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Original Research Article

Effect of Different Surface Treatments on the Shear Bond Strength of Zirconia-Based Crowns Cemented with Self-Adhesive Resin Cements: An Experimental Study Conducted in Tertiary Care Dental Institutes of Pakistan

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Abstract: ***INTRODUCTION*** Zirconia-crowns are highly popular in the field of restorative dentistry as they are very strong, durable, and they possess good esthetic characteristics. Nonetheless, it is still hard to attain a stable relationship between zirconia restorations and resin cements since zirconia does not contain a silica-based glass phase that is used in the conventional etching techniques. Different types of methods of surface treatment have been suggested to enhance bonding performance. This research project was intended to compare the influence of various surface treatments on the shear bond strength of the crowns made of zirconia bonded with self-adhesive resin cements. ***Methodology*** This was an experimental study involving in vitro experiments in tertiary care dental institutes in Pakistan. CAD/CAM technology was used to manufacture a total of 60 zirconia specimens that were randomly separated into 3 groups (n=20). Group A was left untreated to the surface (control), Group B was abraded by airborne-particles with 50 um aluminum oxide particles, and Group C was abraded by airborne-particles and then zirconia primer was applied. Self-adhesive resin cement was applied on all the specimen. A universal testing machine was used to measure the shear bond strength. The analysis of data was done through SPSS. They included Shapiro-Wilk test to evaluate the normality and one-way ANOVA and Tukey post hoc to evaluate differences between groups. ***Results*** The average shear bond strength values of Group A, B and C were 7.12 ± 1.18MPa, 10.46 ± 1.34MPa, and 13.58 ± 1.27 MPa respectively. ANOVA indicated that there was statistically significant difference among groups ($p < 0.001$) using one-way ANOVA. Tukey posthoc analysis was done to show that the bond strength of Group C was significantly stronger than Groups A and B. ***Conclusion*** The abrasion of zirconia crowns cemented with self-adhesive resin cements by airborne particles and the presence of zirconia prime substantially enhanced the shear bond strength of zirconia crowns.

Keywords: Zirconia crowns, self-adhesive resin cement, surface treatment, shear bond strength, abrasion of airborne particles, zirconia crowns, zirconia primer.

INTRODUCTION

Strength and longevity of the bonding between the restorative materials and the underlying tooth structure are the most important factors in the long-term success of dental restorations [1]. Crowns made of zirconia have been popular in the contemporary restorative dental care as a result of superb mechanical robustness, biocompatibility, and positive esthetics. Zirconia is a polycrystalline ceramic material that has a high fracture resistance and better wear properties and therefore is a perfect material to be used as a fixed prosthesis, in fact, the material is best used as a fixed dental prosthesis in the posterior restorations where high occlusal forces exist. Also, the development of computer-aided design and computer-aided manufacturing (CAD/CAM) technology has further promoted the application of zirconia in clinical practice by enabling to fabricate crowns precisely and enhance marginal adaptation of crowns [2].

Although these benefits exist, it is a big challenge to bond zirconia restorations to the tooth structures. Zirconia does not have a phase of glass in it, such as silica-based ceramics, and the material can thus not be effectively etched with the standard methods of hydrofluoric acid. This is because of the absence of silica content in it, which limits the capacity of the conventional adhesive systems to develop a robust micromechanical retention. Consequently, clinicians have to depend on other surface treatment modalities to improve the strength of bond between zirconia restorations and resin cements. A number of mechanical and chemical treatments to the surface have been suggested to increase adhesion, including airborne-particle abrasion (sandblasting), laser treatment, tribochemical silica coating, and the use of special primers with active monomers, such as 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP).

Self-adhesive resin cements have been widely accepted as one of the existing luting agents due to their ease of clinical use and decrease in technique sensitivity. These cements do not require individual etching and bonding processes and this contributes to saving of chair time and eliminating the possibility of operator error [3]. Moreover, the self-adhesive resin cements can develop chemical bonds with the tooth substrate and other particular restorative products [4]. The usefulness of these cements with zirconia restorations may however differ with respect to the nature of surface treatment before cementation. Thus, the surface treatment procedures must be maximized to guarantee the stability of bonding and clinical success of restorations made of zirconium.

The effects of various surface treatments on zirconia restorations bond strength have been examined in various in vitro studies [5]. Techniques that have been found to demonstrate variable degree of reliability in enhancing shear bond strength include sandblasting using aluminum oxide particles, use of zirconia primers, and tribochemical silica coating. Nonetheless, the findings of the literature are inconsistent because the methodologies, the types of the cements that were used, the particle sizes in airborne abrasion, and the conditions of the tests were different. Besides, other environmental, material and operator variables can also affect bonding results [6]. As a result, it is yet to be agreed upon what is the most effective surface treatment process of zirconia restorations in the case of self-adhesive resin cements.

In the developing world like Pakistan, zirconia restorations are being utilized in the tertiary care dental institutes more frequently because of their durability and esthetic merits [7]. Nonetheless, there is a dearth of experimental results in the region on the best surface treatment regimens of zirconia crowns. The majority of the literature review has been carried out in other populations and laboratory but this might not be a complete mirror of the materials, equipment, and clinical effect of the dental institutions in Pakistan. This deficiency of evidence of the area suggests that experimental studies are required to assess the competence of the broadly utilized surface therapy methods in local laboratory settings [8,9].

Research Gap and Objective

Though many studies have been conducted on the ways of strengthening the bond of zirconia restorations, there is an absence of experimental data by tertiary care dental institutes in Pakistan on the comparison of various surface treatment regimens particularly in combination with self-adhesive resin cement. Moreover, differences in materials and laboratory processes require localized assessment to identify the most efficient process of enhancing the bond strength. Thus, the aim of this experimental research will be to compare and contrast the impact of surface treatment of various types of crowns cemented with self-adhesive resin cements in tertiary care dental institutes of Pakistan. This research findings are supposed to be added to the available evidence-based clinical decision-making and attempt to determine which surface treatment method yields the most reliable results in having lasting zirconia crown adhesion.

MATERIAL AND METHODS

Study Design and Setting

The research was conducted in dental materials laboratories of tertiary care dental institutes in Pakistan. All laboratory tests were conducted under standardized conditions to reduce: variability in the preparation of the specimen, treatment of surface and mechanical testing.

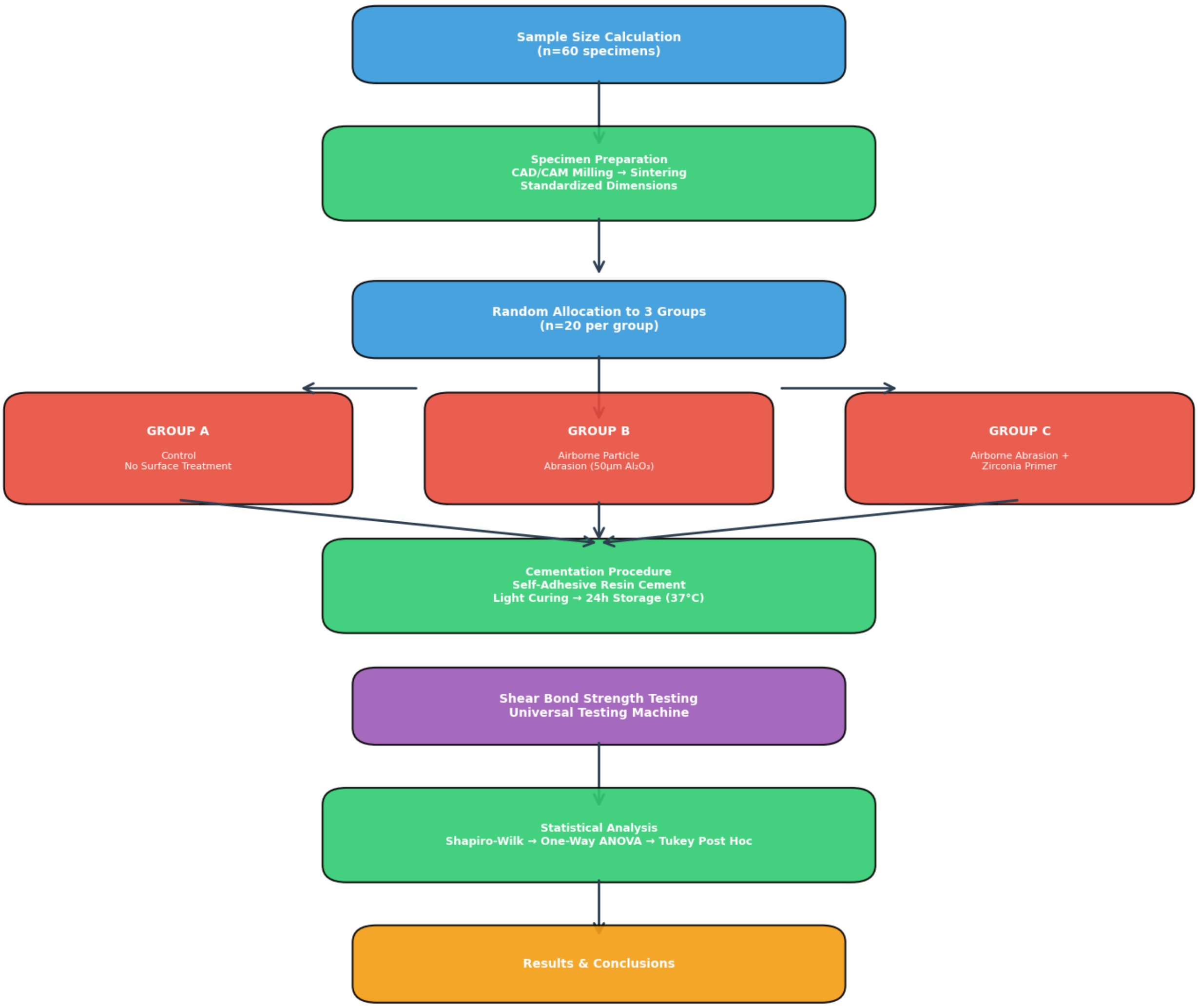

Figure 1. Flowchart to show the methodology

Sample Size Calculation

The formula of calculating the sample size widely used in comparing the mean value of two or more experimental groups in lab work was used. According to the literature that had already tested the shear bond strength of zirconia restorations, it was expected that the mean difference in the bond strength between the group of surface treatment would be in the range of 4-5 MPa with a standard deviation of about 3 MPa. The minimum calculated sample size of 36 specimens was found using a 95-confidence level, a 80-statistical power and a significance level (a) of 0.05. The sample was adjusted to 60 specimens to enhance the reliability of the findings and have equal distribution among the experimental groups. These specimens were also categorized into three groups with each surface treatment group having 20 specimens.

Specimen Preparation

Sixty zirconia-based crown specimens were produced using the CAD/CAM technology. Zirconia blocks were pre-sintered and then milled based on standardized dimensions so as to give all specimens similar size. The sintering of the zirconia specimens in a high temperature furnace that followed the recommended procedure by the producer was done after the milling in order to obtain full strength and density. The surfaces of the zirconia specimens were washed using distilled water and dried using air and then the surface treatments were applied.

Group Allocation and Surface Treatment Procedures

The specimens were randomly grouped into three based on the nature of the surface treatment done on the zirconia surface before cementation. The zirconia surfaces in Group A were not treated and acted as the control group. Group B Abrasion of the airborne particles was done on a constant duration on a constant pressure and distance of 50 um of aluminum oxide particles to obtain micromechanical retention on the zirconia surface. Abbrasion of airborne particles was done in Group C followed by the application of a zirconia primer containing functional

monomers developed to increase the chemical bond between the surface of the zirconia and the resin cement.
All the specimens were thoroughly cleaned under oil-free air and kept in an environment free of contamination before cementation after the respective surface treatments had been done.

Cementation Procedure

Cementation of all zirconia specimens was done in commercially available self-adhesive resin cement as per instructions of the manufacturer. The cement was applied on the treated zirconia in a standardized quantity and the specimens were placed under constant pressure to assure homogenous cement thickness. The surplus cement was avoided by taking care during polymerization. Calibrated LED curing unit was used to cure the resin cement light over the suggested period to allow full polymerization of the resin cement. The specimens that had undergone the cementation process were then kept in distilled water at 37degC during 24hrs in order to approximate the oral conditions and to enable the cement to set.

Shear Bond Strength Testing

The shear bond strength of the cemented zirconia specimen was evaluated using a universal testing equipment. All specimens were positioned in independent holders, ensuring proper alignment throughout testing. A shear force was applied at the zirconia and resin cement contact at a crosshead speed of 1 mm per minute until bond failure occurred. The maximum stress that might cause debonding was quantified in Newtons (N). The ratio of the recorded load to the bonded surface area determines the shear bond strength in megapascals (MPa).

Data Collection and Variables

The shear bond strength in megapascals was the main outcome variable of the research. The independent variable was the nature of surface treatment of the zirconia specimens. All the results of the universal testing machine were noted and summarized in a tabular data sheet to be subjected to statistical analysis.

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) software was utilized for the analysis of the gathered data. Shear bond strength data for each experimental group were computed using descriptive statistics, including mean and standard deviation. The Shapiro-Wilk test was employed to assess the normality of data distribution. The approach employed to ascertain statistically significant differences across the separate groups, given that the research involved comparing the mean bond strength of three distinct groups, is one-way analysis of variance (ANOVA). Upon obtaining significant results from ANOVA, a post hoc multiple comparison analysis utilizing the Tukey test was performed to ascertain particular group differences. The p-value was below 0.05, indicating statistical significance.

RESULTS

A total of 60 zirconia specimens were included in the study and randomly allocated into three groups based on the surface treatment applied prior to cementation with self-adhesive resin cement, with 20 specimens in each group. Group A served as the control and received no surface treatment, Group B underwent airborne-particle abrasion using 50 µm aluminum oxide, and Group C received airborne-particle abrasion followed by the application of a zirconia primer containing functional monomers. The shear bond strength of each specimen was then measured in megapascals (MPa) using a universal testing machine. Descriptive statistical analysis revealed noticeable differences in the mean bond strength among the three groups: the control group exhibited the lowest mean shear bond strength, whereas the specimens treated with airborne abrasion followed by zirconia primer demonstrated the highest bond strength values. Detailed descriptive statistics for the shear bond strength values of each group are presented in Table 1.

Group	Surface Treatment Method	Sample Size (n)	Mean (MPa)	Standard Deviation (SD)	Minimum	Maximum
Group A	No Surface Treatment (Control)	20	7.12	1.18	5.40	9.05
Group B	Airborne Particle Abrasion (50 µm Al_2O_3)	20	10.46	1.34	8.12	12.85
Group C	Airborne Abrasion + Zirconia Primer	20	13.58	1.27	11.32	15.70

As presented in Table 1, Group C demonstrated the highest mean shear bond strength (13.58 ± 1.27 MPa), followed by Group B (10.46 ± 1.34 MPa), while Group A showed the lowest mean value (7.12 ± 1.18 MPa). These findings indicate that the combination of mechanical and chemical surface treatments significantly improved the bonding performance of zirconia crowns compared with untreated surfaces. Prior to performing inferential statistical analysis, the shear bond strength data were assessed for normality using the Shapiro–Wilk test. The results indicated that the data in all three groups followed a normal distribution ($p > 0.05$), thereby justifying the use of parametric statistical methods for further analysis. The detailed outcomes of the Shapiro–Wilk normality test are presented in Table 2.

Table 2: Shapiro–Wilk Test for Normality of Shear Bond Strength Data

Group	W Statistic	p-value
Group A	0.964	0.631
Group B	0.971	0.742
Group C	0.958	0.517

Given that all p-values were higher than 0.05, the normality was met in all experimental groups. The one-way analysis of variance (ANOVA) was used to find out whether statistically significant differences existed in shear bond strength of the three groups of surface treatments. The results of ANOVA showed that the mean value of shear bond strength of the groups was statistically significant ($p < 0.001$). Figure 1 provides the detailed results of the ANOVA.

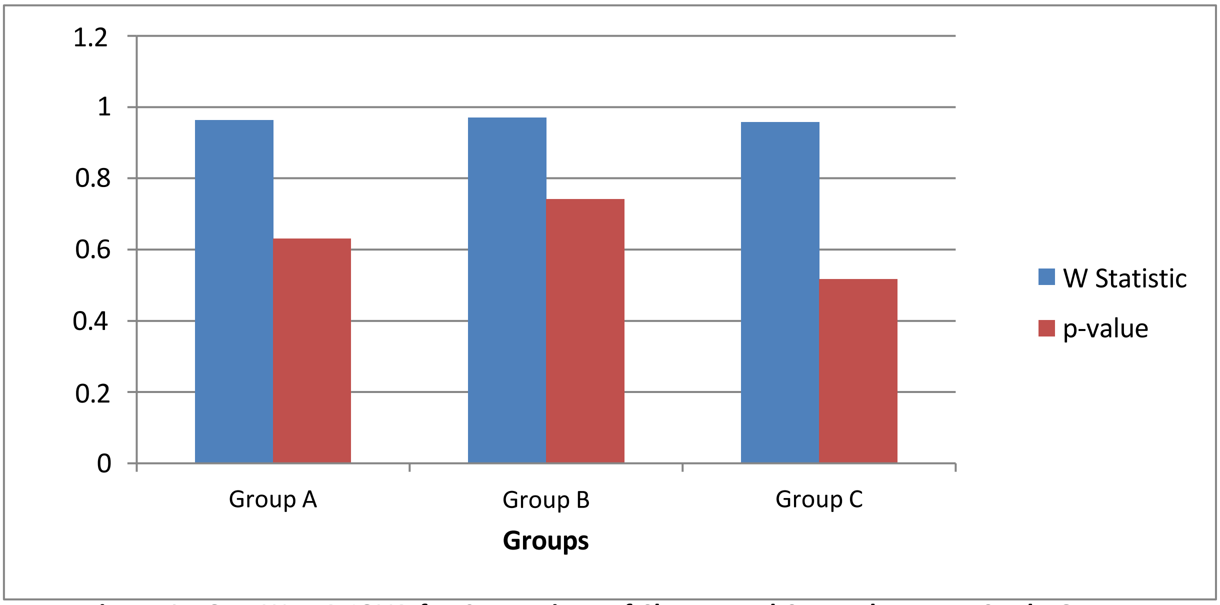

Figure 1. One-Way ANOVA for Comparison of Shear Bond Strength among Study Groups

The ANOVA test has determined that the variations in shear bond strength across the three surface treatments were significant. Following the significant ANOVA results, the Tukey post hoc test was employed to determine the precise differences between pairs of groups. The results indicated statistically significant differences across all three groups. The comparison indicated that airborne-particle abrasion markedly enhanced bond strength relative to the control group, whereas the amalgamation of airborne abrasion and zirconia priming yielded the highest bond strength values. Table 4 presents the comprehensive pairwise comparisons.

Table 4: Tukey Post Hoc Test for Pairwise Comparison of Shear Bond Strength

Group Comparison	Mean Difference (MPa)	Standard Error	p-value
B vs A	3.34	0.39	<0.001
C vs A	6.46	0.39	<0.001
C vs B	3.12	0.39	<0.001

The post hoc test revealed that Group C exhibited much greater shear bond strength than did Group A and Group B ($p < 0.001$). Equally, Group B also recorded very high bond strength in comparison with the control group.
The findings of this experimental research revealed that a considerable influence existed on the shear bond strength in cementing zirconia restorations to self-adhesive resin cement depending on the nature of surface treatment applied on the restorations. There was the weakest bonding performance on the untreated zirconia surfaces.

Abrasion of airborne particles was found to substantially increase bond strength through a micromechanical retention mechanism whereas zirconia primer additive had an effect of enhancing the chemical bond between the zirconia surface and resin cement.

On the whole, the maximum bond strength values were found in the specimens with airborne abrasion and zirconia primer, indicating that mechanical and chemical surface treatments represent the most appropriate bonding approach to zirconia-based crowns. The findings emphasize the need to use the right surface conditioning protocols to enhance the clinical longevity and the overall success of zirconia restorations.

DISCUSSION

The current experimental research compared the shear bond strength of zirconia-based crowns cemented using self-adhesive resin cements depending on various surface treatment methods [10, 11]. The results proved that the surface treatment had a significant effect on the bond strength between zirconia restorations and resin cement. The highest mean shear bond strength of the tested groups was observed in the form of the specimens in which the abrasion of the air particles was carried out and zirconia primer was applied in the final step; the lowest values of shear bond strength were observed on untreated zirconia surfaces. These findings show that mechanical and chemical surface modification are significant in enhancing the adhesion of zirconia restorations [12,13].

The maturity and strengthening of bonds as was experienced in the airborne-particle abrasion group can be ascribed to formation of micromechanical retention on the surface of zirconia [14,15]. Sandblasting of the aluminum oxide particles generates surface roughness that enhances bonding area and forms mechanical interlocking of the zirconia surface and resin cement. Such surface roughness enhances the penetration of the resin cement into the microscopic grooves, hence enhancing the overall bond strength as compared to the untreated surfaces of zirconia [16,17].

The values of highest bond strength were recorded in the group of airborne abrasion followed by zirconia primer which is the reason that the monomers of zirconium oxide present in the cement combine with the cement resin matrix and form a more effective bonding process[18,19]. The mechanism of dual bonding makes the adhesive interface more stable and durable, and the values of shear bond strength are much higher than the values of mechanical treatment [20, 21].

This study has the same results with the literature available that has shown enhancement in bonding performance after airborne-particle abrasion of zirconia surfaces. Past laboratory studies have established that surface roughening by sandblasting enhances the energy of the surface of zirconia and treatment of better sticking adhesion with resin-based cements. On the same note, research comparing the influence of zirconia primers has indicated an increase in chemical bonding by presence of phosphate-based functional monomers that are able to react with zirconium oxide [22].

Moreover, previous experimental studies have also indicated that a combination of mechanical treatment of the surface and application of chemical primers has better bond strength than any of the two approaches when applied separately. The synergistic effect has been extensively observed in the literature review of studies investigating zirconia-resin bonding where primers have a significantly positive effect on the longevity of the bonding interface. These observations have also been supported by the findings of the current study which showed that airborne abrasion together with zirconia primer had the greatest shear bond strength when compared to other groups tested [23].

Conversely, unreacted zirconia surfaces always record lower values of bond strength because of the chemical inertness of zirconia ceramics. The zirconia does not contain silica as well, with the high crystal structure of the material hindering the efficacy of traditional adhesive procedures. Subsequently, surface modification proves to be critical to enhance the bonding performance of zirconia-based restorations. Findings in this study also confirm the significance of using suitable surface conditioning procedures before cementation.

Limitations of the Study

Although this study offered very important information on zirconia bonding, it had a number of limitations. The first one is that, the study was done under in vitro laboratory conditions, and these conditions may not fully recreate the complex oral environment in which saliva, temperature change, and the masticatory forces can affect bonding performance. Second, the evaluation of only three surface treatment protocols was done as compared to many other methods of treating surfaces that include laser treatment, plasma treatment, and tribochemical silica coating which are also clinically applicable. Third, the research only spoke of shear bond strength testing but failed to discuss other critical aspects like long-term durability, thermocycling and failure mode analysis. Also, the sample size was small but sufficient in comparison to experiments but was limited to lab specimens.

Future Recommendations

Further research is needed to test more surface treatment procedures and compare them to determine their effectiveness in enhancing zirconia bonding. Simulations of long term aging like thermocycling and mechanical fatigue testing ought to be included as well so that they can be closer to the intraoral environment. More generalizable results can be received with further studies with larger sample sizes and dental centers. Moreover, other resin cement types and primers should be evaluated in future studies to indicate the best bonding agents to use with zirconia restorations. Real patient environments would also be useful to confirm the laboratory results and offer more solid grounds to clinical practice [24,25].

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