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Original Article

# Effect of Surface Modifications on the Retention of Cement-retained Implant Crowns under Fatigue Loads: An *In vitro* Study

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**Abstract**

**Background:** Masticatory forces cause fatigue to the dental luting agents, adversely affecting the retention of these cement-retained crowns. Sandblasting (SB) and diamond abrading the abutment surface improves the bond strength of luting agents. However, the effect of acid etching (AE) on the implant abutment surface and the effect of other surface modifications under masticatory load are yet to be documented. **Purpose:** The aim of the study was to evaluate the effect of abutment surface modifications on the retention of cement-retained restorations subjected to cyclic fatigue loads. **Materials and Methods:** Forty Ni-Cr copings were made on Cp-titanium laboratory analogs. The specimens were divided into two groups as Group I: Uniaxial tensile loading (UTL) and Group II: Offaxial cyclic loading followed by uniaxial tensile loading [CTL]. Further subgrouped as, subgroup I: Control (C), subgroup II: SB, subgroup III: AE, and subgroup IV: SB + AE. The copings were luted with $Zn_2(PO_4)_3$ and subjected to uniaxial tensile loading. Copings were recemented, and CTL was conducted. Two-way analysis of variance was used as the statistical test of significance. **Results:** In relation to the subgroups, the bond strength of $Zn_2(PO_4)_3$ was higher in Group I than in Group II. The bond strength in subgroup IV was superior in both Group I and Group II (547.170 N ± 5.752 and 531.975 N ± 6.221 respectively). **Conclusions:** For both UTL and CTL, abutment SB + AE elicited maximum coping retention followed by AE. Off-axial cyclic loading adversely affected the retention irrespective of the surface modifications.

**Keywords:** *Abutment surface modifications, acid etching, cement retention, cyclic loading, tensile loading*

## Introduction

Cement-retained restorations are the most common type of implant restoration. There are numerous advantages for cement-retained prosthesis over screw-retained prosthesis such as passive casting, axial loading, accessibility, progressive loading, etc.[1] Numerous dental luting agents are used either temporarily or permanently for cementation of the restorations. It is not suggested that anyone cement is better than the other in retaining cement-retained crowns (CRC) to implant abutments.[2] Zinc phosphate and zinc polycarboxylate are the two commonly used cements in implant restorations.

Abutment modifications improve the bond strength of the luting agents. The predominant modification variables include abutment taper, screw access channel engagement, height, axial wall number, abutment platform, and surface roughness.

Engagement into the screw access channel can offset the loss of retention of the cemented casting with up to 22° of taper.[3-5] Leaving the screw access channel open, with

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or without abutment venting improved the retention of a cemented coping. Placement vent holes significantly improved retention by altering cement flow within the screw access channel.[6] Filling the access hole is inversely proportional to the cement retention.[7]

Abutment height/length is directly related to the cement retention. An increase in the abutment height legibly increased the cement retention.[4,5,8-10] Removal of the axial wall will compromise the retention. Modification of the axial walls has a positive influence on the retention. The number and position of axial walls can be designed or modified to improve the retention. Two opposing walls had a greater retention.[7,11] Selection of an implant with greater platform size will ultimately lead to improved retention.[7]

The surface roughness of the abutment will also affect the retentive quality of the luting agents. Methods such as air abrasion (sand blasting [SB]), roughening with diamond rotary, and circumferential grooving were used until date. Air abraded surface resulted in greater retention with almost all luting agents than unmodified[9,10,12,13] and diamond roughened surface.[14] In contrary, zinc oxide eugenol temporary cement used to lute basemetal crowns showed superior retention with diamond rotary roughened surface than air-abraded surface.[15]

Increase in the number of circumferential grooves on the abutment surface will improve the bond strength of cements.[16] Grooved abutment will have a superior retention than an SB or an unmodified abutment.[17]

Surface roughness on the metals can be also achieved by acid etching (AE) techniques. Maryland bridges, which is a type of resin-bonded fixed partial denture (FPD), falls under this category.[18] However, its effect on implant abutments for crown retention has not been reported.

Cement-retained implant crowns or bridges are exposed to numerous stresses that may lead to reduction of crown retention intraorally, i.e., occlusal loading. The masticatory forces cause fatigue to CRC and abutments and adversely affect the retention. Moreover, the relation between the masticatory loads and the retentive forces is important.

Vertical off-axis loading reduced the retentive force and these retentive forces were not significantly different at different time cycles. However, increased loading cycles had little correlation to decreased retentive forces.[19] However, one study concluded that retention of cast crown copings was significantly affected by cement type and not by compressive cyclic loading.[20] Hence, the effect of masticatory loads on the retention of the cement-retained implant crowns luted on the surface modified implant abutments has to be studied.

The aim of the study was to evaluate the effect of abutment surface modifications by different combinations on the retention of cement-retained implant crowns on applying cyclic fatigue loads.

## Materials and Methods

Forty Cp-titanium, single piece laboratory analogs (Noble Biocare India Pvt Ltd.) [Figure 1], of 5.5 mm height and 4.3 mm diameter, were mounted in acrylic in a straight vertical position using dental surveyor.

For uniform height and thickness, patterns with occlusal platform were made out of a sectioned repositionable aluminum mold with locking device [Figure 2]. A dimple of 1 mm diameter and 0.5 mm deep was created with No. 2 round bur on the occlusal platform, 3 mm away from the long axis of the specimens for off-axial loading. A circular ring provision at the center of the occlusal platform for tensile loading was attached to the patterns.

The patterns were cast with beryllium-free Ni-Cr alloy (Wiron 99®; Bego) [Figure 3]. The intaglio surface of the copings were examined for the presence of any nodules or fins and were removed with round bur in straight hand piece and SB with 50 μm $Al_2O_3$. The fit of the copings were examined utilizing disclosing media, and the stability was assessed by applying finger pressure laterally to the copings while seated on the specimen and considered acceptable if the copings did not have any rocking movements.[10]

Table 1 describes the specimen distribution under groups and subgroups. The specimens ($n$ = 40) were divided into two major groups based on the type of loading, i.e., Group I: Uniaxial tensile loading (UTL) and Group II: Off-axial cyclic loading followed by uniaxial tensile loading (CTL). The copings used in the Group I were reused in the Group II. Further, the specimens were subdivided into four subgroups ($n$ = 10) under each group, based on the surface modifications, i.e., subgroup I: control (C), subgroup II: SB, subgroup III: AE, and finally subgroup IV: SB + AE.

Specimens of the subgroups II and IV were SB by 50 μm $Al_2O_3$ and compressed air at 1 bar pressure from a standard distance of 10 mm for 5 s. Specimens of the subgroups III and IV were AE with 48% sulfuric acid at constant temperature of 60°C for 60 min [Figure 4].[21-23] After 60 min, the specimens were washed in ultrasonic bath containing sodium bicarbonate solution for 15 min to neutralize the acid remnants. Finally, the screw access channels of the specimens were completely filled with light-cure composite resin (3M ESPE; Filtek™ Z350 XT).

Before cementation, all the castings and specimens were steam cleansed and luted with $Zn_2(PO_4)_3$ cement

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**Figure 1:** Single piece laboratory analog

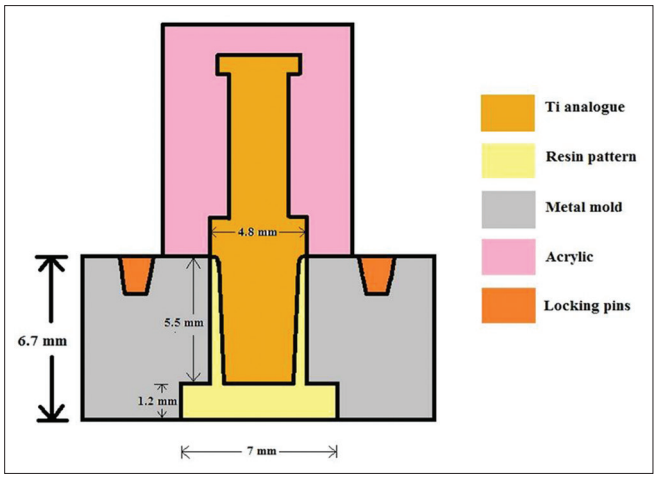



**Figure 2:** Transverse section of specimen assembly



**Figure 3:** Metal coping with ring

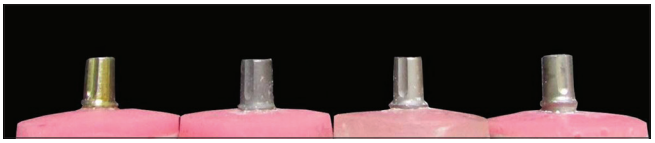


**Figure 4:** Control, sandblasted, acid etched, sandblasted, and acid etched

**Table 1: Specimen distribution**

| Subgroups | Groups | |
|---|---|---|
| | I. UTL (*n*=40) | II. CTL (*n*=40) |
| I. C | 10 | 10 |
| II. SB | 10 | 10 |
| III. AE | 10 | 10 |
| IV. SB + AE | 10 | 10 |

UTL: Uniaxial tensile loading, C: Control, SB: Sand blasting, AE: Acid etching, CTL: Off-axial cyclic loading + UTL

(Elite Cement 100; GC corporation) with a constant known load of 5 kg[9] applied along the long axis of the specimens for 10 min using hydraulic machine. Excess cement was removed using Hollen-Back carver without damaging the margins of the specimens, and the complete seating was visually assessed. All specimens were then stored overnight in distilled water at 37°C.

Uniaxial tensile test was performed using the servo controlled universal testing machine (Model UNITEK-94100; FIE Pvt. Ltd), with a load range of 0–100 KN. A specially designed metallic wire hook was engaged within the loop of the copings, and load was delivered with the metallic hook attached to the upper movable jaw of the testing machine, traveling at a cross-sectional speed of 5 mm/min until the copings failed off from the specimen. Tensile strength values for each subgroup were noted in Newton.

The cement remnants on the specimens and in the intaglio surface of the copings were almost dissolved using removalon followed by mechanical debridement using spoon excavator without surface scratching. The specimens and copings were washed thoroughly in ultrasonic cleanser containing sodium bicarbonate solution for 15 min followed by steam cleansing. The copings were recemented with $Zn_2(PO_4)_3$ cement by following the above-mentioned protocol.[24]

The recemented copings were subjected to off-axial cyclic loading (5000 cycles to simulate 1 year of average human masticatory function, 5 kg load at 80 cycles/min). Point of load application was in the dimple created on the occlusal platform, which was 3 mm away from the long axis of the specimens. UTL adhering to the above-mentioned criteria followed the off-axial cyclic loading and the values noted in Newton.

The samples tested in this study can be considered independent. Two-way analysis of variance (ANOVA) was used to test for any difference between the UTL and CTL groups ($\alpha = 0.05$). A conservative *post hoc*

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test correction was applied (Scheffe test) to see what difference lay between the means of the subgroups.

## Results

Means and standard deviations of loads at failures [bond strength] for all groups are presented in Table 2.

Figure 5 describes that SB + AE subgroup has the highest mean bond strength when compared to other subgroups in both UTL and CTL groups.

Table 3 shows the results of two-way ANOVA. A statistically significant effect of surface modifications (subgroups) on bond strength of $Zn_2(PO_4)_3$ was evident ($P < 0.001$). In addition, a statistically significant effect of the type of loading (Groups: UTL and CTL) on the bond strength was observed ($P < 0.001$). When the effects of surface modifications (subgroups) under the two loading groups (UTL and CTL) were compared, a statistically significant influence on the bond strength of the cement was evident ($P < 0.001$).

Table 4 summarizes a statistically significant interaction between the subgroups in all the compared combinations ($P < 0.001$).

## Discussion

In this study, the effect of modified surface abutments on the retention under fatigue load was evaluated. This study demonstrated that roughening the surface of abutment by SB followed by AE increased the retention of cemented crowns in comparison with AE, SB, and C subgroups. SB the surface of abutment was not as effective as roughening it by AE. In both loading groups (UTL and CTL), surface modifications have a positive correlation, i.e., enhanced the bond strength of $Zn_2(PO_4)_3$. However, application of off-axial cyclic load decreased the retention irrespective of the surface modifications than the UTL group.

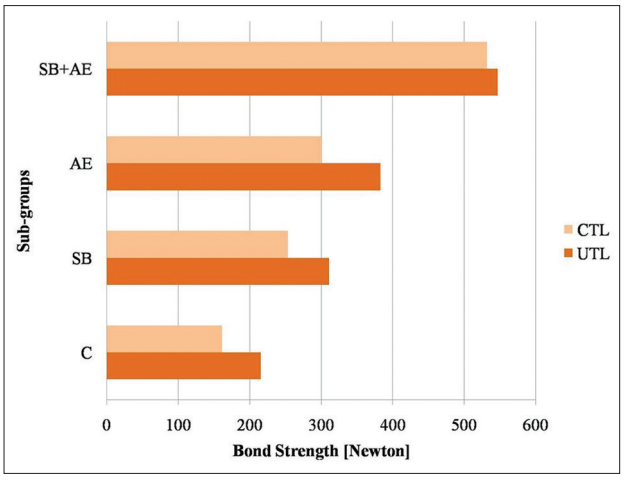



**Figure 5:** Comparative bond strength of subgroups in both uniaxial tensile loading and off-axial cyclic loading + uniaxial tensile loading

In the recent years, attention has been focused toward improving the bond strength of luting agents for CRC. Numerous methods to improve the bond strength are available in the literature. Surface alterations/modifications of the abutments improve the bond strength of the luting agents by creating macro or micro retentive undercuts, and hence, increasing the total surface area for bonding. These modifications can be broadly classified into macroscopic or microscopic. In the present study, surface modifications at only microscopic level were employed. Microscopic surface modifications are obtained by two popular methods until date. One, SB/air abrading with alumina and the other being diamond abrading.

In the present study, SB the abutment surface with 50 μm $Al_2O_3$ was employed followed by only UTL. SB surface resulted in greater retention with almost all luting agents than unmodified abutment surface. By this method, microscale retention associated with micro cavities for cement bonding was created.[22] For the SB-subgroup (311.335 N ± 4.169), the retentive values were greater ($P < 0.001$) than the unmodified/C-subgroup (215.726 N ± 8.333) which is in accordance

**Table 2: Bond strength means and standard deviations for subgroups**

| Subgroups | Groups, arithmetic mean (N)±SD | |
|---|---|---|
| | UTL | CTL |
| C | 215.726±8.333 | 161.794±7.309 |
| SB | 311.335±4.169 | 253.480±5.191 |
| AE | 383.410±7.237 | 301.530±4.762 |
| SB + AE | 547.170±5.752 | 531.975±6.221 |

UTL: Uniaxial tensile loading, C: Control, SB: Sand blasting, AE: Acid etching, SD: Standard deviation, CTL: Off-axial cyclic loading + UTL

**Table 3: Summary of two-way analysis of variance**

| Source | *F* ratio | *P* |
|---|---|---|
| Subgroups | 11,212.103 | <0.001 |
| Groups | 1389.169 | <0.001 |
| Groups × subgroups | 97.034 | <0.001 |

**Table 4: *Post hoc* test (Scheffe test) results**

| Subgroup | Compared subgroup | Difference | *P* |
|---|---|---|---|
| C | SB | 93.648 | <0.001 |
| C | AE | 153.710 | <0.001 |
| C | SB + AE | 350.813 | <0.001 |
| SB | AE | −60.063 | <0.001 |
| SB | SB + AE | −257.165 | <0.001 |
| AE | SB + AE | −197.103 | <0.001 |

C: Control, SB: Sand blasting, AE: Acid etching

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to the previous studies conducted. This can be attributed to the higher surface roughness, thus creating increased surface area for the cement contact.[9] Michalakis *et al*. have suggested that the surface roughness of the prepared teeth results in an increase in retention of cemented restorations. This increase is a result of micromechanical interlocking of the cement medium with roughened tooth surface.[13] Hence, the present study demonstrates that this principle applies also to the metal implant components.

Another method of obtaining microscopic abutment rough surface used in this study was AE. AE improved the retention of the copings than SB. For subgroup AE, AE the abutment surface with 48% $H_2SO_4$ at 60°C for 60 min was employed and followed by UTL. This improved the bond strength (383.410 N ± 7.237) of $Zn_2(PO_4)_3$, which was significantly higher than ($P < 0.001$) SB and C subgroups. In SEM analysis, it was observed that AE the samples contributed to increased surface undercuts (~2–2.5 μ) than SB samples. The reason should be higher arithmetic mean roughness (Ra), measured by color laser 3D profile microscope, for AE specimens than SB specimens.[22] Greater undercuts and nanocavities in AE specimens increased the micro- and nano-mechanical retention, which in turn contributed to high-bond strength of $Zn_2(PO_4)_3$ in this study. Another explanation for inferior bond strength in SB subgroup is that after SB some alumina particles probably remained on the surface of the abutments, which interfered with the micromechanical retention. Whereas, in AE subgroup, AE brought about several benefits to titanium surface: increased micro- and nano-scale mechanical interlocking, increased effective bonding area, and decreased contaminants from the surface.[22] Technique for AE base metal alloys was first described by Tanaka *et al*.[25] for resin-bonded FPDs to improvize the bond strength of resin cements to base metal alloys. In implantology literature, AE the implant fixtures with inorganic or organic acids was quite popular for a better adhesion of the blast cells on the fixture surfaces for rapid osseointegration. However, none of the studies has addressed AE on the abutment surface.

In the subgroup SB + AE, AE was done following SB the abutment surface with 50 μm $Al_2O_3$ and subjected to UTL alone. Surprisingly, the bond strength (547.170 N ± 5.752) of this subgroup was significantly superior ($P < 0.001$) to that of AE subgroup. These findings suggested a synergistic effect between SB and AE, which would have created micro- and nano-surface roughness, respectively. AE the SB surface removed the alumina remnants and other surface contaminants thus, improvizing the bond strength of the luting agent.[22]

In the present study, off-axial cyclic loading (CTL) on the specimens with modified abutment surfaces (subgroups: SB, AE, and SB + AE) significantly decreased ($P < 0.001$) the bond strength of $Zn_2(PO_4)_3$ when compared to the specimens of UTL. Off-axial cyclic loading was applied on the occlusal platform of the specimens. The UTL values obtained for the subgroups C, SB, AE, and SB + AE were 215.726 N ± 8.333, 311.335 N ± 4.169, 383.410 N ± 7.237, and 547.170 N ± 5.752, respectively. The obtained CTL values were 161.794 N ± 7.309, 253.480 N ± 5.191, 301.530 N ± 4.762, and 531.975 N ± 6.221, respectively. Even after the application of off-axial tensile loading, subgroup SB + AE had the greatest retentive values than the other three subgroups. UTL was employed in the current study as it permitted comparison with previous investigations of a similar nature.[19,20] Wiskott *et al*.[26] studied the effect of SB the abutment surface on the resistance of CRC under rotational/lateral dynamic fatigue loads and concluded that SB increased the resistance of luting agents. However, none of the studies had described the effect of surface modifications on the retention of CRC under off-axial vertical cyclic loadings.

The advantages and disadvantages of restoring dental implants with CRC are documented vividly in the dental literatures. However, its universal applicability is restricted by one profound disadvantage, which is the loss in ease of retrievability of the cemented superstructure. On the one hand, cement selected with superior retentive properties could damage both fixture and abutment while employing aggressive removal techniques; on the other hand, the selection of cement that is not retentive enough could be a potential source of embarrassment for the patient. Consecutively, prosthodontists who plan for a progressive loading, desire retrievability of the superstructure, and generally turn toward using cements yielding submaximal retention.[2]

Therefore, cement type is the deciding factor of retention if retrievability of the prostheses is the issue.[27,28] No single retrievable cement will suffice for all clinical situations.[2,29] Dental cements may be selected on a case-by-case basis, according to individual cement advantages and the anticipated requirement for crown retrievability.[30]

$Zn_2(PO_4)_3$ serves as a gold standard for luting the implant-supported restorations.[31-34] In the present study, $Zn_2(PO_4)_3$ has been used to lute the copings. Specimens subjected to UTL showed cohesive failure in subgroups SB, AE, and SB + AE. When the specimens subjected to CTL, adhesive failure occurred in the cement-crown interfaces of subgroups AE and SB + AE, which may be due to stronger micro- and nano-mechanical adherence of $Zn_2(PO_4)_3$ to the abutment surface than to the intaglio surface of the coping. Adhesive failure

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occurred between the cement-abutment interfaces of SB subgroup because of the presence of alumina remnants and other contaminants on the abutment surface, which interfered in the cement bond. Moreover, irrespective of loading type (UTL/CTL), adhesive failure between cement-abutment interface of subgroup C were observed which is attributed to the smooth machined surfaces of the abutments.

In the present study, the ultrasurface characteristics of the SB, AE, and SB + AE specimens were not studied through which a definitive explanation could have been proposed for the results obtained. This *in vitro* study used simulations of the oral environment that were not able to accurately reproduce all oral factors such as thermal fluctuations, salivary pH, its buffering capacity, and flow rate. The clinical relevance of the findings from the current study relies on the validation of *in vitro* conditions accurately simulating the complex oral environment.

Number of fatigue cycles and applied load used in this study were smaller, i.e., 5000 cycles to simulate 1 year of average human masticatory function, 5 kg load at 80 cycles/min,[20] than other studies,[19,20,26] although great variation in the estimation of numbers of cycles that equate to average human daily, weekly, and yearly masticatory function exists. Chewing rate is subjective, varies from person to person, and may be related to the type of food; it also varies within the same person. No known study has validated this due to apparent difficulties in ethics and measurement. Further research regarding CRC may investigate dental cements with various implant systems under validated, standardized *in vitro* conditions. Future research should be mindful that most cement currently used in implant dentistry was initially intended for use with natural teeth. Development of novel cements specifically in the field of implantology may be warranted.

## Conclusion

Within the limitations of the *in vitro* investigation, the following conclusions were derived:

1. Modifying abutment surface improved the retention of the cement-retained copings
2. Combination of the surface modification methods is better than individual modification methods
3. Combination of SB and AE improved the retention of the cement-retained copings
4. Among individual surface modifications, AE offered better retention than SB
5. Off-axial cyclic loading adversely affected the retention irrespective of the surface modifications
6. SB + AE provided the greatest retention than the individual modifications even under off-axial cyclic loading
7. SB + AE can consider as method to improvize the cement retention under masticatory loads.

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### Conflicts of interest

There are no conflicts of interest.

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