The effect of nitric acid – hydrofluoric acid etching solution on the shear bond strength and mode of failure of resin cement to zirconia (In vitro study)

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Abstract

The aim of this study is to determine the effect of an etching material which is the compound of nitric acid-hydrofluoric acid as a pretreatment agent on the shear bond strength of resin cement to two different types of zirconia and comparing it with air particle abrasion. 52 CAD/CAM Zirconia disks were prepared into 3D cubes of 8×8mm and thickness of 3mm. 26 of them were fabricated from high translucent white zirconia 'group I' and the other 26 from natural 3D multilayer monolithic zirconia 'group II'. Each group is then divided into subgroup A and subgroup B according to the surface treatment. All Zirconia cubes were bounded to resin cubes 6x6 mm. 13 of the cubes in subgroup A were treated with the etching material (the test group) and the other 13 in subgroup B were treated with air abrasion (control group). All samples were subjected to thermocycling. Shear bond strength and failure mode were evaluated. The data was collected, tabulated and statistically analyzed using Statistical Package for Social Sciences (SPSS) version 26. The results of the independents samples t-test revealed that there is a statistically significant difference between the shear bond strength in Etched and Air Abrasion in the High Translucent White Zirconia and that there is a statistically significant difference between the shear bond strength of etched and air abrasion in the 3D Multilayered Zirconia. However, there was no statistically significant difference between the shear bond strength among the two types of zirconia after air abrasion and after etching. Regarding the failure mode, it was revealed that most of the specimens that were etched in both types of zirconia have cohesive failure, while the majority of the specimens after air abrasion in both types of zirconia have adhesive failure. Zircos-E etching solution significantly improved bonding to zirconia, increasing shear bond strength with resin cement. Air abrasion on zirconia types resulted in low shear bond strength, indicating a weaker surface treatment compared to Zircos-E etching solution..

Keywords: Zirconia; CAD CAM zirconia; Resin cement; Ceramics; Control group; Nitric acid-hydrofluoric acid; Social sciences.

Introduction

The increasing awareness regarding beauty and dental esthetics has become one of the most important aspects of oral rehabilitation and can provide the integration of esthetic dentistry into the total spectrum of oral health care. Each patient has unique expectations and desire, so the challenge is to fulfill the need for the patient at least near their expectations. This can be achieved using esthetic materials that carry the required properties to restore patients' mouth (1).

Providing long lasting treatment outcomes mainly four basic principles should be fulfilled as biocompatibility of materials, reduced tissue damage, longevity of restorations and esthetic considerations (2). This is achieved from the steady advances in the development of ceramic materials, accompanied by an enhanced understanding of ceramic bonding (2). Many advancements in the field of ceramic materials science for dental purposes have been achieved leading to a class of high fracture strength materials represented by alumina (Al_2O_3) and zirconia-based ceramics (ZrO_2) (3). These materials hold the potential to offer long-term durability (3). The enhancement of mechanical properties through the addition of ZrO_2 is accompanied by a decrease in the glassy matrix and silicon content, resulting in ceramics that are resistant to acids. Unlike Silica-based ceramics, hydrofluoric acid (HF) etching selectively removes the glassy matrix, increasing surface roughness for micromechanical bonding. This process is typically followed by the application of a silane coupling agent, which bonds and copolymerizes with the organic matrix of the resin cement (4). However, the absence of a glassy matrix makes acid etching combined with silane application ineffective in modifying and treating the zirconia surface, leading to no apparent improvement in bond strength. The clinical success of ceramic restorations is primarily dependent on the cementation process in such cases (4). Adhesive cementation to Zirconia ceramics is desirable due to its ability to enhance retention, marginal adaptation, fracture resistance, reduce the risk of recurrent decay, and contribute to the longevity of Zirconia restorations (5).

Different approaches have been suggested to facilitate proper adhesion between resin cement and Zirconia.: air particle abrasion using alumina (Al_2O_3), in addition to laser treatment (6). But it was reported that many problems may result from the laser surface treatment and air abrasion. A durable bond may not be achieved through laser treatment, as justified by the observation that zirconia exhibits a limited ability to absorb laser energy. Additionally, laser irradiation has the potential to induce the formation of microcracks and subsurface destruction in the ceramic (7).

According to studies, abrasive blasting may cause erosive damage on zirconia surface such as scratches, micro cracks, fissures, or the removal of material grains from the surface.

However, some investigations have found that the hardness of the grain, the pressure used during processing, the type and size of the grain, and other factors all affect the surface quality (8). In addition to that surface treatment using air abrasion may be affected by the contamination with saliva and blood which will affect the zirconia surface thus resulting in a decrease in bond strength. A newly introduced material for chemically etching zirconia is the Zircos-E etching agent, a liquid-based etching solution. Comprising a mixture of hydrofluoric acid (HF) and nitric acid (HNO_3), this solution is designed to create surface roughness on zirconia, increasing its surface area through preconditioning (4). The main goal is to improve interfacial adhesion, ultimately leading to an increased bond strength between the zirconia and the resin material (4,9).

The objective of this research is to assess the impact of an etching material, specifically a combination of nitric acid and hydrofluoric acid as a pretreatment agent, on the shear bond strength of two distinct types of zirconia, and to compare it with the effects of air abrasion. The null hypothesis in this study is that there is no disparity in the surface roughness of zirconia when utilizing the etching system, a compound of nitric acid and hydrofluoric acid, in comparison to other surface treatment methods. Furthermore, the null hypothesis suggests that this etching system has no significant influence on shear bond strength when coupled with resin cements.

Materials and Methods

Sample size was estimated assuming 5% alpha error and 80% study power. Cho et al. (2017), reported that the mean (SD) shear bond strength was 7.42 (1.22) and 5.71 (1.39) for zirconia blocks pretreated with Zircos-E etching and air abrasion, respectively (6). Based on difference between two independent means using the highest SD = 1.39 to ensure enough power, the sample size was calculated to be 12 specimens per group, increased to 13 specimens per group to make up for processing errors. Total sample size = number per group x number of groups = 13 x 4 = 52 specimens. Software Sample size was based on Rosner's method calculated by G*Power 3.1.9.7 (10).

52 sintered zirconia ceramic specimens were used to determine the effect of the etching material as a surface treatment and were randomly divided into two main groups:

1. Group I: 26 specimens from high translucent white zirconia.
2. Then these groups were subdivided into 2 subgroups A and B.
3. Subgroup A: 13 was treated with the etching material (study group).
4. Subgroup B: 13 was treated with air abrasion (control group).
5. Group II: 26 specimens from natural 3D multilayer monolithic zirconia.
6. Then these groups were subdivided into 2 subgroups A and B.
7. Subgroup A: 13 was treated with the etching material "study group".
8. Subgroup B: 13 was treated with air abrasion "control group".
9. Then these 2 subgroups were tested after thermocycling.

Using CAD/CAM milling machine, 52 zirconia cubes was prepared, 26 cubes of high translucent white zirconia (polycrystalline ceramic, 4.5%-5.5% Yttrium oxide, SuperfectZir, Aidite, China) and 26 cubes of natural 3D multilayer monolithic zirconia (polycrystalline ceramic, 4% - 10% Yttrium oxide; 3D Pro, Zirc, Aidite, China) (8×8mm and thickness of 3mm). The design was drawn and exported as STL (Standard Triangulation Language) file to CAD/CAM software.

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A disk of each material was mounted in the milling machine in dry mode. Following milling, each cube underwent a cleaning process using air jets, followed by air drying and placement in a ceramic oven for sintering in accordance with the manufacturer's instructions. The sintering process involved reaching a temperature of 1550°C with an increasing rate of 100°C/min, maintaining this temperature for 2 hours, and then decreasing the temperature at a rate of 100°C/min (6).

Transparent plexi frames, with a thickness of 3mm, were fabricated through laser cutting. In the center of one of these frames, a (6x6) cube was laser cut to standardize the size of resin cubes obtained from the plexi. Another transparent plexi frame was cut to serve as a base. The two plexis were positioned on top of each other. Composite material (3M Nanofill, filtek Z250 Universal) was injected into the (6x6) hole created in the middle of the plexi, supported below by the other plexi. To ensure a flat composite surface on top, a histology glass slide was used, and the composite was then light cured. After curing, the two plexis were separated, and the composite was pushed out from the created hole (11).

For the study groups: Group I (A) and group II (A); the treatment with this etching material was done by placing the specimens for 30 mins in an ultrasonic cleaner. During the insertion and removal of specimens from the etching solution, it was mandatory to observe personal protection measures, including wearing a mask, eyeglasses, and gloves. The disks were immersed in Zircos-E etching solution for a precise duration of 30 minutes. Subsequently, the disks were taken out and rinsed in cold running water for a period of 2 minutes (4).

For the control groups: Group I (B) and group II (B); air abrasion was done on the specimens of these groups; sandblast by 110 Microns Al_2O_3 particles for 10 seconds, at 2.5 bar pressure, from 10 mm distance (12).

All samples were embedded in cubes of chemical-curing acrylic resin (Imicryl, Konya, Turkey) using a specially designed plastic mold. Following the manufacturer's instructions, a zirconia primer (Monobond plus, Ivoclar Vivadent Inc. 175 Pineview Drive, Amherst, N.Y. 14228, USA) was applied for 60 seconds to the treated surface of zirconia using a micro brush and dispersed with oil-free air for 10 seconds. A bonding agent (Single bond, 3M ESPE 2501 Hudson Rd, St, Paul, MN 55144, USA) was applied to the fitting surface of the composite cubes. Subsequently, the composite resin cubes were affixed to the zirconia disks using a self-adhesive resin cement (3). The steps of cementation are as follows:

- First, zirconia surface was treated by zirconia primer.
- We place zirconia cubes carefully without touching the treated surface on top of central hole in plexi to fill it. Then the bonding agent is applied to composite surface. Self-adhesive resin cement (3M RelyX U200 dual cure) was auto mixed and applied to the primed surface.

The specimens were light cured under 5 kg; excess cement was removed first after 5 seconds curing then kept for 6 minutes. All the specimens were cemented in the same way. After bonding, all specimens were stored in distilled water for 24 hours and then subjected to a thermocycling process using a thermocycling apparatus (SD Mechatronik, Feldkirchen Westerham, Germany) with distilled water for 10,000 cycles. The thermocycling involved alternating between temperatures of 5°C and 55°C, which is considered clinically equivalent to approximately one year of clinical service (4,13).

Specimen Testing; Shear Bond Strength: All specimens were stored in distilled water at 37°C for 24 hours.

Following 10,000 cycles of thermocycling, the shear bond strength of each specimen was measured using a universal testing machine (Fig. 1) (YLE GmbH Waldstrabe Bad Konig, Germany).

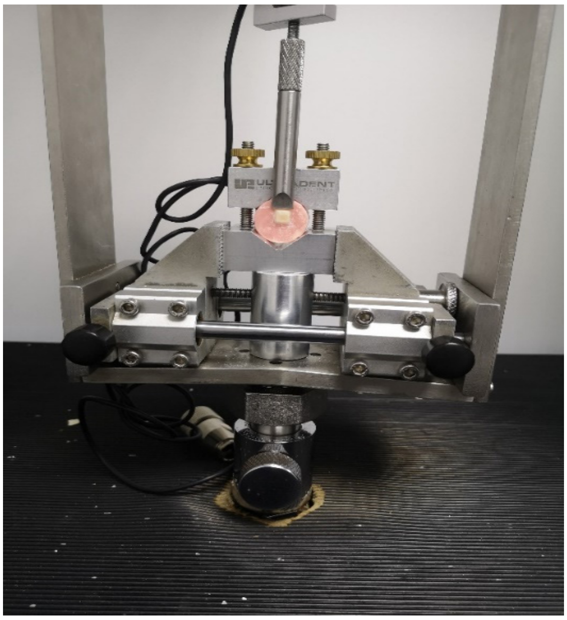

Figure 1. Placing the prepared specimen into the universal machine.

A blunt knife-edge blade was positioned perpendicularly, touching only the bonding interface (Fig. 2). The testing was conducted at a crosshead speed of 1 mm/min until fracture occurred, in accordance with ISO/TS 11405:2015. The knife edge was situated at the adhesion point between the zirconia and the resin cement, aiming to assess the maximum shear bond strength at the failure point between zirconia and the resin cement (Fig. 1) (3). The failure load of each specimen was measured in Newtons. The SBS was calculated as follows: SBS (MPa) = load (N)/area (mm2).

Specimen Testing: Failure Mode: Comparison of failure modes between bonding surfaces was made to evaluate mode of fracture by inspecting the fractured surfaces with a stereo microscope (Olympus SZ51 Stereo Zoom Microscope, Japan) and classifying it as adhesive, cohesive, or mixed failures (6).

Statistical Analysis: The shear bond strength results were collected and entered to Statistical Package for Social Sciences (SPSS) version 26. For descriptive Statistics, frequencies and percentages were used to provide a quantitative understanding of the distribution and prevalence of specific outcomes or variables.

The numerical data was input, and the assumption of normal distribution for the dataset was assessed using the Shapiro-Wilk test. The results of the test indicated that the data followed a normal distribution. Consequently, the independent sample t-test was employed to compare the means between the etched and air abrasion groups in both High Translucent Zirconia and 3D Multilayered Zirconia. The independent samples T test was also applied to compare the High Translucent Zirconia and 3D Multilayered Zirconia groups in terms of etching and air abrasion effects. Bar charts were used to present the findings. The p-value in each t-test represents the probability of obtaining the observed results if there were no true difference between the means. A p-value below a predetermined significance level (0.05) indicates that the difference between the means is statistically significant, suggesting that it is unlikely to have occurred by chance and that there is a statistically significant difference between the means of the compared groups.

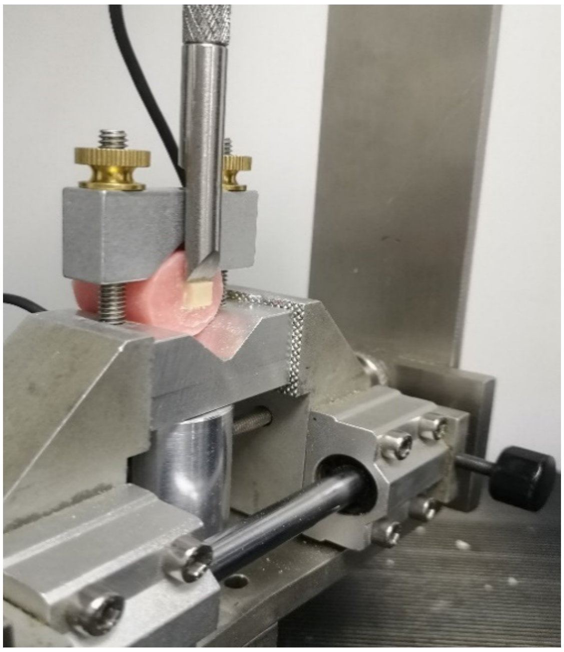

Figure 2. Placing the knife edge blade perpendicular to the bonding surface.

Results

The data presented in (Table 1) presents the results of comparing the means of shear bond strength in "Etched" and "Air Abrasion," groups in the High Translucent White Zirconia. For the shear bond strength in Etched the mean value obtained was 19.538 with a standard deviation of 1.983. On the other hand, for the shear bond strength in Air Abrasion group the mean value of 10.615 with a standard deviation of 1.556. The data suggests that there is a statistically significant difference between the shear bond strength in Etched and Air Abrasion in the High Translucent White Zirconia since (p-value=0.000) is <0.05.

- A *p-value* less than 0.05 indicates that the results is statistically significant.

The data presented in Table 2 depicts the outcomes of comparing the mean shear bond strength between the Etched and Air Abrasion groups in the 3D Multilayered Zirconia. In the Etched group, the mean shear bond strength was 19.692, with a standard deviation of 1.182. Conversely, the Air Abrasion group exhibited a mean shear bond strength of 11.615, accompanied by a standard deviation of 1.386. The associated p-value for these findings is (p-value=0.000), signifying a statistically significant difference in shear bond strength between the etched and air abrasion techniques in the 3D Multilayered Zirconia, given that the p-value is less than 0.05.

- A *p-value* less than 0.05 indicates that the results is statistically significant.

The data provided in Table 3 and Fig. 3. compares the means of shear bond strength in etched and air abrasion results of two zirconia materials: High Translucent White Zirconia and 3D Multilayered Zirconia. For shear bond strength in etched, the mean values for both groups were similar, with the High Translucent Zirconia group having a mean of 19.5385 and the 3D Multilayered Zirconia group having a slightly higher mean of 19.692. The standard deviations were 1.983 and 1.182, respectively. The p-value of (p-value=0.812) indicates that there is no statistically significant difference between the shear bond strength of etched in the two groups. Regarding the shear bond strength of air abrasion, the mean value for the High Translucent Zirconia was 10.615, with a standard deviation of 1.556, while the 3D Multilayered Zirconia had a mean of 11.615 and a standard deviation of 1.386. The p-value (p-value= 0.097) suggests a lack of statistical significance, indicating that there is no significant difference between the shear bond strength of air abrasion of the two zirconia groups.

Table 1. T-test for the shear bond strength in etched and air abrasion in the high translucent white zirconia

Group	**Etched/Air Abrasion**	**N**	**Mean**	**Std. Deviation**	***p-value***
High Translucent White Zirconia	Etched	13	19.538	1.983	
	Air Abrasion	13	10.615	1.556	

Table 2. T-test for the shear bond strength in etched and air abrasion in the 3D multilayered zirconia group

Group	**Etched/Air Abrasion**	**N**	**Mean**	**Std. Deviation**	***p-value***
3D Multilayered Zirconia	Etched	13	19.692	1.182	
	Air Abrasion	13	11.615	1.386	

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Table 3. T-test comparing the shear bond strength between the groups

	Group	N	Mean	Std. Deviation	*p-value*
Etched	High Translucent Zirconia	13	19.538	1.983	0.812
	3D Multilayered Zirconia	13	19.692	1.182	
Air Abrasion	High Translucent Zirconia	13	10.615	1.556	0.097
	3D Multilayered Zirconia	13	11.615	1.386	

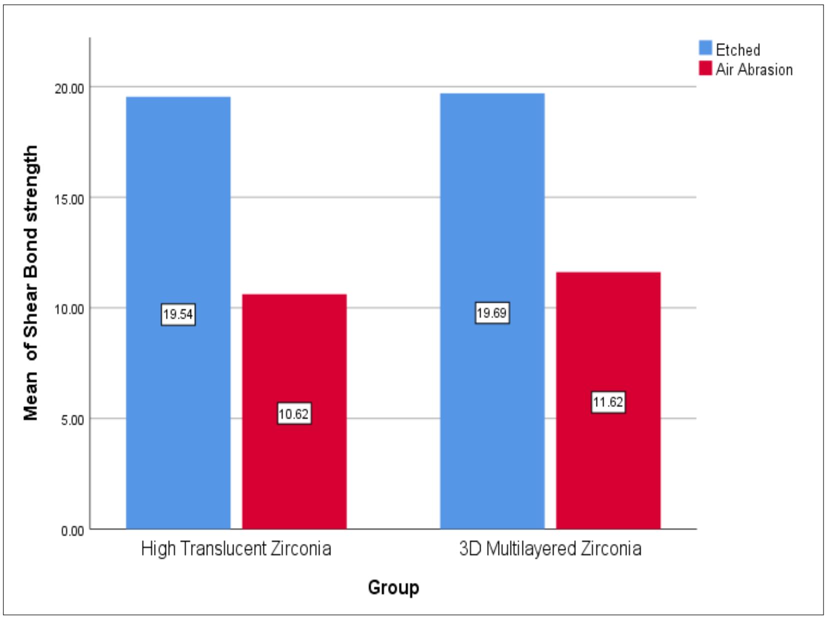

Figure 3. The mean of shear bond strength of etched and air abrasion between the groups.

As Table 4 shows, in terms of frequency, for High Translucent White Zirconia, adhesive failure mode was observed in 3 out of 13 samples (23.1%), cohesive failure mode in 7 out of 13 samples (53.8%), and a mixed failure mode in 3 out of 13 samples (23.1%). Similarly, for 3D Multilayered Zirconia, adhesive failure mode occurred in 2 out of 13 samples (15.4%), cohesive failure mode in 7 out of 13 samples (53.8%), and a mixed failure mode pattern in 4 out of 13 samples (30.8%). These frequencies indicate that cohesive failure mode was the most frequently observed outcome for both zirconia materials, followed by adhesive failure mode and mixed failure mode.

Stereo-microscopic images showing the different types of failure modes are presented (Fig. 4, 5, and 6).

Table 4. The different failure mode outcomes cross tabulation between the groups

Frequency		Etched		Air Abrasion	
		%	Frequency	%	
High Translucent White Zirconia	Adhesive	3	23.1%	9	69.2%
	Cohesive	7	53.8%	3	23.1%
	Mixed	3	23.1%	1	7.7%
3D Multilayered Zirconia	Adhesive	2	15.4%	9	69.2%
	Cohesive	7	53.8%	1	7.7%
	Mixed	4	30.8%	3	23.1%

Figure 4. Microscopic picture of adhesive failure showing complete debonding of the composite from the zirconia surface.

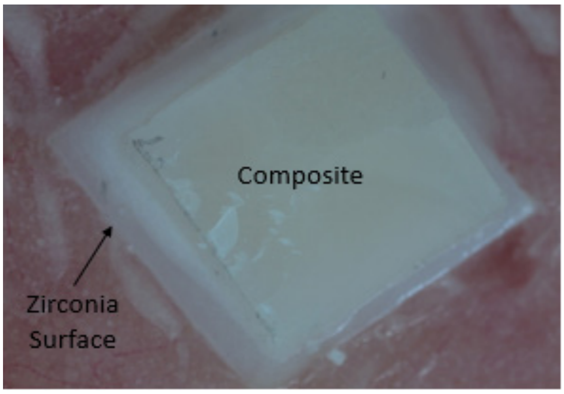

Figure 5. Microscopic picture of cohesive failure showing that there was no separation of the composite from the zirconia surface.

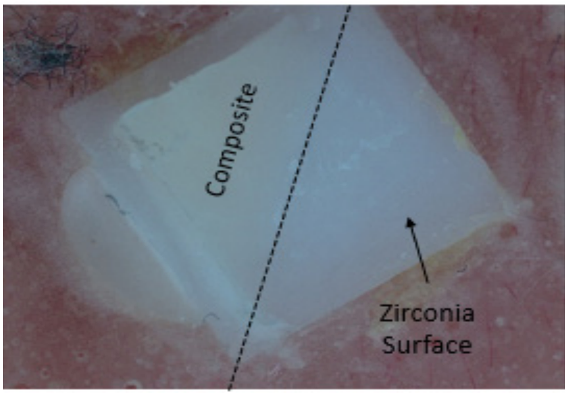

Figure 6. Microscopic picture of mixed failure by which part of the composite was de-bonded by the zirconia surface.

Discussion

In the current study, composite samples were chosen over natural teeth due to their nearly identical modulus of elasticity and the advantage of a uniform structure. Additionally, composite build-ups or fiber posts are commonly encountered in dental preparations. While using natural teeth is considered optimal for bonding to zirconia in shear bond strength (SBS) tests, the challenge lies in the varying history of each natural tooth. Factors such as patient age, degree of calcification, dentinal tubule count, moisture content, time of extraction, among others, are challenging to control and standardize. These uncontrollable variables can potentially impact the reliability and consistency of the study results (14). Various surface treatment methods, including air abrasion and acid etching, as well as the choice of resin cements, play pivotal roles in enhancing the retention of dental restorations with natural teeth. While it has been traditionally considered that chemical surface conditioning with hydrofluoric acid is not effective for zirconia, recent research indicates that hydrofluoric acid, when used at different concentrations and temperatures, can induce alterations in zirconia surfaces.

As for the APA the parameters were selected based on previous studies. In current study, all APA parameters were the same. So far in the study, it is advised to employ sandblasting with a particle size of 110 μm, maintaining a distance of 10 mm and applying a pressure of 2.5 bar. These parameters are recommended based on the guidelines provided by references (16) and (17). While a study done by (18) tested effect of APA of different abrasive powders on zirconia specimens. They concluded that APA of zirconia using 50µm Al2O3 is capable of producing more roughness when compared to other particle sizes and types. Nevertheless, the study conducted by Moon et al. (2016) investigated the impact of various airborne-particle abrasion (APA) protocols on shear bond strength. The research involved alterations in Al2O3 particles, pressure, angulations, and timing. The authors were able to deduce that using 50µm particles at 4 bar pressure for 20 seconds yielded the highest shear bond strength based on their findings.

Regarding zirconia etching, a study conducted by (19) discovered that a thirty-minute etching period using a zirconia etching solution induced morphological changes in zirconia and enhanced bond strength. Therefore, in the current study, the surface treatment involving zirconia etching material was compared to surface treatment using air particle abrasion.

The Zircos-E etching solution, similar to many commercially available zirconia etching solutions like Zeta Etching Solution (Eunjin Chemical Co., Gunsan, Korea) utilized by (19), was applied at room temperature. In (19), the solution was applied to zirconia for 60 minutes in an ultrasonic bath at room temperature. In contrast, (20) investigated the effects of a hydrofluoric acid-based smart etching solution at an elevated temperature on yttria-stabilized tetragonal zirconia polycrystal ceramics concerning bond strength and morphological changes. The rationale behind this approach was the belief that a higher application temperature enhances the molecular activity of the etchant, allowing for quick and efficient etching of the zirconia surface in a shorter time. In this study, the smart etching solution was applied for 10 minutes at 70°C–80°C.

Regarding the duration of application of the etching material, Zircos-E was applied in this study for 30 minutes at room temperature, like the study that was done by (4). Whereas (6) used in their study Zircos E etching system which was applied to zirconia for 3 hours at room temperature.

The findings of this study suggest that Zircos E is a highly effective solution for the surface treatment of zirconia. However, a review conducted by (21) highlighted that, despite numerous positive outcomes in research on

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various zirconia surface treatment methods, the current most effective technique, supported by both in-vitro and clinical tests, involves sandblasting at moderate pressure. This method is often combined with the application of a primer containing the MDP monomer or tribochemical-siliconization using the Rocatec system (22).

The outcomes of our study indicated that the study group, where zirconia etching was performed, exhibited the highest Shear Bond Strength (SBS) value. Notably, there was no significant difference observed between the two types of zirconia within this study group. However, a significant difference was noted when compared to the control group, which showed the lowest SBS value. These findings align with previous studies conducted by (23), (24), (25), and (26), all of which concluded that shear bond strength tends to be higher when zirconia is etched using higher concentrations of hydrofluoric (HF) acid or a strong acid mixture consisting of nitric acid (HNO_3) and HF acids, as opposed to utilizing the air abrasion technique alone.

However, our findings contrast with other studies conducted by (27), (28), (29), (16), (30), (31), (32), and (17), which suggested that air abrasion at moderate pressure offers reliable bonding to zirconia-based restorations. These studies particularly highlighted the effectiveness of combining air abrasion with phosphate monomer-containing primers and/or luting resins, as evidenced by their reported highest Shear Bond Strength (SBS) values in sandblasted subgroups. The rationale behind these results is often attributed to the impact of sharp abrasive particles hitting the surface, creating retentive spaces. Additionally, the presence of impinged abrasive particles on the zirconia surface, due to the force of blasting pressure, may contribute to an increased available surface area, facilitating micro-mechanical bonding with the adhesive resin and resulting in higher shear bond strength.

In the case of etched specimens, the application of Zircos-E etching solution resulted in significantly higher Shear Bond Strength (SBS) compared to the control specimens. This improvement in bonding strength can be attributed to the Zircos-E etching solution's capacity to etch the zirconia surface, creating porosities of various shapes and depths. This preferential action occurs at the grain boundaries, where external atoms are more chemically reactive and prone to dissolution earlier than those located inside the crystal structure. This process may lead to a reduction in grain size or even dislodgment of the grains themselves. These observations align with the etching mechanism of zirconia described by (15).

The Shear Bond Strength (SBS) results achieved through the Zircos-E etching process on both types of zirconia were consistent with findings reported by (19), (6), and (33). These studies also observed a significant enhancement in SBS results for specimens treated with Zircos-E etching solution, accompanied by noticeable morphological changes on the zirconia surface. Notably, the effect was more pronounced on fully stabilized zirconia compared to partially stabilized zirconia, attributed to the higher percentage of cubic phase and larger grain size in fully stabilized zirconia, as highlighted by (19).

In terms of failure modes, the control group predominantly exhibited adhesive failure between zirconia and the resin cement. This finding aligns with observations made by (2) and (17), suggesting that air abrasion surface treatment may result in a weaker bond between zirconia and resin. Conversely, the etched groups revealed predominantly cohesive failure, with some instances of mixed failure. This suggests a more satisfactory bond between zirconia and the resin when treated with Zircos-E. These findings are consistent with studies conducted by (6) and (34). Overall, these observations could suggest that the bond between etched zirconia and resin cement is comparable to the bond between resin cement and enamel, as also supported by (25) and (34).

It can be asserted that the notable occurrence of mixed failures is likely attributed to the testing method employed, specifically the macroshear bond strength test. A broader bonding interface is likely to contain more defects, thereby increasing the prevalence of cohesive and mixed failures when compared to the microtensile bond strength test. The latter provides higher precision due to the homogeneous distribution of forces on the bonded interface, suggesting a limitation of this study (35). Furthermore, compared to the microtensile bond strength test, the macroshear bond strength test helps in avoiding pre-testing failures as it does not require cutting before testing, which could be problematic with a brittle material like ceramics (36). The null hypothesis was rejected in the current study, signifying a significant difference between the tested groups.

Conclusion

Due to the major importance of the adhesion between zirconia and resin, numerous studies have been conducted to identify optimal surface treatments for achieving robust adhesion. The results of this study indicate that employing Zircos-E as a surface treatment for zirconia leads to significant improvements compared to the control groups treated with air particle abrasion. This suggests that the use of Zircos-E holds promise as a technique for enhancing zirconia-resin bonding and has the potential to increase shear bond strength. While when comparing the two types of zirconia there is no significant difference between them. Therefore, the surface treatment using Zircos-E etching solution provided a great improvement in the bonding to zirconia, and that by increasing the shear bond strength between the two types of zirconia to the resin cement. Whereas the surface treatment using air abrasion on both types of zirconia showed low values of shear bond strength which would be considered a weak surface treatment option in comparison with the Zircos-E etching solution.

Within the limitations of this study, it can be concluded that the Zircos-E etching system enhances the shear bond strength of zirconia restorations. Consequently, we recommend dental practitioners, especially those specializing in esthetic and prosthetic dentistry, to consider incorporating this etching material to enhance shear bond strength in various types of zirconia restorations. However, it is crucial to note that the long-term success rate and clinical applicability of this approach require further evaluation.

Further research should delve into obtaining a more comprehensive understanding of the effects of Zircos-E surface treatment on the bonding surface and addressing any challenges encountered in clinical applications.

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