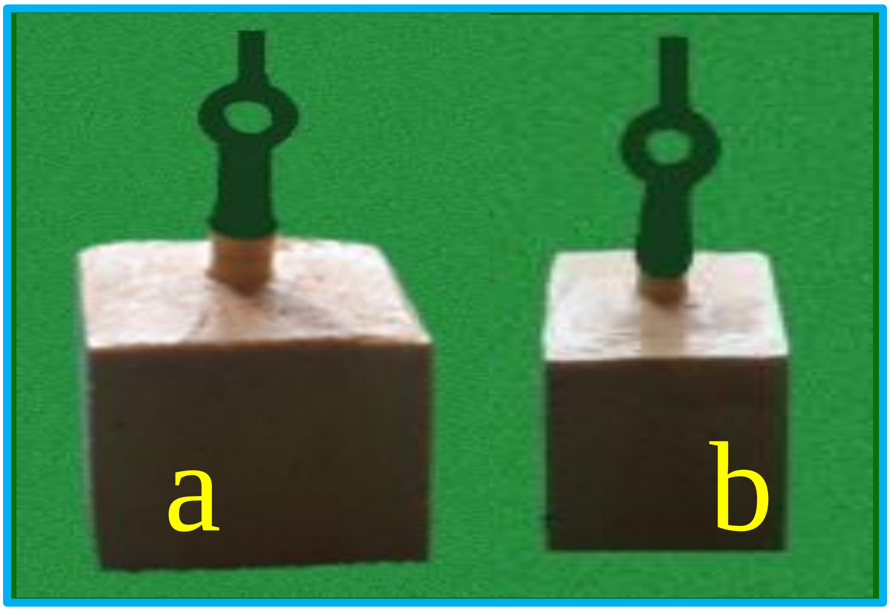


Fig.37: Wax Patterns with loop attachment

a: Master die of Straight abutment with wax pattern and loop attachment

b: Master die of 15^o angulated abutment with wax pattern and loop attachment

CASTING PROCEDURE

Fig.38: Casting Procedure

a: Surfactant spray
b: Investment procedure
c: Burn out procedure
d: Casting
e: Removal of investment from cast copings
f: Ni-Cr cast alloy coping
g: Checking the fitting of copings on die

CEMENTATION

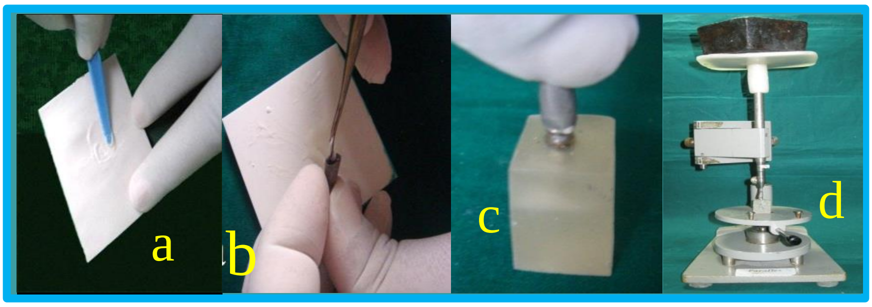


Fig.39: Zinc Phosphate Cementation Procedure

a: Mixing of zinc phosphate cement
b: Application of cement to the intaglio surface of cast coping
c: Seating of cast coping with finger pressure
d: Seating of cast coping on surveyor under 2 kg weight

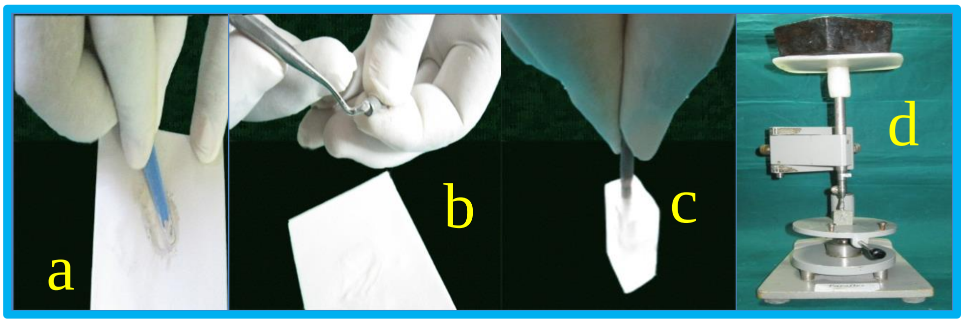


Fig.40: Glass Ionomer Cementation Procedure

a: Mixing of glass ionomer cement

b: Application of cement to the intaglio surface of cast coping

c: Seating of cast coping with finger pressure

d: Seating of cast coping on surveyor under 2kg weight

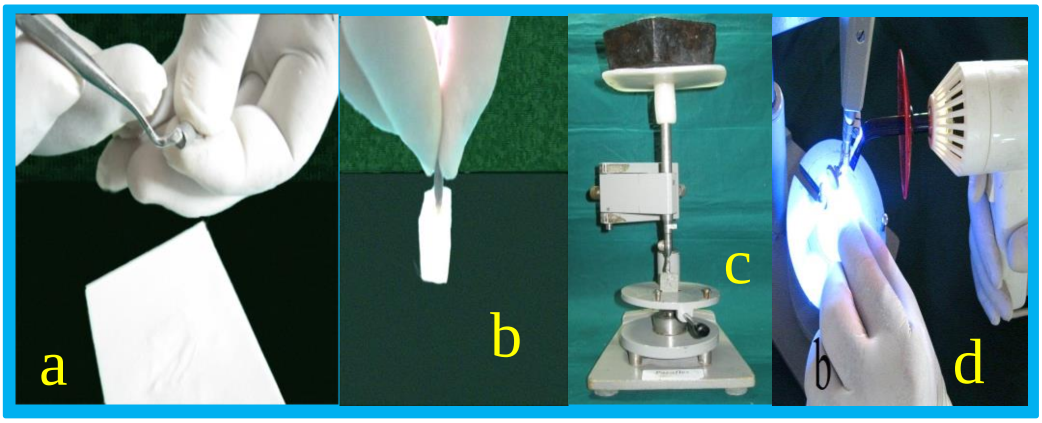


Fig.41: Dual Cure Resin Cementation Procedure

a: Application of cement to the intaglio surface of cast coping

b: Seating of cast coping with finger pressure

c: Seating of cast coping on surveyor under 2kg weight

d: Curing of dual cure resin done during cast coping is on surveyor

GROUPING OF TEST SAMPLES

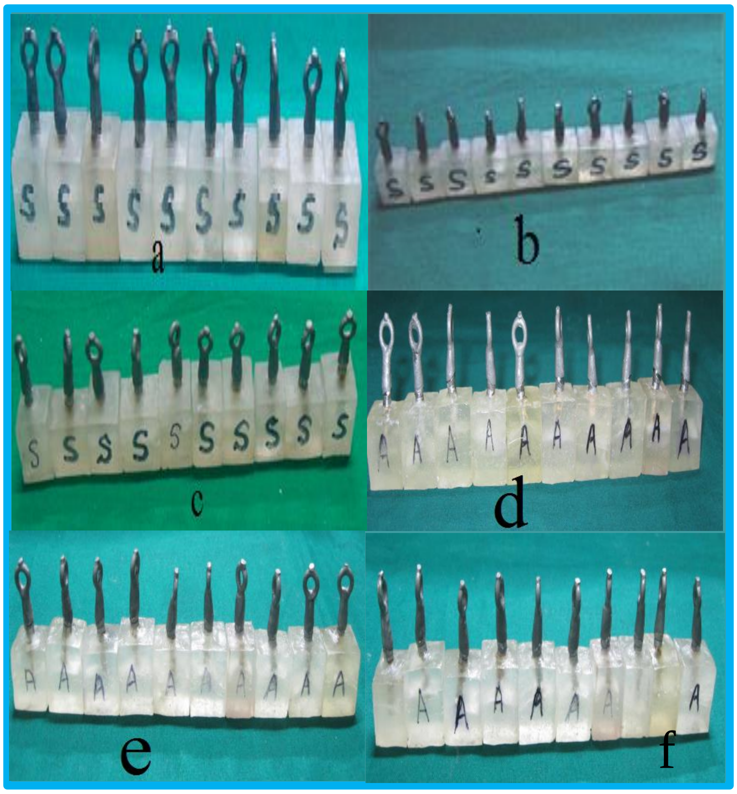


Fig.42: Grouping of Test Samples

a: Cast copings luted with zinc phosphate cement on straight titanium implant abutments (GI)

b: Cast copings luted with glass ionomer cement on straight titanium implant abutments (GII)

c: Cast copings luted with dual cure resin cement on straight titanium implant abutments (GIII)

d: Cast copings luted with zinc phosphate cement on 15° angulated titanium implant abutments (GIV)

e: Cast copings luted with glass ionomer cement on 15° angulated titanium implant abutments (GV)

f: Cast copings luted with dual cure resin cement on 15° angulated titanium implant abutments (GVI)

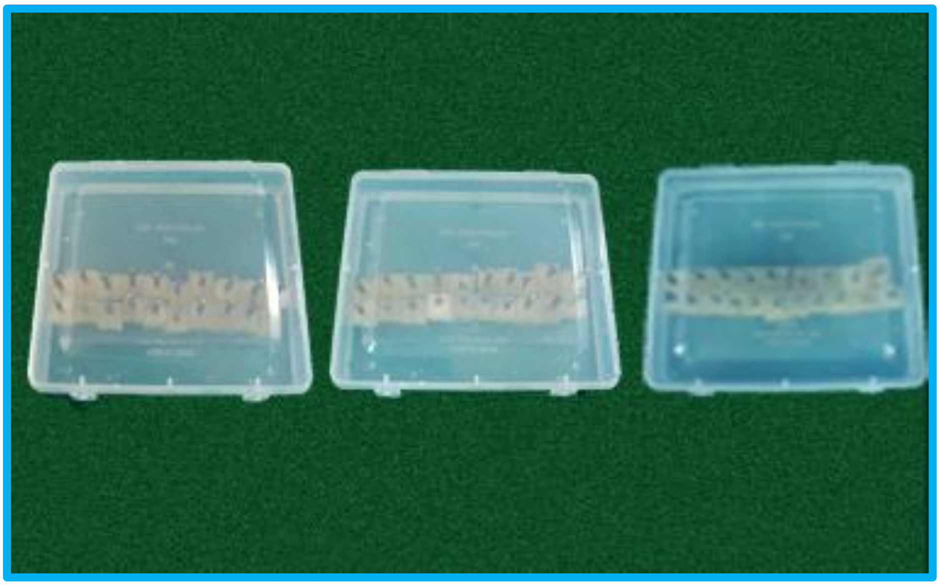


Fig.43: Aging of all the Test Samples

Fig.44: Universal Testing Machine with Test Sample

DEBONDED CAST COPINGS

Fig.45: Debonded Cast Copings

a: Debonded cast copings of straight and 15^{o}angulated titanium implant abutments luted with zinc phosphate cement

b: Debonded cast copings of straight and 15^{o}angulated titanium implant abutments luted with glass ionomer cement

c: Debonded cast copings of straight and 15^{o}angulated titanium implant abutments luted with dual cure resin cement

S: Straight titanium implant abutment

A: 15^{o} angulated titanium implant abutment

RESULTS

The present in vitro study was conducted for comparative evaluation of the tensile bond strength of three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement on retention of implant- supported cast copings with effect of abutment angulation.

A total of sixty (60) titanium implant abutments along with their analogs and three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement were selected for this study. Among the titanium abutments thirty (30) were straight titanium implant abutments and thirty (30) were 15^o angulated titanium implant abutments. The surface area of the straight titanium implant abutment and 15^o angulated titanium implant abutment were measured under scanning electronic microscope (SEM) which was calculated for straight titanium implant abutment as 90.94 mm^2 and for 15^o angulated titanium implant abutment as 89.84 mm^2. Sixty (60) implant analogs were embedded individually into autopolymerizing acrylic resin block out of which thirty (30) implant analogs were placed parallel to the long axis and other thirty (30) at an angle of 15^o to the long axis of the block. Titanium implant abutments were connected with a hex driver to their corresponding embedded implant analogs in the acrylic resin block and torqued to 35 Ncm with a torque wrench. Impression of the straight titanium implant abutment and 15^o angulated titanium implant abutment was made, casting procedure was done to fabricate Ni-Cr alloy cast copings, which were cemented on straight titanium implant abutments and 15^{o}angulated titanium implant abutments, and were divided into six groups (GI, GII, GIII, GIV, GV, GVI), each group having ten (10) test samples according to the type of titanium implant abutment and the cement used.

Group I (GI): Cast copings luted with zinc phosphate cement on straight titanium implant abutments.

Group II (GII): Cast copings luted with glass ionomer cement on straight titanium implant abutments.

Group III (GIII): Cast copings luted with dual cure resin cement on straight titanium implant abutments.

Group IV (GIV): Cast copings luted with zinc phosphate cement on 15^{o} angulated titanium implant abutments.

Group V (GV): Cast copings luted with glass ionomer cement on 15^{o} angulated titanium implant abutments.

Group VI (GVI): Cast copings luted with dual cure resin cement on 15^{o} angulated titanium implant abutments.

All sixty (60) test samples were subjected to testing for tensile bond strength using universal testing machine. The results obtained in Newton from the study were converted to megapascals (MPa) and then tabulated and subjected to statistical analysis.

Table 1: Basic data values of tensile bond strength of zinc phosphate cement for luting cast copings on straight titanium implant abutments (GI)

Sample No.	Tensile bond strength in MPa
1	2.03
2	1.91
3	1.97
4	2.07
5	2.21
6	2.16
7	2.26
8	2.01
9	2.17
10	1.96
Mean	2.08

Inference:

Table 1 shows the maximum tensile bond strength for zinc phosphate cement used for luting cast coping on straight titanium implant abutment was 2.26MPa and minimum was 1.91MPa. The mean tensile bond strength was 2.08 MPa.

Table 2: Basic data values of tensile bond strength of glass ionomer cement for luting cast copings on straight titanium implant abutments (GII)

Sample No.	Tensile bond strength in MPa
1	2.40
2	2.32
3	2.30
4	2.34
5	2.32
6	2.28
7	2.33
8	2.37
9	2.40
10	2.38
Mean	2.34

Inference:

Table 2 shows the maximum tensile bond strength of glass ionomer cement used for luting cast coping on straight titanium implant abutment was 2.40MPa and minimum was 2.28MPa. The mean tensile bond strength was 2.34MPa.

Table 3: Basic data values of tensile bond strength of dual cure resin cement for luting cast copings on straight titanium implant abutments (GIII)

Sample No.	Tensile bond strength in MPa
1	3.78
2	3.73
3	3.72
4	3.84
5	3.68
6	3.79
7	3.65
8	3.69
9	3.76
10	3.87
Mean	3.75

Inference:

Table 3 shows the maximum tensile bond strength of dual cure resin cement used for luting cast coping on straight titanium implant abutment was 3.87MPa and minimum was 3.65MPa. The mean tensile bond strength was 3.75MPa.

Table 4: Basic data values of tensile bond strength of zinc phosphate cement for luting cast copings on 15^o angulated titanium implant abutments.(GIV)

Sample No.	Tensile bond strength in MPa
1	1.78
2	1.51
3	1.78
4	1.89
5	1.83
6	1.68
7	1.78
8	1.88
9	1.75
10	1.65
Mean	1.75

Inference:

Table 4 shows the maximum tensile bond strength of zinc phosphate cement used for luting cast coping on 15^o angulated titanium implant abutment was 1.89MPa and minimum was 1.51MPa. The mean tensile bond strength was 1.75MPa.

Table 5: Basic data values of tensile bond strength of glass ionomer cement for luting cast copings on 15^{o} angulated titanium implant abutments (GV)

Sample No.	Tensile bond strength in MPa
1	1.91
2	1.98
3	1.94
4	2.05
5	1.92
6	2.02
7	1.82
8	1.99
9	2.11
10	1.92
Mean	1.97

Inference:

Table 5 shows the maximum tensile bond strength of glass ionomer cement used for luting cast coping on 15^{o} angulated titanium implant abutment was 2.11MPa and minimum was 1.82MPa. The mean tensile bond strength was 1.97MPa.

Table 6: Basic data values of tensile bond strength of dual cure resin cement for luting cast copings on 15^{o} angulated titanium implant abutments (GVI)

Sample No.	Tensile bond strength in MPa
1	3.26
2	3.30
3	3.33
4	3.35
5	3.39
6	3.32
7	3.25
8	3.41
9	3.45
10	3.46
Mean	3.35

Inference:

Table 6 shows the maximum tensile bond strength of dual cure resin cement used for luting cast coping on 15^{o}angulated titanium implant abutment was 3.46MPa and minimum was 3.25MPa. The mean tensile bond strength was 3.35MPa.

Table 7: Comparison of mean and standard deviation of tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on straight titanium implant abutments (GI, GII, GIII)

Groups	No.of test samples	Mean (MPa)	Standard Deviation	p-Value
Zinc phosphate cement for luting cast copings on straight titanium implant abutments(GI)	10	2.08	0.12	0.000*
Glass ionomer cement for luting cast copings on straight titanium implant abutments (GII)	10	2.34	0.04	0.000*
Dual cure resin cement for luting cast copings on straight titanium implant abutments (GIII)	10	3.75	0.21	0.000*

*p=0.000<0.05 statically significant difference

Inference:

The table 7 shows the comparison of mean value of tensile bond strength for three test groups between three cements. One way analysis of variance (ANOVA) was used to calculate the ‘p’ value. Since the ‘p’ value is less than 0.05 there is significant difference between the three groups in tensile bond strength. Multiple range tests by Tukey’s test was employed to identify significant groups at 5% level. The mean tensile bond strength was statistically significant from each other. GIII showed greatest, GII moderate and GI least tensile bond strength GIII> GII>GI.

Table 8: Comparison of mean and standard deviation of tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on 15^o angulated titanium implant abutments (GIV, GV, GVI)

Groups	No.of test samples	Mean (MPa)	Standard Deviation	p-Value
Zinc phosphate cement for luting cast copings on 15^o angulated titanium implant abutments (GIV)	10	1.75	0.11	0.000*
Glass ionomer cement for luting cast copings on 15^o angulated titanium implant abutments (GV)	10	1.97	0.08	0.000*
Dual cure resin cement for luting cast copings on 15^o angulated titanium implant abutments (GVI)	10	3.35	0.07	0.000*

*p=0.000<0.05 denotes statistically significant difference

Inference:

The table 8 shows the comparison of mean value of tensile bond strength for three test groups between three cements. One way analysis of variance (ANOVA) was used to calculate the ‘p’ value. Since the ‘p’ value is less than 0.05 there is significant difference between the three groups in tensile bond strength. Multiple range tests by Tukey’s test was employed to identify significant groups at 5% level. The mean tensile bond strength was statistically significant from each other. GVI showed greatest, GV moderate and GIV least tensile bond strength GVI>GV>GIV.

Table 9: Comparison of mean and standard deviation of tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on straight titanium implant abutments and 15^{o} angulated titanium implant abutments (GI, GII, GIII,GIV,GV,GVI)

Groups	No.of test samples	Mean (MPa)	Standard Deviation	p-Value
Zinc phosphate cement for luting cast copings on straight titanium implant abutments.	10	2.08	0.12	0.000*
Zinc phosphate cement for luting cast copings on 15^{o} angulated titanium implant abutments. (**GI** & **GIV**)	10	1.75	0.11	
Glass ionomer cement for luting cast copings on straight titanium implant abutments.	10	2.34	0.04	0.000*
Glass ionomer cement for luting cast copings on15^{o} angulated titanium implant abutments. (**GII** & **GV**)	10	1.97	0.08	
Dual cure resin cement for luting cast copings on straight titanium implant abutments.	10	3.75	0.21	0.000*
Dual cure resin cement for luting cast copings on 15^{o} angulated titanium implant abutments. (**GIII** & **GVI**)	10	3.35	0.07	

*p=0.000<0.05 statically significant difference

Inference:

The table 9 shows the comparison of mean value of tensile bond strength for six test groups between three cements. One way analysis of variance (ANOVA) was used to calculate the 'p' value. Since the 'p' value is less than 0.05 there was significant difference between the six groups in tensile bond strength as GI>GIV, GII>GV, GIII>GVI. So GIII & GVI showed greatest, GII & GV moderate, and GI & GIV least tensile bond strength (GIII & GVI) > (GII & GV) > (GI & GIV).

Table 10: Comparison of mean and standard deviation of tensile bond strength for six test groups (GI, GII, GIII, GIV, GV, GVI)

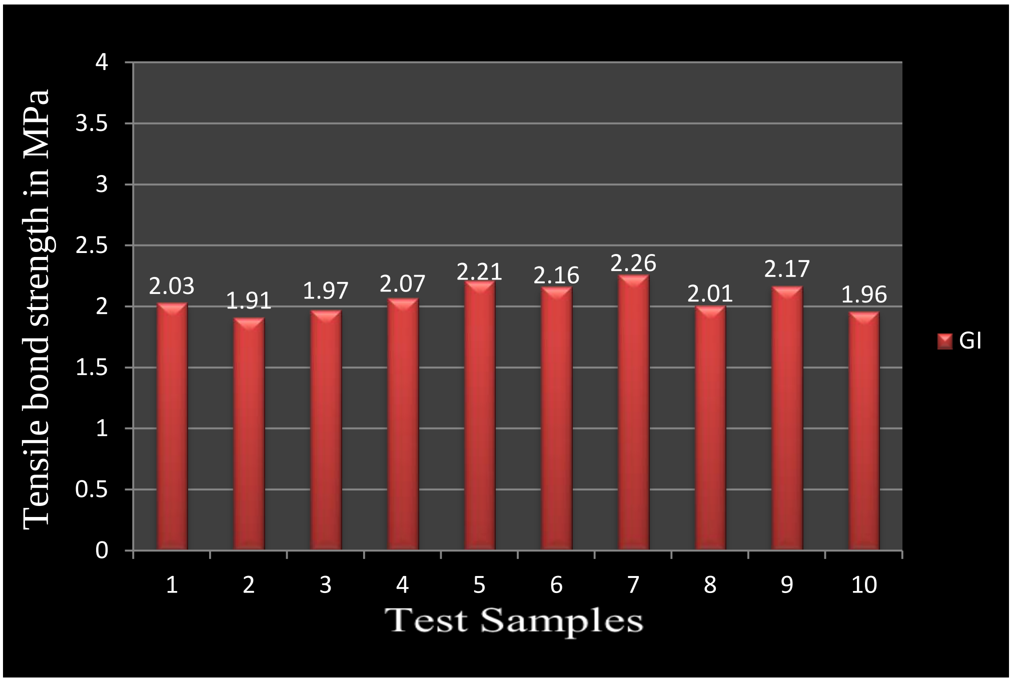
Groups	No. of test samples	Mean (MPa)	Standard Deviation	p-Value
Zinc phosphate cement for luting cast copings on straight titanium implant abutments (GI).	10	2.08	0.12	0.000*
Glass ionomer cement for luting cast copings on straight titanium implant abutments (GII).	10	2.34	0.04	
Dual cure resin cement for luting cast copings on straight titanium implant abutments (GIII).	10	3.75	0.21	
Zinc phosphate cement for luting cast copings on 15^{o} angulated titanium implant abutments (GIV).	10	1.75	0.11	0.000*
Glass ionomer cement for luting cast copings on 15^{o} angulated titanium implant abutments (GV).	10	1.97	0.08	
Dual cure resin cement for luting cast copings on 15^{o} angulated titanium implant abutments (GVI).	10	3.35	0.07	

*P=0.000< 0.05 statically significant difference

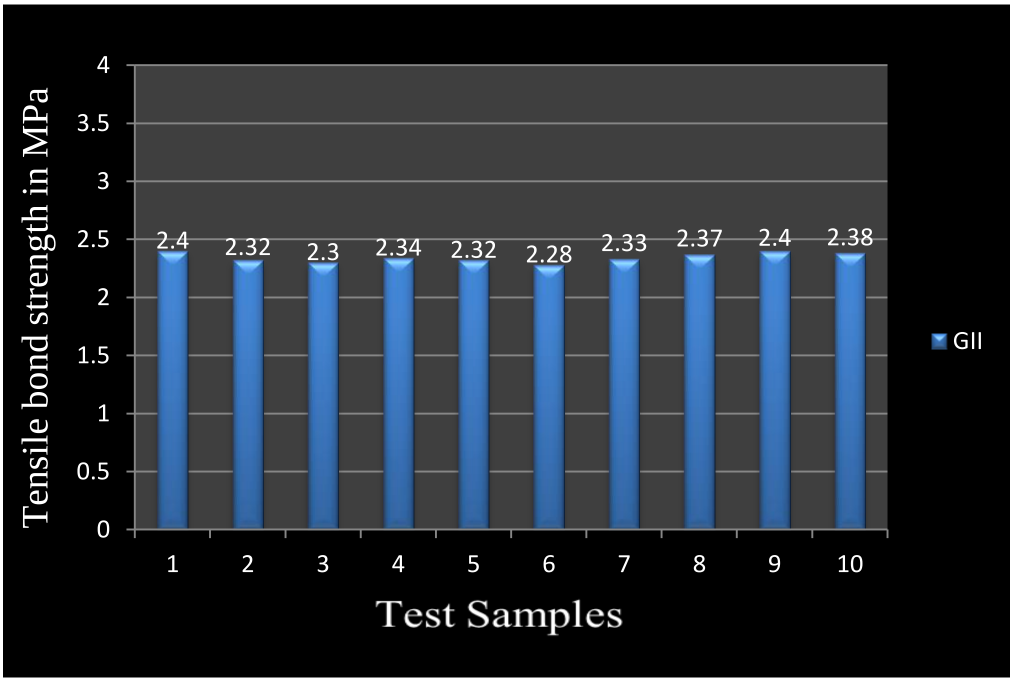
Inference:

The table 10 shows the comparison of mean and standard deviation of tensile bond strength for six test groups. One way analysis of variance (ANOVA) was used to calculate the ‘p’ value. Since the ‘p’ value is less than 0.05 there is significant difference between the six groups in tensile bond strength. Multiple range test by Tukey’s test was employed to identify significant groups at 5% level. The mean tensile bond strength was statistically significant from each other. GIII showed maximum mean tensile bond strength and GIV minimum tensile bond strength i.e. GIII>GVI>GII> GI> GV>GIV.

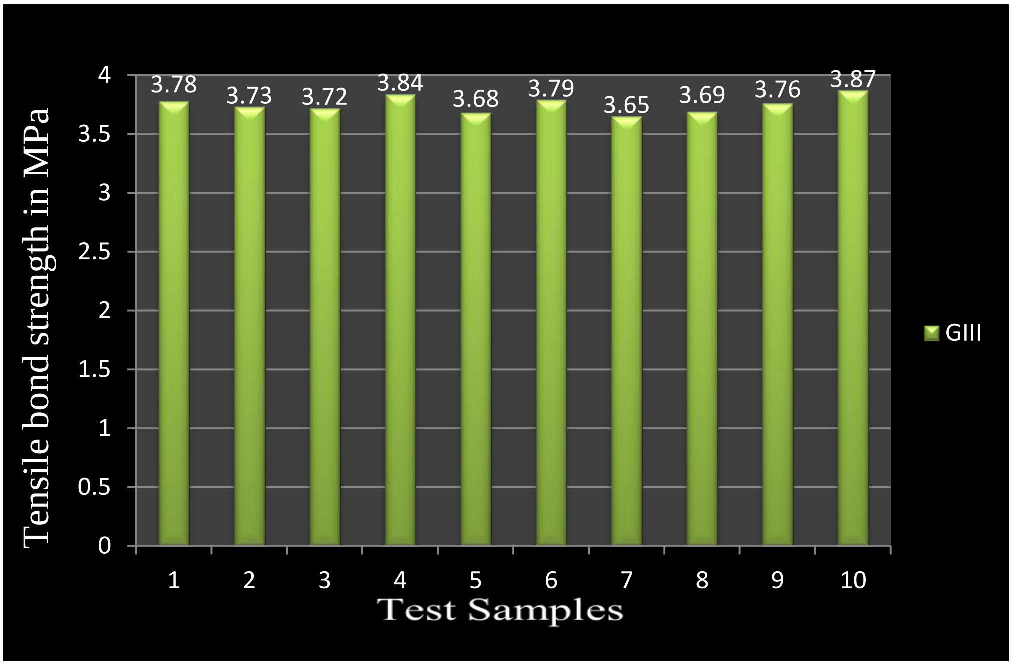
Graph I: Basic data values of tensile bond strength of zinc phosphate Cement for luting cast copings on straight titanium implant abutments (GI)



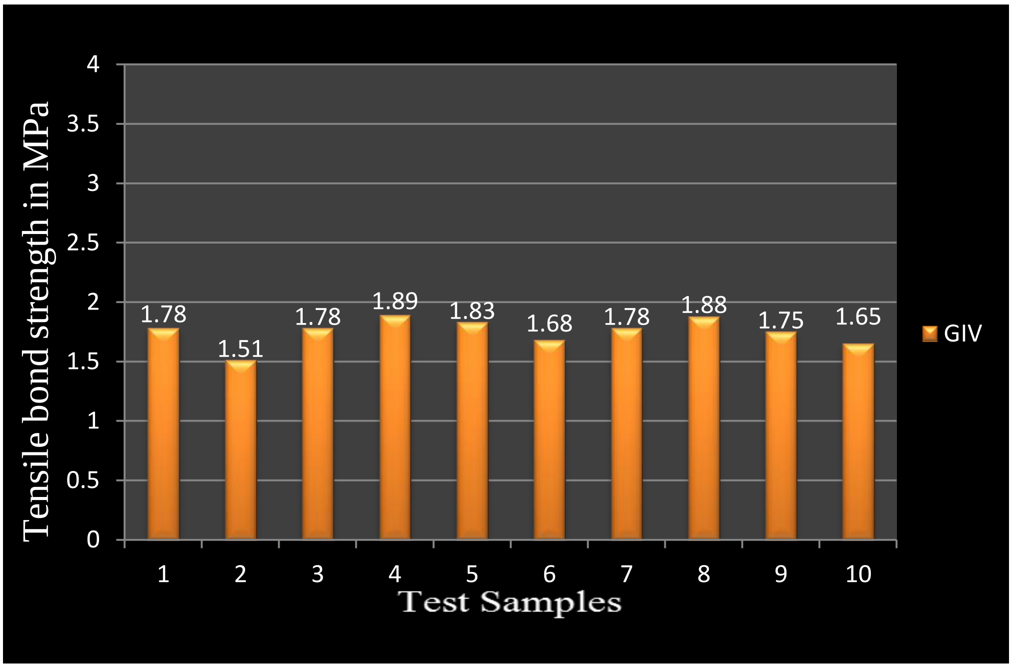
Graph II: Basic data values of tensile bond strength of glass ionomer cement for luting cast copings on straight titanium implant abutments (GII)



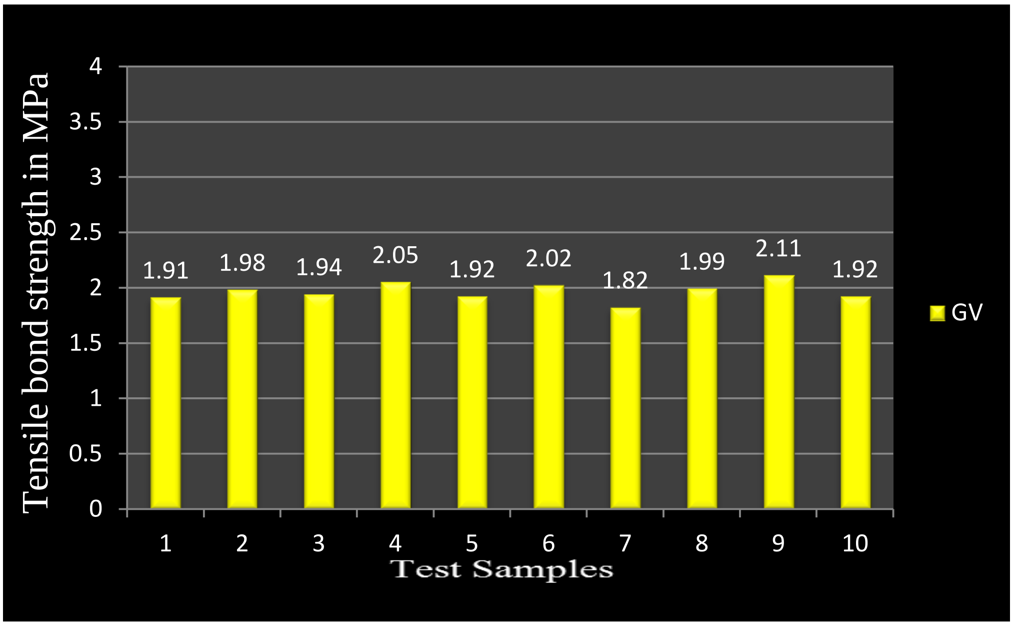
Graph III: Basic data values of tensile bond strength of dual cure resin cement for luting cast copings on straight titanium implant abutments (GIII)



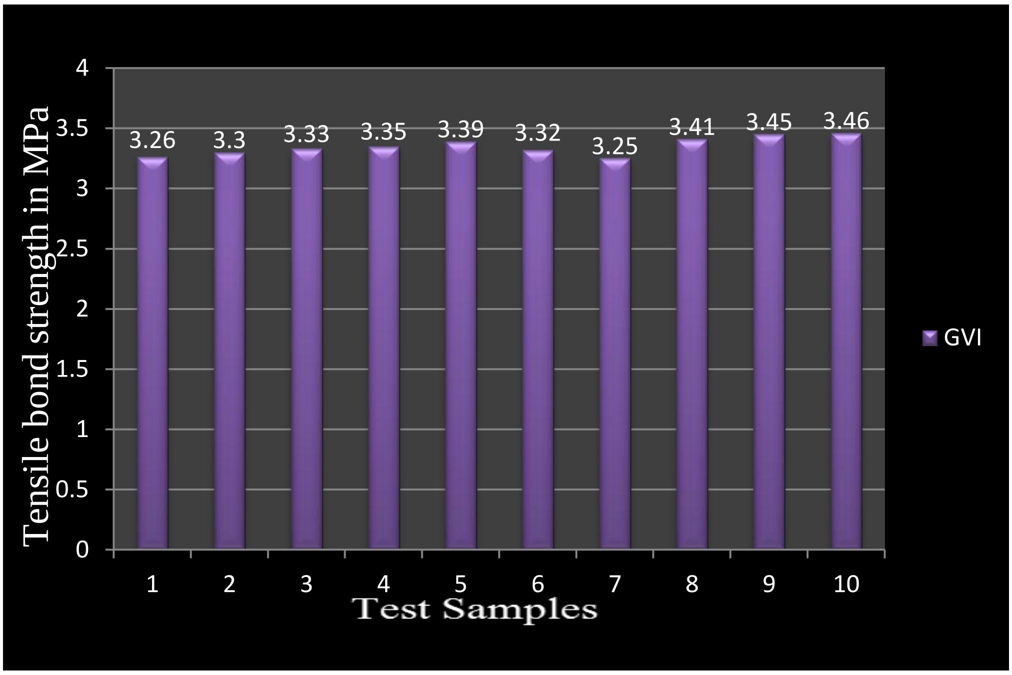
Graph IV: Basic data values of tensile bond strength of zinc phosphate cement for luting cast copings on 15^o angulated titanium implant abutments (GIV)



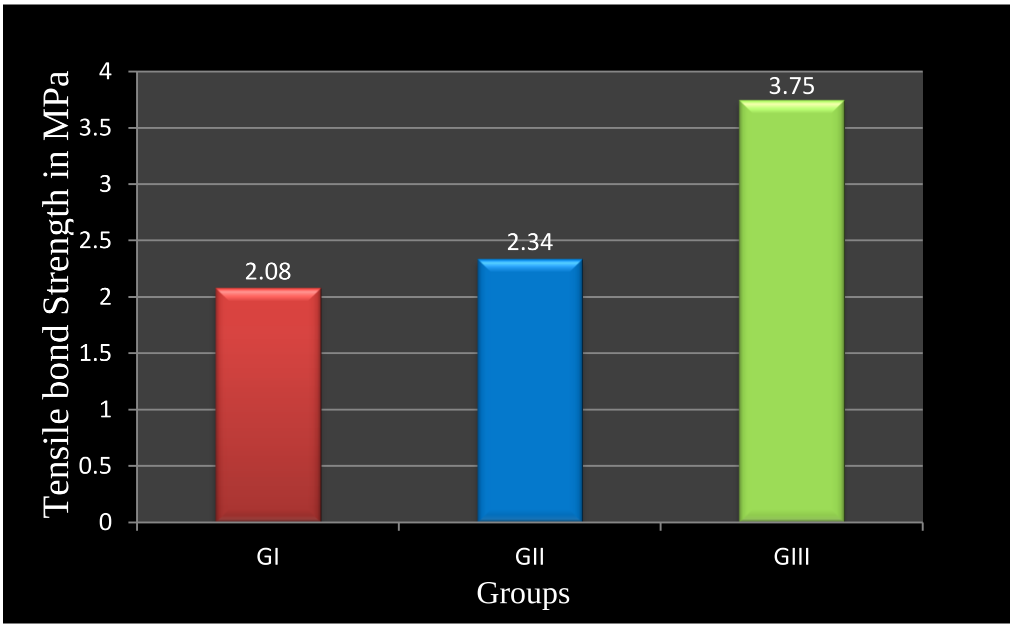
Graph V: Basic data values of tensile bond strength of glass ionomer cement for luting cast copings on 15^{o} angulated titanium implant abutments (GV)



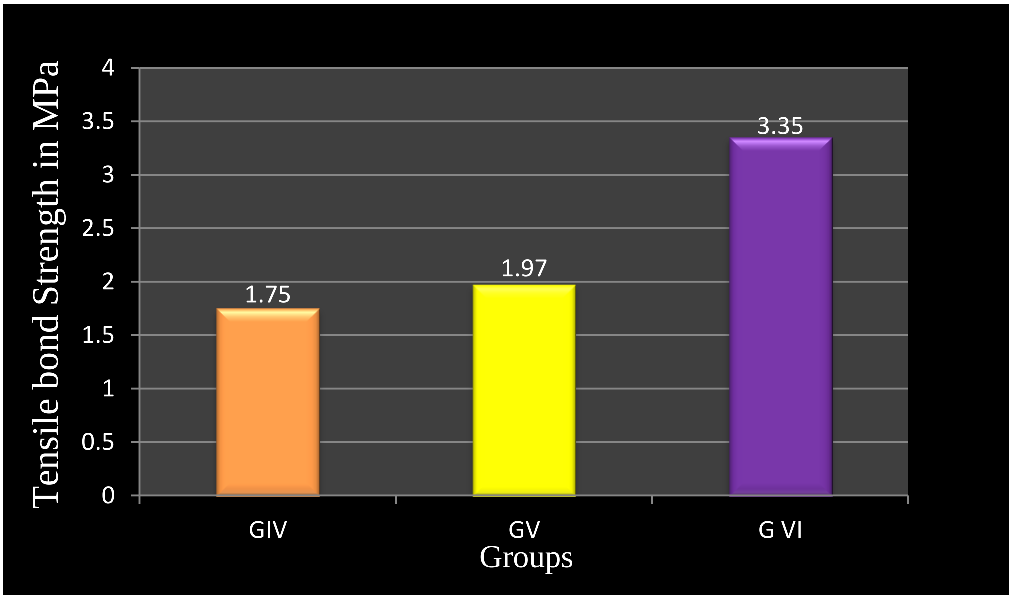
Graph VI: Basic data values of tensile bond strength of dual cure resin cement for luting cast copings on 15^{o} angulated titanium implant abutments (GVI)



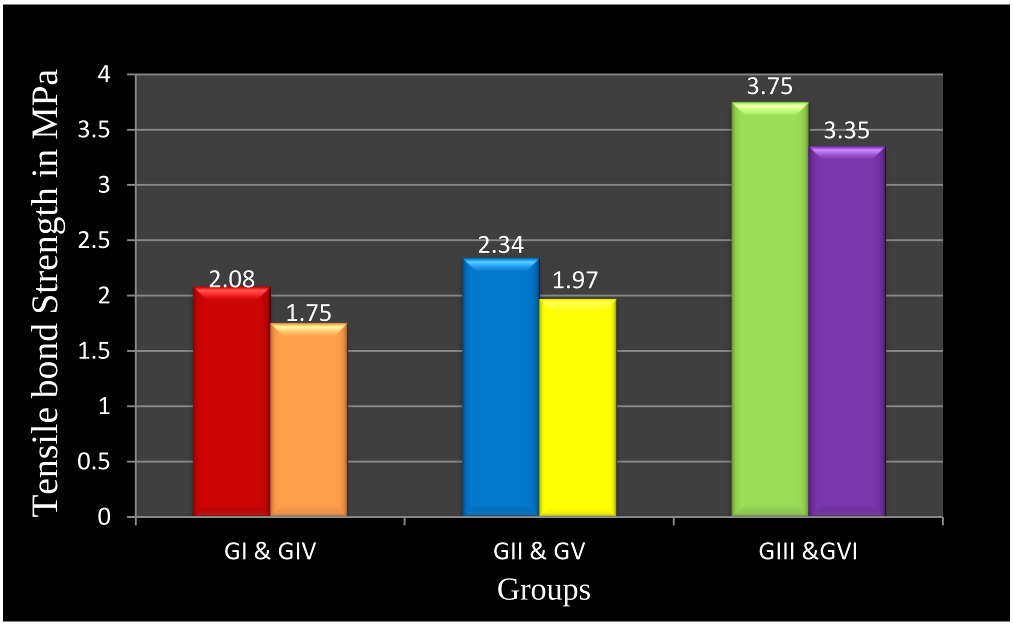
Graph VII: Comparison of mean and standard deviation of tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on straight titanium implant abutments (GI, GII, GIII)



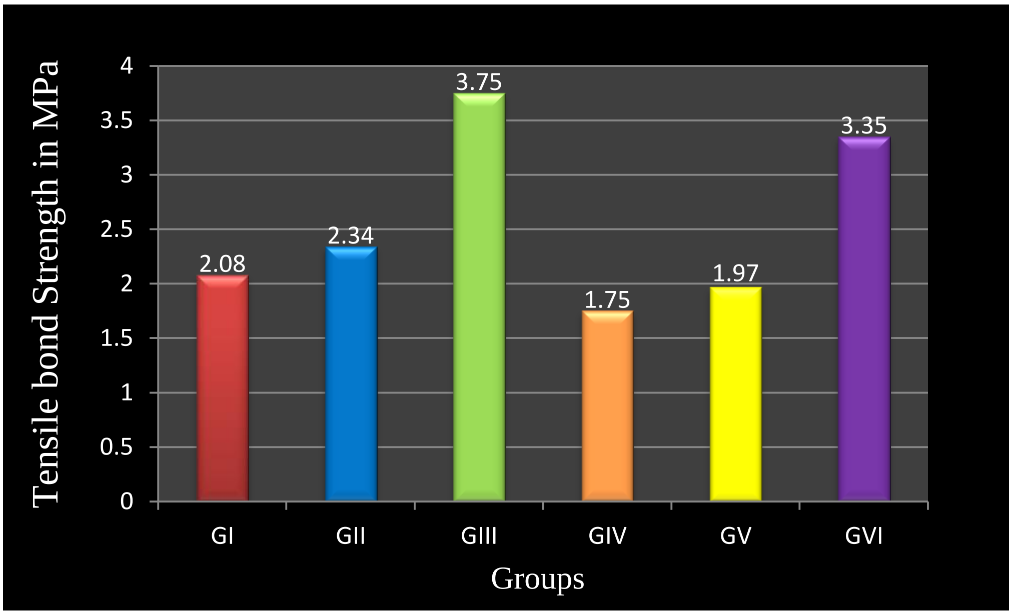
Graph VIII: Comparison of mean and standard deviation of tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on15^{o} angulated titanium implant abutments. (GIV, GV, GVI)



Graph IX: Comparison of mean and standard deviation of tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on straight titanium implant abutments and 15^{o} angulated titanium implant abutments (GI, GII, GIII,GIV,GV,GVI)



Graph X: Comparison of mean and standard deviation of tensile bond strength for six test groups (GI, GII, GIII, GIV, GV, GVI)



DISCUSSION

Dental implants have been used successfully for restorative treatment for more than twenty years. The completely edentulous and partially edentulous patients are being treated with implant supported prostheses. Currently, there are many options for prosthetic designs that differ from those proposed by Branemark et al. These options are related not only to the materials used, but also to the method of fixation of the restorations to the implant. Implant restoration can be screw-retained, cement retained or both.[33] Many clinicians suggest that cementation offers many advantages over screw retention.[18,23] Cement-retained, implant-supported prostheses have gained popularity because they allow completion of clinical procedures using conventional fixed prosthodontic techniques.

There are many factors that can influence the amount of retention that can be achieved when luting a restoration to either an abutment or a natural tooth. Factors affecting implant supported restorations are similar to those affecting the luting of crowns to natural teeth, which include taper, height, width of the abutments and the type of luting agent.[48] It has been demonstrated that an increase in surface area and height increases retention and resistance form.[23] A wide variety of cements exist with varying degree of strength are either provisional or definitive. Provisional were developed for short term use and are weak in nature while as definitive cements were developed to provide strong and long lasting cementation for restoration.

Implant placement is often less than ideal because of the morphology of existing bone. This is especially true for the anterior maxilla. One solution to this clinical problem is to use pre-angled abutments. One of the mechanical variables for implant-supported prostheses is the abutment angulation.[6] Pre-angled abutments have been introduced by implant companies as a prosthetic option for cases that are otherwise difficult to restore because of implant location or angulation. The angulation of these abutments varies from 15^{o} to 35^{o}.[9]

Ideally implants should be placed parallel to each other and to adjacent teeth and be aligned vertically with axial forces. However, achieving this may not be possible owing to deficiencies in the ridge's anatomy.[19] It has always been recommended to direct occlusal loads as close to the long axis of the fixture as possible. But it is important to understand the risks involved when restored prostheses are subjected to non-axial loading.[19] Other types of failure related to angled abutment in reviewed articles include fracture of the occlusal material, fracture in parts of the framework, loosening or fracture of abutment screws.[35] The clinical performances of angled abutments have mostly been satisfactory.[19] In various studies it was found, that the cumulative survival rates for angled abutments were 94.8% and 94.1% for the maxilla and mandible respectively. These are comparable to those of straight abutments which were 91.3% in the maxilla and 97.4% in the mandible.[23]

The present in-vitro study was conducted for comparative evaluation of the tensile bond strength of luting cements with effect of abutment angulation on retention of cement-retained implant supported restorations.

In this study two types of prefabricated titanium implant abutments were selected, straight titanium implant abutments and 15^o angulated titanium implant abutments. The straight titanium implant abutments were having grooved surface but the 15^o angulated titanium implant abutments had a smooth surface while other parameters were nearly same, so milling was done to smoothen the surface of the straight abutment with milling machine. After then the surface dimensions of both the abutments were measured under scanning electron microscope (SEM) with the help of a mathematic formula (Surface area = $\pi \times d \times h$) the surface area was calculated which for straight titanium implant abutment was $90.94mm^2$ and for 15^o angulated titanium implant abutment was $89.84mm^2$ and was standardized for each test sample.

Guillermo Bernal et al in their study concluded that factors that affect the retention of the provisional restorations are the geometry of abutment preparation, abutment taper, surface area, and abutment height.[3] It has been documented by Edward G Kaufman and coworkers, that increase in surface area and height increases retention and resistance form.[26] David A covey et al in their study on effect of abutment size and luting cement type on the uniaxial retention force of implant-supported crowns and they concluded that the abutment size has an effect on crown-to-abutment retention which increases with the increase in abutment vertical height or the height-to-width ratio and has a positive effect on tensile testing values of cemented restorations.[10] After the measurement, the square form of silicone mold was obtained with polyvinyl siloxane having internal space of 2mm x 2mm in all dimensions. In this space implant analog was embedded. Each titanium implant abutment was tightened with hand hex driver onto its corresponding implant analog, which were embedded in an individual acrylic resin block and followed by tightening the screw to 35 Ncm of torque with a rachet hex driver and torque rachet. The acrylic resin was left 1mm short of the titanium implant-abutment joint.

A total of sixty (60) test samples were made thirty (30) for straight titanium implant abutments and thirty (30) for 15^{o} angulated titanium implant abutments. The screw access hole of the straight titanium implant abutments and 15^{o} angulated titanium implant abutments were filled and sealed off with polyvinyl siloxane. A single stage impression of the master model with polyvinyl siloxane was made both for straight titanium implant abutment and 15^{o} angulated titanium implant abutment separately and master dies were made using type IV die stone. The master dies were used for fabrication of cast copings for straight titanium implant abutments and for 15^{o} angulated titanium implant abutments. Many of the previous studies have used individual dies for making each cast coping which involves multiple laboratory steps, thus incorporating multiple variables in the study. Hence to overcome multiple variables, one impression was made and single master die was fabricated for straight titanium implant abutment and 15^{o} angulated titanium implant abutment separately, which were used for fabrication of the cast copings. Wax pattern was made on master dies. A silicone mold was obtained from this wax pattern to allow for multiple wax pattern replications.

A total of sixty (60) wax patterns were invested, casted with Ni-Cr alloy and then divested, sandblasted and inspected for any surface irregularities, if present, were removed with a round bur. Castings were steam cleaned, air dried, and seated on the respective abutments. Castings were examined visually for marginal fit. Castings with poor marginal adaptation and poor fit were not included in the study. New castings were made according to the previously described procedures. Three types of cements were used namely zinc phosphate cement, glass ionomer cement and dual cure resin cement in this study. James L Sheets et al in their study on cement selection for cement-retained crown with dental implants and found resin cement, zinc phosphate cement, glass ionomer cement and glass ionomer reinforced cement at the top of retention list.[52] Sule Ergin et al. found that resin cement demonstrated the highest mean retentive strength when compared to zinc phosphate cement and resin-reinforced ionomer cement.[15] Currently among all the luting cements, resin cement is considered the most retentive cement for luting crowns on titanium implant abutments.

A custom-made autopolymerizing acrylic resin table was fabricated and was attached to the surveying arm of the surveyor. A 2kg cast iron weight was placed on this custom-made table. Zinc phosphate cement which is available as powder and liquid system was mixed as per the manufactures directions. Cast copings luted with zinc phosphate cement on straight titanium implant abutments were grouped as (GI) and cast copings luted with zinc phosphate cement on 15^o angulated titanium implant abutments were grouped as (GIV), each group with ten (10) test samples. Same procedure was used for glass ionomer cement which is available as powder/ liquid in bottles and the cast copings luted on straight titanium implant abutments were grouped as (GII), and cast copings luted on 15^o angulated titanium implant abutments as (GV), each group with ten (10) test samples.

Dual cure resin cement which is available as a two-paste system in clicker was used for cementation of the cast copings on the straight titanium implant abutments and 15^o angulated titanium implant abutments. Straight titanium implant abutments with cemented cast copings were grouped as (GIII) and 15^o angulated titanium abutments with cemented cast copings were grouped as (GVI), each group with ten (10) test samples. Total of sixty (60) test samples were made. These completed test samples were grouped as Group (GI) Cast copings luted with zinc phosphate cement on straight titanium implant abutments. (GII) Cast copings luted with glass ionomer cement on straight titanium implant abutments. (GIII) Cast copings luted with dual cure resin cement on straight titanium implant abutments. (GIV) Cast copings luted with zinc phosphate cement on 15^{o} angulated titanium implant abutments. (GV) Cast copings luted with glass ionomer cement on 15^{o} angulated titanium implant abutments. (GVI) Cast copings luted with dual cure resin cement on 15^{o} angulated titanium implant abutments.

After one hour of cementation test samples were kept in distilled water for 24 hours at 37^{o}C temperature for aging to simulate the oral environment. But aging also affects the retention due to inability to accurately simulate the intraoral environment, the specific physical conditions imposed and correlation of artificial aging with a clinically comparable time period.[38] The retentive properties of cement may also be substantially affected by immersion in water and saline.

After aging the tensile bond strength of the test samples were measured by universal testing machine. Intraorally implant supported crowns would be subjected to various types of forces such as tensile, compressive and shear force. The combination of such forces may induce high stress at the interface between an abutment and cement layer, which results in crown dislodgement.[28] However, it is difficult to produce such a complicated environment in vitro. Tensile bond strength is the maximum tensile force to separate the copings from the abutments. Static tensile loading is commonly used for testing coping retention provided by definitive cements, it provides an estimation of the bond strength of the crown during mastication and the force required to remove the definitive restoration.

It is difficult to compare tensile bond strength with other studies, because units such as kilograms or Newton are often used. Force per unit area measurements would allow more comparison among studies.[27] The test samples were attached to a universal testing machine by clamping them onto the loop attachment and a vertical tensile force was applied at a crosshead speed of 5mm/minute (by International organization of Standardizations-ISO specifications) to dislodge the cast coping from the abutment. The peak load to dislodge the cast copings from the abutment was obtained in Newton and was converted into MPa by the formula:

$$\text{Tensile Strength MPa} = \frac{\text{Force applied}}{\text{Surface area}}.$$

The mean and standard deviation estimated from the test samples of each group was statistically analyzed. Mean values were compared by One-way analysis of variance (ANOVA). Multiple range tests by Tukey-HSD procedure were employed. A ‘p’ value of 0.05 was used as the boundary of significance. ’t’ test was used to compare the difference between the tensile bond strength of all the groups.

The tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement used for luting the cast copings on straight titanium implant abutments showed the highest value for dual cure resin cement group GIII (3.75MPa) > glass ionomer cement GII (2.34MPa) > zinc phosphate cement GI(2.08MPa). While the tensile bond strength of three different cements zinc phosphate cement, glass ionomer cement, and dual cure resin cement used for luting the cast copings on 15^{o}angulated titanium implant abutment showed the highest value for dual cure resin cement group GVI(3.35MPa) > glass ionomer cement GV(1.97MPa) > zinc phosphate cement GIV(1.75MPa).

In this study the tensile bond strength of zinc phosphate cement, glass ionomer cement and dual cure resin cement used for luting cast copings on straight titanium implant abutments and 15^{o} angulated titanium implant abutments showed significant difference between the six groups as GI > GIV, GII > GV, GIII > GVI, and dual cure resin cement (GIII & GVI) showed greater, glass ionomer cement (GII & GV) moderate & zinc phosphate cement (GI & GIV) least tensile bond strength (GIII & GVI) > (GII & GV) > (GI & GIV).

The dual cure resin cement was most retentive followed by glass ionomer cement with moderate retention and zinc phosphate cement with least retention in both straight titanium implant abutments and 15° angulated titanium implant abutments.

Differences in superstructure construction, cements, cementation surface area, surface treatment, modifications to cement protocols and testing methodologies are few of the variables which make comparisons between the studies of this nature difficult. Some of the studies have reported in the literature regarding the retentiveness of resinous cement, superior to that of glass ionomer cement and zinc phosphate cement which is in consensus with the results of this study.

JE Dudley et al conducted a study on retention of cast crown copings cemented to implant abutment with a resin, glass ionomer, and temporary cement and have found that resin cement demonstrated significantly greater mean retention values than the other two cements. Resin cement is the cement of choice for the definitive cement of crown coping to implant abutment.[14]

Yu-Hwa Pan et al in their study on the effect of luting agents on retention of dental implant-supported crowns and found significant differences in cement failure loads among the various cements tested. The values obtained were zinc phosphate 1.225± 0.229 Mpa, Advance 1.205±0.197MPa, All Bond 2, 1.752±0.211 Mpa, Panavia F 1.679±0.176Mpa, Durelon 0.535MPa, Temp Bond 0.274±0.079MPa, and ImpProv 0.319±0.107MPa. They concluded that the resin cement showed much higher retention than the other tested cements.[41] Yu-Hwa Pan in an another study demonstrated that the resin cement used for luting dental implant restorations being most retentive followed by resin modified glass ionomer, zinc phosphate and zinc polycarboxylate cement.[42]

Farahnaz Nejatidanesh et al in their study on retentiveness of implant-supported metal copings using different luting agents, has quoted previous studies that indicate superior retentive strength for resinous cement as compared to zinc phosphate and zinc polycarboxylate cements.[38] A survey conducted by Diane Yoshinobu Tarica on cementation protocols for implant crown restorations in United States dental schools and found that resin-modified glass ionomer cement was most frequently cited as the cement used for inserting implant restorations.[54]

Mona Wolfart et al in their study found that glass ionomer cement with tensile bond strength of 469N for zinc phosphate cement 346N for polycarboxylate 813N and 653 for self-adhesive resin and concluded that polycarboxylate cement and self-adhesive resin cement showed the highest retention values followed by glass ionomer, and zinc phosphate cements .[60] Yu-Hwa Pan quoted from other authors who found that resin cement demonstrated the highest mean retentive strength when compared to zinc phosphate cement and resin-reinforced ionomer cement. Resin cements are still regarded as strongest luting agent among available cements.[41] Breeding et al in their study also compared 3 provisional luting agents, a glass ionomer and 2 resin luting agents. They found that the 3 provisional cements were less retentive than glass-ionomer and 2 resin luting agents.[11]

Another possible explanation for the improved retention seen in straight titanium implant abutments in all the cements when compared with 15^{o} angulated titanium implant abutments was the presence of the screw access channel on the axial wall and its filling material. Previous studies have found that different cements responded in different manners to filled or unfilled abutment screw access channels.[54,55] The recommendation provided by Straumann was to seal the abutment screw access channel with wax or gutta percha to crown cementation. It may be possible that filling abutment screw access channels with composite resin, and indeed some other materials, affects the crown retention.[54] Filling the abutment screw access channels with a rigid material may prevent cement escape into the internal abutment cavity, thus creating a greater internal cement pressure between the copings intaglio surface and abutment forcing cement into the micromechanical irregularities of the crown copings intaglio surface under greater pressure.[55] There may also be potential for a chemical bond between the abutment screw access channel filling material (e.g.,composite resin) and compatible luting cement that may laid in metal coping retention and the authors have concluded that significantly higher cement failure load values were produced when the access openings to gold screw in the abutment were filled compared to when they were not filled.[41]

Rachel S Squier studied retentiveness of dental cements used with metallic implant components and stated that the resin composite, resin-reinforced glass ionomer and zinc phosphate also performed as expected and were highly retentive. Surprisingly, glass ionomer cement used routinely as permanent cement for natural tooth structure, did not perform as anticipated and was minimally retentive with metal implant abutments.[53]

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 rates on the validation of in vitro conditions accurately simulating the complex oral environment. Since thermal cycling and load cycling may have an additive effect, especially with resin based cements, testing both conditions concurrently would be preferred and would better stimulate the intra-oral condition.

The retentive values of the luting agents used in this study can be compared only loosely to those with cementation of conventional fixed restorations to natural teeth. At this time, cement microstructure have not been comprehensively described or related to mechanical failure modes. Such studies would facilitate the design of improved cements. Limited data shows that glass ionomer cement tends to fail within their matrices and in the matrix-particle interfaces. All types of cements need to be investigated in this way, and laboratory failure mechanism must be related to clinical failure mechanism. The relevance of laboratory testing is unproven, but it is possible that these large in vitro performance differences might have clinical trials of luting cements have been prospective, controlled, double-blind, or of long duration. Much clinical data is needed so that the critical parameters for clinical success are elucidated and a rational clinical choice of luting cements can be made.[28]

Further research should be mindful that most cement 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.

CONCLUSION

The following conclusions were drawn from the data obtained in this in vitro study conducted for comparative evaluation of the tensile bond strength of three different cements on retention of implant supported cast copings with effect of abutment angulation. The three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement were used for luting cast copings on straight titanium implant abutments and 15^o angulated titanium implant abutments.

1. The mean tensile bond strength of zinc phosphate cement for luting cast copings on straight titanium implant abutments (GI) was 2.08MPa.
2. The mean tensile bond strength of glass ionomer cement for luting cast copings on straight titanium implant abutments (GII) was 2.34MPa.
3. The mean tensile bond strength of dual cure resin cement for luting cast copings on straight titanium implant abutments (GIII) was 3.75MPa.
4. The mean tensile bond strength of zinc phosphate cement for luting cast copings on 15^o angulated titanium implant abutments (GIV) was 1.75MPa.
5. The mean tensile bond strength of glass ionomer cement for luting cast copings on 15^o angulated titanium implant abutments (GV) was 1.97MPa.
6. The mean tensile bond strength of dual cure resin cement for luting cast copings on 15^o angulated titanium implant abutments (GVI) was 3.35MPa.
7. On comparison of the mean tensile bond strength of three different cements namely zinc phosphate cement, glass ionomer cement and

dual cure resin cement for luting cast copings on straight titanium implant abutments was found for group GI(2.08MPa), GII (2.34MPa), and GIII(3.75MPa) and by One-way ANOVA test the results were statistically significant. GIII showed maximum, GII moderate and GI least tensile bond strength. GIII>GII>GI.

8. On comparison of the mean tensile bond strength of three different cements namely zinc phosphate cement, glass ionomer cement and dual cure resin cement for luting cast copings on 15^{o}angulated titanium implant abutments was found for group GIV(1.75MPa), GV(1.97MPa),and GVI(3.35MPa) and by One-way ANOVA test the results were statistically significant . GVI show maximum, GV moderate, and GIV least tensile bond strength. GVI>GV>GIV.

9. On comparison of the mean tensile bond strength of zinc phosphate cement for luting cast copings on straight titanium implant abutments and 15^{o}angulated titanium implant abutments was for group GI (2.08MPa), and GIV (1.75MPa). The results showed were statistically significant GI>GIV.

10. On comparison of the mean tensile bond strength of glass ionomer cement for luting cast copings on straight titanium implant abutments and 15^{o} angulated titanium implant abutments was for group GII (2.34MPa), and GV (1.97MPa). The results showed were statistically significant GII>GV.

11. On comparison of the mean tensile bond strength of dual cure resin cement for luting cast copings on straight titanium implant abutments and 15^{o}angulated titanium implant abutments was for group GIII (3.75MPa), and GVI (3.35MPa). The results showed were statistically significant GIII>GVI.

GIII &GVI showed greatest, GII & GV moderate, and GI & GIV least tensile bond strength (GIII & GVI) > (GII & GV) > (GI & GIV).

12. On comparison of the mean tensile bond strength of zinc phosphate cement, glass ionomer cement and dual cure resin cement for luting cast copings on straight titanium implant abutments and on15^{o}angulated titanium implant abutments was for group GI(2.08MPa), GII(2.34MPa), GIII(3.75MPa), GIV (1.75MPa), GV(1.97MPa) and GVI(3.35MPa) which resulted statistically significant by One-way ANOVA test.(GIII) > (GVI) > (GII) > (GI) > (GV) > (GIV).

The tensile bond strength of zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on straight titanium implant abutments was for GI (2.08MPa), GII (2.34MPa) and GIII (3.75MPa) which were significantly higher than that of cast copings luted on 15^{o}angulated titanium implant abutments GIV (1.75MPa), GV (1.97MPa), and GVI (3.35MPa). It is concluded that the cast copings luted on straight titanium implant abutments and 15^{o}angulated titanium implant abutments with dual cure resin cement were having highest tensile bond strength followed by glass ionomer cement with moderate and zinc phosphate cement with least tensile bond strength.

SUMMARY

An in vitro study was conducted for comparative evaluation of the tensile bond strength of three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement on retention of implant supported cast copings with effect of abutment angulation.

A total of sixty (60) titanium implant abutments and their analogs were used which comprises of thirty (30) straight titanium implant abutments and thirty (30) 15^o angulated titanium implant abutments. All the selected titanium implant abutments were torqued to their respective implant analogs which were embedded in clear autopolymerizing resin blocks. Ni-Cr alloy cast copings were fabricated from the wax patterns obtained from straight titanium implant abutments and 15^oangulated titanium implant abutments. The cast copings were divided into six groups, ten (10) in each group and were luted with three different cements namely zinc phosphate cement, glass ionomer cement, and dual cure resin cement on two types of abutments and were divided into six groups (GI, GII, GIII, GIV, GV and GVI).

The cast copings were luted to their respective abutments with three different cements using regular cementation protocol. After one hour the test samples were kept in distilled water for 24 hours at 37^oc for aging. The test samples were subjected for tensile test with a universal testing machine to determine the tensile bond strength of these cements used in this study. The

tensile force required to separate the cemented cast copings from the abutments were recorded in Newton and then converted in to megapascals (MPa). The mean tensile bond strength for each group was tabulated and statistically analyzed.

On comparison of the mean tensile bond strength of three different cements used in this study for luting cast copings on straight titanium implant abutments revealed statistically significant difference among them and the dual cure resin cement demonstrated the highest mean tensile bond strength whereas the zinc phosphate exhibited the lowest mean retentive strength. The glass ionomer showed intermediate mean tensile bond strength.

On comparison of the mean tensile bond strength of three different cements used in this study for luting cast copings on 15^o angulated titanium implant abutments revealed statistically significant difference among them and dual cure resin cement demonstrated the highest mean tensile bond strength whereas the zinc phosphate cement exhibited the lowest mean retentive strength. The glass ionomer cement showed intermediate mean tensile bond strength.

On comparison of mean tensile bond strength of three different cements used in this study for luting cast copings on straight titanium implant abutments and 15^o angulated titanium abutments revealed statistically significant difference among them and the dual cure resin cement demonstrated highest tensile bond strength with both the types of abutments whereas the zinc phosphate cement exhibited the lowest mean retentive strength. The glass ionomer cement showed intermediate mean tensile bond strength. The tensile bond strength of zinc phosphate cement, glass ionomer cement, and dual cure resin cement for luting cast copings on straight titanium implant abutments was significantly higher than that of the cast copings luted on 15^o angulated titanium implant abutments.

Dual cure resin cement exhibited the highest retentive value compared to glass ionomer cement and zinc phosphate cement with both types of abutments in this study. The cast copings cemented with the cements used in this study on straight titanium implant abutments exhibited higher retention compared to 15^o angulated titanium implant abutments. Since there are no criteria for minimum amount of tensile bond strength required for preventing easy dislodgement of metal copings from implant abutments, the selection of cement is based on clinician's choice. The 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. The minimum retentive force required to prevent dislodgement as well as for easy retrievability without damaging the implant component and osseointegration need to be explored in future.

The most commonly, currently used cement in implant dentistry was initially intended for use with natural teeth. The development of cements especially for use in implant dentistry may be warranted. Further studies regarding the effect of various angulation of titanium implant abutment on the retention of crown with various cements would be of great use before their acceptance into dental laboratory and practice.

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