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EFFECT OF AIR BORNE PARTICLE ABRASION ON THE BOND STRENGTH OF CUSTOMIZED HYBRID ZIRCONIA IMPLANT ABUTMENT TO ZIRCONIA SUPERSTRUCTURE: IN VITRO STUDY

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ABSTRACT

Purpose: The purpose of this study was to evaluate the effect of air abrasion with aluminum oxide particles (Al2 O3) on the bond strength between customized two-piece zirconia implant abutments and zirconia (CAD/CAM) monolithic milled crowns using self-adhesive resin cement with a (MDP) containing primer.

Method: This study was carried out on 16 zirconia monolithic crowns. Hybrid zirconia abutments were fabricated using customized zirconia copings cemented on ready-made titanium bases. Monolithic zirconia crowns were fabricated then divided into two equal groups (n=8). The first group represented zirconia crowns without air abrasion and the second group represented zirconia crowns subjected to 50 μm Al2 O3 air abrasion. Zirconia crowns were then cemented to their corresponding abutments using resin cement and a MDP containing primer. A universal testing machine (Autograph AG-IS Series, Shimadzu Universal) was used to test the shear bond strength (SBS) of specimens in both groups.

Results: The statistical analysis for comparison of shear bond strength between samples revealed significant statistical differences in their mean values, with a t-test value of 2.961 and a p-value of 0.010, indicating that surface treatment with alumina air abrasion significantly enhances shear bond strength.

Conclusion: Surface treatment of zirconia crowns with air-borne particle abrasion can provide a strong bond to zirconia hybrid, implant abutments when using a self- adhesive resin cement and a MDP monomer containing primer.

KEYWORDS: Resin cement, Shear bond strength, Ti-base.

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INTRODUCTION

The gold standard material in oral implantology over the last decades has basically been titanium [1]. Metals like titanium offer excellent material stability, biocompatibility, resistance toward distortion and the results of clinical investigations indicated that the rates of survival were high. However, titanium metal abutments have been reported to cause a grayish discoloration of the adjacent soft tissues, particularly in the anterior region, as a result of their dark color. This has the potential to compromise the esthetic outcome [2].

In addition to the esthetic drawback, the standard, prefabricated titanium abutments supplied by implant manufacturers, were shown to exhibit other shortcomings. Firstly, the natural emergence profile of a crown is difficult to achieve due to the cylindrical cross-section of the prefabricated abutment. Achievement of this naturally occurring emerging profile requires crown shape modifications that results in excessive crown contouring. The excess cement was also found to be hard to remove if the predetermined height of the crown margin does not correspond to the gingiva's natural anatomy [3].

Because of its special stress-induced transformation toughening mechanism, zirconia is a biocompatible material with ideal mechanical and esthetic properties, such as high mechanical strength, resistance to corrosion, and high loading capacity[4]. Zirconia implant abutments are divided into two different forms: standardized abutments and customized abutments. There are two methods to fabricate customized zirconia abutments. In a monolithic design, the abutment is formed entirely from a single material; in a hybrid design, it is formed in a two-piece design. Utilizing a resin-based luting agent, the two-piece design connects a standardized titanium base to an individually fabricated zirconia coping [5,6].

The one-piece design zirconia abutment was shown to have a higher rate of failure, resulting from cracks in the implant-abutment junction or the abutment's transmucosal part [7]. Compared to one-piece zirconia abutments, the two-piece design's titanium inserts have been demonstrated to improve marginal fit, prevent implant connection wear, improve overall fracture resistance, and overcome the ceramic's brittleness. [8].

The weak point of the two-part abutment is the adhesive connection between the titanium base and the zirconia coping, which is essential for the prolonged success of the clinical procedure [9].

The form of the implant, the type of screw used, and surface treatments all play a role in how well the prosthetic superstructure is retained to the zirconia implant abutment [10-12]. The retention of restorations to zirconia implant abutments is also enhanced by the type of cement used [13]. It was confirmed that the use of a conventional resin cement in addition to an MDP-containing primer gave extra promising adhesive bond forces compared to self-adhesive resin cements that do not constitute MDP in their composition [14].

Assuming zirconia is used for the prosthesis restoration, the lack of glass and elevated crystalline content in zirconia makes it resistant to etching by hydrofluoric acid [15]. Silane coupling was also found ineffective when used with zirconia due to absence of silica [16]. The addition of silica coating to zirconia followed by silane application was found to increase the bonding strength to zirconia however, after thermocycling the bond declined in strength [17].

The aim of this study was to determine the influence of air abrasion with aluminum oxide particles (Al_2O_3) on the bond strength between customized two-piece zirconia implant abutments and Zirconia CAD/CAM milled monolithic crowns. The Null hypothesis assumed is that air- borne particle abrasion of the fitting surface of zirconia crowns will have no effect on the bond strength to zirconia two-piece abutments.

METHODS

This controlled and experimental study was conducted on 16 zirconia monolithic crowns which were evaluated to test the effect of $Al_2 O_3$ air abrasion on the bond strength between zirconia monolithic crowns and two-piece zirconia implant abutments using self- adhesive resin cement and an MDP containing primer.

Fabrication of Sample Blocks:

Custom made Acrylic Resin Cylindrical Blocks were fabricated for fixation of the implant fixtures. The acrylic resin blocks were fabricated with dimensions of 17 mm in length and 10 mm in diameter. Acrylic resin was inserted into a copper mold. A copper lid with a centralized hole was placed over the mold after the insertion of the acrylic resin mix. The implant fixture was placed in the acrylic resin through the hole on the copper lid using a surveyor to ensure the fixture is centralized and the angulation is standardized. The implant fixtures used were made of titanium (Neo Biotech Co., Gangwondo, Republic of Korea). Dental implant fixtures measured 4.8 mm in diameter and 10 mm in length.

Ready-made titanium base abutments (ti-base) (Neo Biotech Co., Gangwondo, Republic of Korea) compatible with the titanium implant fixtures were used in this study. Ti-bases measured 4.5 mm in diameter, 7.5 mm in height, and 0 degrees angulation. Each ti-base was secured and tightened to the implant fixture with the corresponding screw driver. (Fig. 1)

Fabrication of Zirconia Copings:

Zirconia copings were designed on (EXO- CAD) software (Exocad GmbH, Darmastadt, Germany) according to the required standardized Ti-base dimensions. (Fig. 2) The zirconia copings were designed to be 11 mm in height, with a diameter of 3.5 mm. CAD/ CAM technology was then utilized for the milling of the zirconia copings using XTCERA 3D Multilayer Zirconia disc (Shenzhen Xiangtong Co.). Sintering of zirconia copings was in a sintering furnace in accordance to manufacturer's instructions.

The zirconia copings and titanium bases had their bonding surfaces blasted with aluminum oxide powder. A pressure of 2 bars and an average particle size of 50 µm were used in this procedure. The titanium bases and zirconia copings were then cleaned with acetone and subsequently blown dry. The surfaces were treated with an (MDP) containing priming agent, Z-Prime™ Plus, (BISCO, Inc. Schaumburg, USA). Z prime plus was utilized to enhance the bond strength between the Ti- base and

Fig. (1) Ti-base fastened to the implant fixture

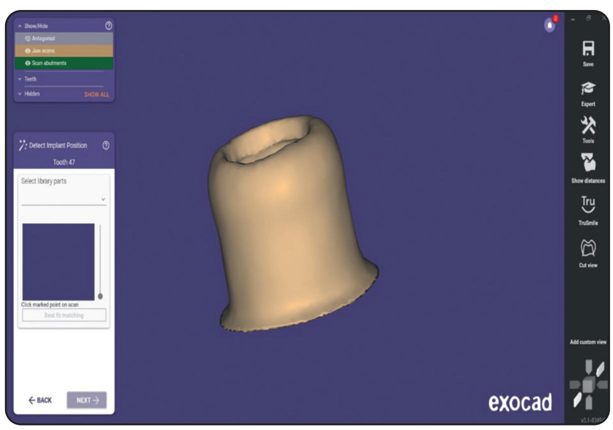

Fig. (2) Zirconia coping designed on EXO-CAD software the zirconia coping of the hybrid zirconia implant abutment. It was applied on the outer surface of the Ti-base and on the inner surface of the zirconia coping before their cementation.

Cementation of Zirconia Copings:

Bis Cem, a self-etching, self-adhesive, dual cure luting resin cement (BISCO, Inc. Schaumburg, USA) was used to cement the zirconia copings to the Ti-bases.

Upon completion of sintering and surface treatment, zirconia copings were cemented to the ti -bases. (Fig. 3) A layer of Bis-Cem adhesive cement was applied on the surface of the titanium bases and on the surface of the zirconia copings. The zirconia coping was then firmly compressed over the ti-base then placed under a customized static load of 2kg using a static load device. Margins were initially light polymerized for 2-3 seconds to aid in the removal of excess cement. Abutments were then light polymerized for 20-30 seconds [18,19].

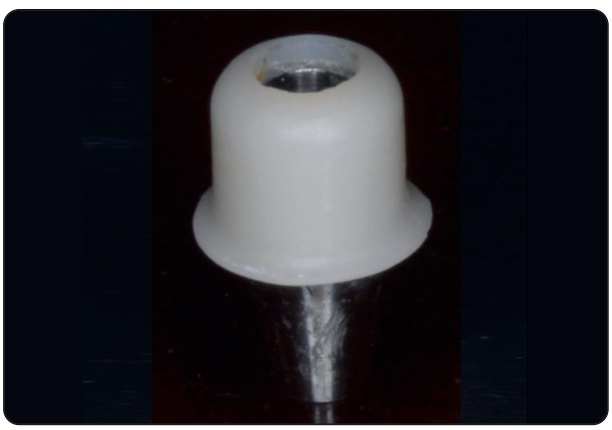

Fig. (3) Zirconia abutment cemented to the Ti- base

All surfaces of the fabricated abutments were subjected to aluminium oxide particles air abrasion using 50μm sized particles at 2 bar pressure at 10mm for 20 seconds. The surfaces of the abutment were then cleaned ultrasonically in water to remove the blasting particles and dried using oil free air water syringe. (Fig. 4)

Fig. (4) Surface treated zirconia coping after cementation to titanium base

Fabrication of Zirconia Superstructure:

A maxillary right first premolar crown was designed in correspondence to the previously designed zirconia copings using (EXO-CAD) software. To simplify crown removal after cementation, a bar on the occlusal surface of the crown was designed. (Fig. 5) Margins were determined automatically, and the insertion axis of the design was adjusted for the path of insertion. A 50 µm cement space was planned, starting 0.5 mm away from the margins. All crowns were designed with a uniform thickness of 2 mm for the axial walls and a 2 mm occlusal surface. Zirconia ceramic crowns were milled using the milling machine, ED5X EMAAR MILLS, (Emar CNC, 10th of Ramadan City, Egypt).

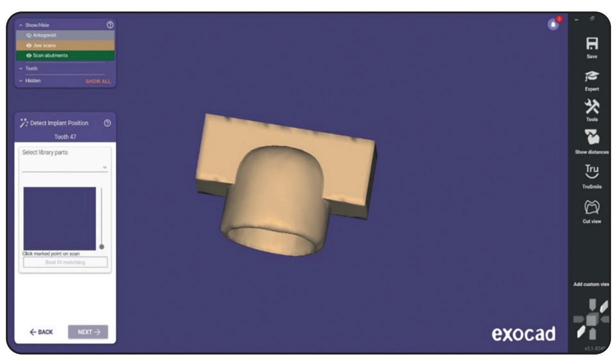

Fig. (5) Design of zirconia crown on EXO-CAD software with occlusal bar

Sintering of the crowns was done using the sintering furnace (MHM- VOGT Dental- Geratebau). The milled crowns were placed in the sintering furnace and sintered according to manufacturer's instructions. The sintering temperature was (1530 ^{o}C) and the duration of the sintering process was approximately (10 hours). A 60-minute holding period at 1200 ^{o} C was followed by a 150-minute holding period at 1530 ^{o}C. The rate of cooling was 15 ^{o}C/minute.

A total sample size of 16 monolithic zirconia crowns was determined. Sample size determination was based on Rosner's method calculated by G* power 3.1.9.7 [20]. The fabricated zirconia crowns were grouped randomly into two groups, eight specimens each. The fitting surfaces of the crowns in the first group (control) were not subjected to air abrasion. (N=8) The fitting surface of the crown in the second group were subjected to 50 μm A_2O_3 air abrasion at 2 bar pressure at a distance of 10mm for 20 seconds [21]. (N=8).

All crowns in both groups received pre-cementation treatment with the universal primer Z-prime plus: A disposable brush was used to apply primer to the fitting surfaces of crowns. The primer was left on the fitting surface for 30 seconds then the specimens were dried using oil-free air for 3-5 seconds to remove any excess primer.

Each zirconia crown in both groups was filled with sufficient amount of resin cement. The crowns were then seated onto the corresponding abutments with finger pressure and then the pressure was gradually increased to ensure complete seating. (Fig. 6) Pressure was maintained for 15 seconds for each crown. Then a specially customized static load device was used to maintain the pressure during curing as previously mentioned.

Aging of Specimen:

Subsequent to cementation, the specimens were incubated at 100% humidity in a 37°C water bath for twenty-four hours as to simulate thermal stresses encountered in the oral environment [14].

Fig. (6) Seating of crown on abutment

After water storage, specimens were subjected to thermocycling in 5°C to 55°C water over a 15,000-cycle span [14]. Within each cycle, the test specimens were transferred between two temperature-controlled water baths and submerged for 15 seconds (dwell time) in each bath and were subsequently exposed to room air for a duration of ten seconds during transportation between baths.

Assessment of Debonding Strength:

Following the aging simulation, a shear bond strength test was conducted on each specimen to separate zirconia crown from zirconia copings. A Universal Testing Machine (Autograph AG-IS Series, Shimadzu Universal Testing Machine, Shimadzu Co.) was used to conduct the test. (Fig. 7) Each of the 16 crowns was attached to the Universal Testing Machine's upper moving holder through the occlusal bar. Crown debonding was achieved by applying a vertical dislodging force along the apico-occlusal axis at a crosshead speed of 0.5 mm/min. The maximum load at failure (in Newtons) was noted. The failure load was then divided by the bonded area in mm^2 to obtain the values of shear bond strength [22]. The shear bond strength values at dislodgment in megapascals (MPa) were recorded.

Fig. (7) Universal Testing Machine

Data were entered and analyzed using IBM SPSS version 23 (SPSS Inc., Chicago, IL, USA). Shapiro Wilk test was used to confirm the normal distribution of SBS. Quantitative data were represented using range, mean, standard deviation and median. Difference between the two studied groups was analyzed using independent t test. All tests were two tailed and the significance level was set at p value<0.05.

Assessment of Failure Modes:

Failure modes of the luting cement and fracture patterns of zirconia crowns were also assessed in this study through the examination of surfaces after debonding. Failure modes were classified into adhesive, cohesive and mixed failures. If there is less than 25% of cement material left on the surface of the abutment, it is considered an adhesive failure. Cohesive failure occurs if more than 75% of the cement material remains on the abutment surface. Adhesive/cohesive or mixed failure occurs when less cement material remained on the abutment surface than cohesive failure but more than adhesive failure [23].

Fracture patterns were classified according to the following criteria: Type 0 fracture pattern: no fracture of crown; Type 1 fracture pattern: slight cervical chipping; Type 2 fracture pattern: separation of crown at cervical area; Type 3 fracture pattern: High damage to crowns [24].

RESULTS

A range of (SBS) values were obtained for zirconia crowns without surface treatment (control group) and varied from 173-558, with a mean SBS value of 295 and a standard deviation of ± 122.65.

Zirconia crowns that received surface treatment demonstrated a range of shear bond strength (SBS) values that varied from 343-691, with a mean SBS value of 470.25 and a standard deviation of ± 113.19. (Table 1)

TABLE (1) Comparison of shear bond strength between Zirconia crowns with and without surface treatment

	With surface treatment (n=8)	**Without surface treatment (n=8)**
Mean ±SD	470.25 ±113.19	295.50 ±122.65
Median	439.00	255.00
Min - Max	343.00 – 691.00	173.00 – 558.00
t test (*p* value)	2.961 (0.010*)	

**** Statistically significant difference at** p **value<0.05, t test: Independent t test***

The statistical analysis for comparison of shear bond strength between samples with and without surface treatment revealed significant differences in their mean values as shown in Figure 8. This difference was statistically significant, with a t-test value of 2.961 and a p-value of 0.010, indicating that surface treatment significantly enhances shear bond strength.

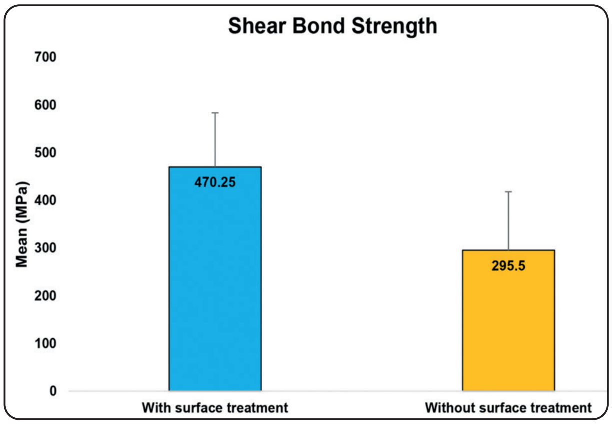

Fig. (8) Comparison between the two studied groups according to shear bond strength

Fig. (9) Type 0 crown fracture pattern (No damage to crown during debonding)

Analysis of Fracture Patterns and Failure Modes

Crowns that received air-abrasion surface treatment mostly displayed Type 2 and Type 3 fracture patterns (high damage to crowns). The observed high damage to crowns during debonding indicates that the crown material was weaker than the bond strength [23].

Type 0 and Type 1 fracture patterns however, were observed frequently in the group which did not receive air abrasion meaning that no damage occurred to the crowns during debonding or only minimal chipping in the cervical area [23].

Most specimen in both groups also displayed cohesive failure modes meaning that more than 75% of cement material remained on the abutment surface. This indicates a stable bond between the cement and the air abraded abutment surfaces of both groups [23].

DISCUSSION

The abutment design used in this study constitutes a prefabricated, standardized titanium insert cemented to a CAD/CAM fabricated zirconia coping. This abutment design was shown to display advantages of both zirconia and titanium abutments which include improved esthetics, optimal biocompatibility, and superior mechanical properties, and showed no adverse effects on the implant–abutment interface. The titanium insert acts as the contact point between the abutment and the implant fixture to avoid the fracture at the implant-abutment contact area which is found to be the weakest and the most fracture prone point. Zirconia abutments with a titanium insert were found to show more resistance to loading than zirconia abutments alone [25].

Zirconia crowns are recently being widely used as a restorative material due to their excellent biocompatibility, optimal esthetics and high mechanical properties such as elevated mechanical strength, resistance to corrosion and increased loading capacity.

Bis Cem cement, a self- adhesive, dual cure resin cement was selected to be used in this study. Self-adhesive resin cements were reported to show high values of retention forces when used to cement zirconia crowns to zirconia implant abutments [14]. This was found to be attributed to the action of the phosphate monomer present in its composition.

An MDP- containing primer, Z -Prime plus, was also used in the study in addition to the resin cement. Z-Prime Plus is a priming agent that is intended to enhance the adhesion between resin cements, titanium and restorative materials. It possesses a combination of two active monomers, MDP, a phosphate monomer, and BPDM (biphenyl dimethacrylate), a carboxylate monomer, to achieve very high bonding strengths.

Retention of a zirconia superstructure to implant abutments depend on several factors including the material composition of the abutment, cement type and surface treatment. The effect of the type of cement and different types of surface treatments on the retention between zirconia superstructures and titanium implant was assessed in various studies. Few studies however, are available around bonding of zirconia superstructures to zirconia implant abutments. The current study was conducted to evaluate the effect of Al_2O_3 particle air abrasion on the bond strength of a zirconia superstructure to a hybrid zirconia implant abutment.

In this study, the null hypothesis was rejected as the results indicated significantly higher shear bond strength in zirconia crowns that received Al_2O_3 particle air abrasion. This might be a result of the increased roughness of the surface of zirconia after alumina air abrasion which in return enhanced the mechanical interlocking between the surface of zirconia and resin cement. Surface free energy analysis also revealed that alumina air abrasion causes an increase in the polar component of zirconia. The number of functional groups (surface OH groups) were found to increase after alumina air abrasion of zirconia, therefore increasing surface free energy and wettability [26].

These findings were consistent with the results of a study conducted by K. Nakamura, et al that investigated the effect of alumina air- abrasion on the bond strength and durability of zirconia. Results of their study concluded that the combination between the use of alumina air-abrasion and MDP-based primers significantly affects the bond strength between zirconia and resin cements [26].

However, the current findings contradict with a study conducted by Motohiro UO et al. which concluded that the bonding strength of zirconia depended on the type of cement used for bonding rather than the surface roughness caused by surface treatment with Al_2O_3 particle abrasion [13].

Airborne particle sizes of 50 μm were used in the current study at 2 bar pressure at 10mm for 20 seconds. This was in accordance with recommendations of Ji-Eun Moon et al. which revealed a significant effect of the size of airborne particles used [21]. Their study was structured to reduce the number of variables as much as possible by focusing only on the effect of air abrasion. An increased particle size (125 µm) was shown to develop high stresses resulting in severe surface cracks causing reduced strength and reliability of zirconia. However, when relatively smaller particle sizes (25 and 50 μm) were used, there was a significant increase in the flexural strength of zirconia. Therefore, a mean of 50 µm is recommended for the size of alumina particle due to its ideal contribution to surface roughness, leading to significantly increased shear bond strength [21].

Determination of failure modes through the assessment of the surfaces after debonding revealed that most of the specimen in both groups displayed cohesive failures. This indicates a stable bond between the cement material and the surface of the air-abraded zirconia abutments in both groups [23].

Assessment of fracture patterns revealed that most crowns in the group that did not receive air-abrasion surface treatment did not fracture during debonding (Type 0). (Fig. 9) However, Type 3 fracture patterns were observed more frequently in the group of crowns that received air- abrasion. The observed high damage to crowns during debonding indicated that the crown material was weaker than the bond strength [23].

Limitations of this in vitro study included that only one cement type was used. Thus, further studies should evaluate the effect of different types of cement on the retention of air abraded zirconia crowns to hybrid zirconia abutments.

CONCLUSION

The following was concluded based on this in vitro study findings:

1. Surface treatment of zirconia crowns with 50 μm A_2O_3 air abrasion provides a strong bond to zirconia hybrid implant abutments with the use of self- adhesive resin cement and a primer containing a 10 (MDP) monomer.
2. Type 3 fracture patterns (high damage to crowns) were observed more frequently in the group of crowns that received air- abrasion. Such high damage to crowns during debonding indicates a high bond strength.

LIST OF ABBREVIATIONS

CAD/CAM Computer-aided design and computer-aided manufacturing

MDP Methacryloyloxydecyl dihydrogenphosphate

μm micrometer

mm millimeters

N newton

Ti Titanium

SBS Shear Bond Strength

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