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ORIGINAL ARTICLE

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Load to failure of three different monolithic zirconia inlay- retained fixed dental prosthesis designs with three surface treatments

Carga até falha de três diferentes desenhos de inlays de zircônia monolítica com três tratamentos de superfície

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ABSTRACT

Objective: The purpose of the study was to evaluate the effect of different preparation designs and different surface treatments on the fracture resistance of monolithic zirconia inlay-retained fixed dental prosthesis [IRFDP]. **Material and methods:** Forty-five translucent zirconia IRFDPs were divided into three groups according to preparation designs (n = 15); group I: proximal box, group II: inlay-box and group III: butterfly wing (modified inlay). Each group was further subdivided into three subgroups according to the surface treatments utilized (n = 5); sandblasting, tribochemical silica coating (Cojet system) and erbium, chromium: Yttrium, scandium, gallium, garnet (Er, Cr: YSGG) laser irradiation. All zirconia IRFDPs were cemented to their respective resin models using self-adhesive resin cement. All cemented IRFDPs were subjected to fracture resistance test using universal testing machine. The initial fracture site was determined by using a stereomicroscope (x6.7magnification). Two-way analysis of variance (ANOVA) was used to evaluate the effect of different designs, different surface treatments and their interaction on the mean fracture resistance. Bonferroni's post-hoc test was used when ANOVA is significant ($P \leq 0.05$). **Results:** Butterfly wings design showed the highest fracture resistance values followed by inlay and box designs respectively ($P \leq 0.05$). Sandblasting and Cojet showed significantly the highest mean fracture resistance values than Laser with no significance difference between them. **Conclusion:** The butterfly wing design increased the fracture resistance of the zirconia IRFDPs. Sandblasting and tribochemical silica coating of zirconia surfaces had a greater effect than Er, Cr: YSGG laser to gain higher fracture resistance of zirconia IRRDPs.

KEYWORDS

Inlay-retained FDPs; Monolithic zirconia; Preparation designs; Surface treatments; fracture resistance.

RESUMO

Objetivo: O objetivo do estudo foi avaliar o efeito de diferentes modelos de preparações e diferentes tratamentos de superfície na resistência à fratura de inlays de zircônia monolítica. **Material e métodos:** Quarenta e cinco inlays translúcidos de zircônia foram divididos em três grupos de acordo com os desenhos de preparação (n = 15); grupo I: caixa proximal, grupo II: inlay convencional e grupo III: asa de borboleta (inlay modificado). Cada grupo foi subdividido em três subgrupos de acordo com os tratamentos de superfície utilizados (n = 5); jateamento de areia, revestimento triboquímico de sílica (sistema Cojet) e érbio, cromo: ítrio, escândio, gálio, granada (Er, Cr: YSGG) irradiação a laser. Todos os inlays de zircônia foram cimentados em seus respectivos modelos de resina usando cimento de resina auto-adesivo. Todos os inlays cimentados foram submetidos a teste de resistência à fratura usando máquina de teste universal. O local inicial da fratura foi determinado usando um estereomicroscópio (ampliação de 6,7x). A análise de variância (ANOVA) de dois fatores foi usada para avaliar o efeito de diferentes desenhos, diferentes tratamentos de superfície e sua interação na resistência média à fratura. O teste post-hoc de Bonferroni foi usado quando a ANOVA foi significativa ($P \leq 0,05$). **Resultados:** O design das asas de borboleta apresentou os maiores valores de resistência à fratura, seguidos pelos designs de inlay convencional e caixa, respectivamente ($P \leq 0,05$). O jateamento de areia e o Cojet apresentaram significativamente os maiores valores médios de resistência à fratura do que o Laser, sem diferença de significânc=ia entre eles. **Conclusão:** O design da asa de borboleta aumentou a resistência à fratura dos inlays de zircônia. O revestimento por jato de areia e triboquímica de sílica das superfícies de zircônia teve um efeito maior que o laser Er, Cr: YSGG para obter maior resistência à fratura dos inlays de zircônia.

PALAVRAS-CHAVE

Inlay; Zircônia monolítica; Desenhos de preparação; Tratamentos de superfície; Resistência à fratura.

INTRODUCTION

Nowadays, minimal invasive treatment modalities are the main concern in the field of dentistry. Although, implant-supported FDP considered to be the most conservative approach for replacement posterior missing single tooth, clinical contraindications and sometimes patient's rejection due to financial aspect and/or fear from surgical intervention may be encountered. The use of inlay-retained fixed dental prosthesis (IRFDPs) with different materials may offer qualified alternatives to conventional full coverage FPDs; thus preserving tooth structure and periodontal tissues [1-7].

The main factors of preparation design that influence the longevity of the inlay-retained restoration are: cavity depth, cavity / isthmus width, preparation taper and the morphology of internal line angles [8]. To improve the strength performance of IRFDPs, clinical trials indicated new preparation and framework designs with the following main features: a) 1-mm shallow occlusal inlay; b) 0.6-mm lingual retainer wing, and c) non-veneered retainer [9,10]. Attempts by Wölfert and Kern [11] to add an additive feature to the inlay/box design was to in cooperate a wing like preparation done only in the enamel on the lingual surfaces of the premolar and molar. The inlay retainers were constructed from computer-aided-design/computer-aided-manufacturer (CAD/CAM) zirconia to improve the fracture resistance and veneering of the zirconia inlays was omitted [11].

Generally, the main drawback of any bi-layered restoration is relatively the weak bond of the veneering ceramic to the underlying substrate (coping) which was documented in several previous reports [12-19]. As an attempt to pursue a better longevity of zirconia fixed dental prosthesis, the introduction of monolithic zirconia side-steps many of the afore mentioned constraints. Monolithic Zirconia microstructure was modified to produce better translucency by management of factors that can affect the esthetic appearance, including porosities, grain size and oxygen vacancies [13-15,19]. These modifications were proposed to decrease the effect of aging on Zirconia-based restorations.

Chemical inertness of zirconia presented a problem to adhesion [20]. Several coating agents were used to enhance the formation of chemical bonding with zirconia and many authors [10,21-23] claimed that only resin cements containing 10-metacryloxydecyl dihydrogen phosphate (MDP) monomer were effective in establishing a reliable bond with zirconia materials. In addition to chemical bonding, micromechanical interlocking plays an important role for achieving durable bond at the ceramic/resin cement interface. Various approaches are carried out; acid etching, grinding, airborne-particle abrasion with aluminum oxide or aluminum oxide particles modified with silica, and recently laser irradiation [23]. Several authors [21,24-26] believed that airborne-particle abrasion with aluminum oxide remains the gold standard and the most suitable method for enhancing the bond strength between zirconia and resin cement. Tribochemistry involves creating chemical bonds by applying kinetic energy in the form of sandblasting, without any application of additional heat or light [25, 27-29]. This procedure renders the ceramics with a reactive silica-rich outer surface prone to silanization and the following resin adhesion for securing a better bond. Several researchers [30-35] had proposed the use of laser irradiation with different parameters especially carbon dioxide (CO_2), erbium, yttrium, aluminum, garnet (Er:YAG), neodymium, yttrium, aluminum, garnet (Nd:YAG) and recently erbium, chromium: Yttrium, scandium, gallium, garnet (Er, Cr: YSGG) for treating Y-TZP ceramic aiming to improve the bond strength with resin cement. They claimed that laser radiation will increase zirconia surface roughness and increase the adhesion area for interlocking of resin cement. Er, Cr: YSGG was first used in the field of dentistry to remove carious hard tissues and it can cut dental tissues efficiently and cleanly [34]. The Er, Cr: YSGG laser had the ability to remove particles by a process called ablation, including micro explosions and vaporization [30]. On vaporization, the internal pressure builds within the tissue until the explosive destruction of the inorganic substance which occurs before the melting point is reached [34]. So, by documented review, the effect of those surface treatment protocols on the mechanical properties of zirconia and the bond strength to resin cement is dialectical, each of them has its positive and negative results [31]. Therefore, the most appropriate surface treatment protocol for treating zirconia is a provocation and not yet decided. Therefore, this study in vitro was aimed to evaluate the effect of different preparation designs and different surface treatment protocols on the fracture resistance of monolithic zirconia inlay- retained FDPs. The null hypothesis was that both preparation designs and different treatment protocols will not significantly affect the fracture resistance of monolithic zirconia inlay- retained FDPs.

MATERIAL AND METHODS

Forty-five translucent zirconia [Incoriz TZI C, SironaBensheim, Germany] IRFDPs were constructed using CAD/CAM technology for restoring mandibular missing first molar. They were divided into three equal groups (n = 15) according to the preparation design involved. Group I (box design); the premolar and the molar were prepared with only a box preparation which was prepared mesial for the molar and distal for the premolar of 3mm occluso-gingival depth, 2mm bucco-lingual and 2mm mesiodistally (figure 1a and 1b). Group II (inlay-box design); the premolar was prepared with an ocluso-distal inlay preparation and the molar was prepared with an occluso-mesial inlay preparation (figure 1, c and d). Group III (butterfly wing design); preparations were performed as the second design with wings executed to resemble that of the resin-bonded bridges on the lingual walls of the molar and the premolar. Wings were extended lingually to half the molar and premolar, covering most of the mesial cusp lingually on the molar and half the lingual cusp on the premolar. Occluso-gingivally, they stopped at the lingu-occlusal line angles leaving the occlusal surface intact and extended 0.6 mm depth (figure 1c and 1d). [9,10]

Inlay preparation procedures were performed on master model acrylic teeth by one operator in accordance with general principles for ceramic inlay restorations on the mandibular second premolar and the second molar with a distance between them 11 mm, which corresponds to the approximate size of a missing mandibular first molar [36]. The inlay preparation design had the following dimensions in order: cavity depth of 2 mm; isthmus cavity width >> 1/3 the intercuspal width; occluso-cervical Taper >> 20°and roundation of all internal line angles (figure 1d). Master models were scanned by a Omnicam Intraoral scanner [Sirona, Benseheim, Germany] and IRFDPs were designed on the scanned virtual models using Inlab 3D software (V4.2) [Sirona, Benseheim, Germany]. The monolithic zirconia blocks were milled by using InLab MCX5 machine [Sirona, Benseheim, Germany]. Sintering process was carried out for all the IRFDPs in MihmVogt tabeo furnace (MihmVogt catalogues and technical brochures, Germany) at a sintering temperature of 1540° C following the manufacturer's recommendations.

Each group was further subdivided into three equal subgroups (n = 5) according

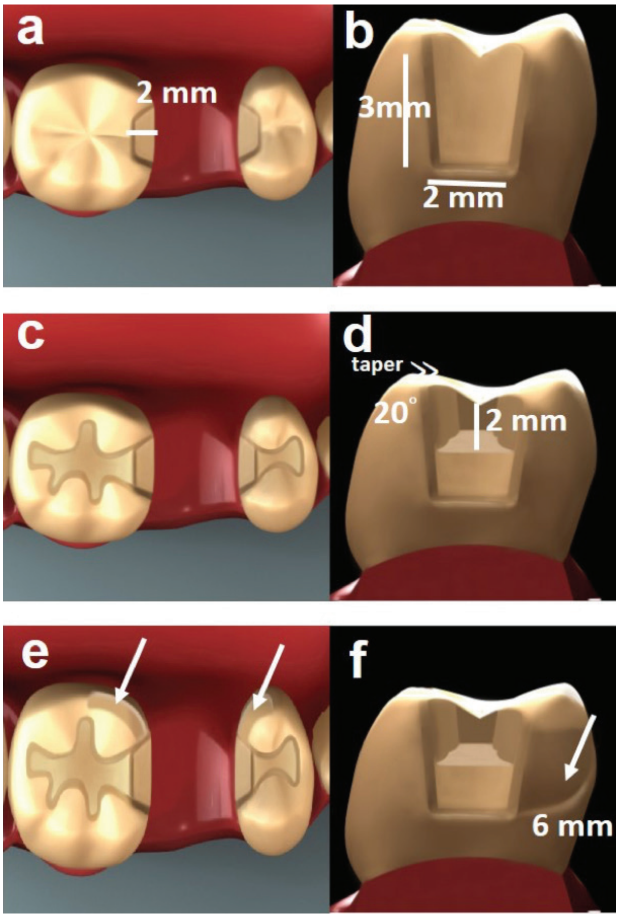

Figure 1 - Schematic diagrams for three different preparation designs for monolithic zirconia IRFDPs; a and b, box design. c and d, inlay-box design. e and f, butterfly wing design. a, c and e (top views). b, d, and f (proximal views). Arrows represent butterfly wings of 0.6 mm which extend lingually to half of the molar and premolar.

to the surface treatment protocols utilized. Subgroup i: specimens were sandblasted using 110 μm alumina oxide [Cobra 110 μ Renfert GmbHUntere Gießwiesen] particles for 10 s at 0.2 MPa pressure. The distance between the nozzle and the surface was approximately 10 mm. Subgroup ii: specimens were abraded with 30μm silica modified Al2O3 [Cojet, 3M, ESPE. Germany] for 10 seconds at 0.2 MPa. The nozzle was rotated perpendicularly to the surface at distance of 10 mm. The inner surfaces of the specimens were then silanized with one coat of a fresh, unopened silane coupling agent [ESPE Sil; 3M ESPE, Seefeld, Germany]. Subgroup iii: specimens were treated with Er:CrYSGG with 2780 nm, with setting parameters of average power of 4.5 Watt, frequency of 50 Hz, H mode (60 microseconds), water 80%, air 60% and a MZ8 tip of 800μ.

Cementation

The master model of each group was duplicated into fifteen epoxy resin models [37,38] (KemaPoxy 150, CMB International. ARE) to simulate the modulus of elasticity of normal teeth. After surface treatments, IRFDPs were ultrasonically cleaned [Toption Digital Ultrasonic cleaner, Shaanxi, China] in distilled water for 30 min and dried prior to cementation. All restorations were cemented to their respective epoxy resin models using self-adhesive resin cement; Rely X U200 automix [3M ESPE, 82229, Seefeld,Germany] following the manufacturer's recommendations (figure 2). Copious amount of the resin cement was applied to the IRFPD bonding surface and cemented with finger pressure, and the specimens was light cured [Mini L.E.D , Satalec, France]. Light curing was done using intensity of 1250 mW/cm^2. A blast of 3 s light cure is done. Excess cement was removed and then another 20 s are applied to ensure complete setting of the cement. The cemented restorations were stored for 24 hours in distilled water at 37°.

Fracture resistance test

Fracture resistance test was carried out using a universal testing machine [Instron universal testing machine model 3345, UK]. To prevent primary cracks at the point of loading, 0.5-mm thick tin foil was inserted between the steel ball and the pontic. The load was vertically applied with a 5-mm diameter stainless steel ball placed at the center of occlusal surface of the pontic with a crosshead speed of 1 mm/min. The fracture resistance was determined by mechanical load to failure. The initial fracture site was determined by a stereomicroscope (Nexius Zoom Evo-Range stereomicroscope NZ.1903-S, Holland) at x6.7 magnifications and photographed.

Data analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Fracture resistance data showed parametric distribution. Data were presented as mean and standard deviation (SD) values. Two-way analysis of variance (ANOVA) was used to evaluate the effect of different designs, different surface treatments and their interaction on the mean fracture resistance. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at P ≤ 0.05. Statistical analysis was performed with IBM®SPSS®Statistics Version 20 for Windows.

RESULTS

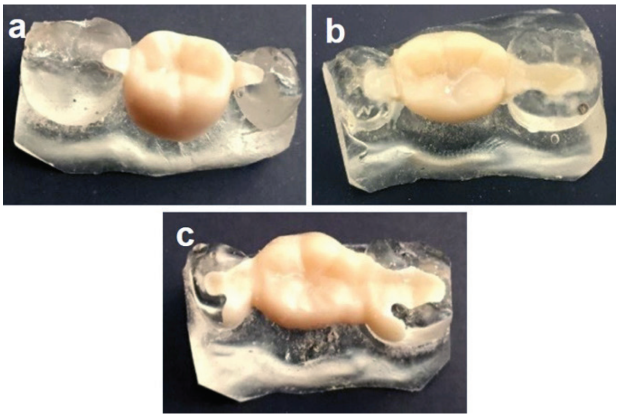

Figure 2 - Representative samples of cemented monolithic zirconia IRFDPs with three different designs; a) box design. b) inlay-box design. c) butterfly wing design.

The results of Two-way ANOVA are shown in table I. The design, different surface treatment protocols as well as the interaction between the two variables had a statistically significant effect on the mean fracture resistance values.

Table I - Two-way ANOVA results for the effect of different variables on mean fracture resistance values

Source of variation	Type III Sum of Squares	df	Mean Square	F-value	*P*-value	Partial Eta Squared (Effect size)
Design	2108051.5	2	1054025.8	58.458	<0.001*	0.765
Surface treatment	657489.5	2	328744.7	18.233	<0.001*	0.503
Design x Surface treatment interaction	843607.8	4	210901.9	11.697	<0.001*	0.565

df: degrees of freedom = (n-1), *: Significant at P ≤ 0.05

Regardless different surface treatment protocols, group III (butterfly wing design) showed the statistically significantly the highest mean fracture resistance value. While, no significant difference was found between group I (box design) and group II (inlay-box); both showed the lowest mean fracture resistance values (figure 3). Regardless the preparation designs, there was no statistically significant difference between the mean fracture resistance values of sandblasting and Cojet; both showed statistically significantly the higher mean fracture resistance values than Laser irradiation (figure 3).

Regarding the effect of different surface treatment protocols within each group, Two-way analysis of variance (ANOVA) showed that for group I (box design), there was no statistically significant difference between the three surface treatment protocols (p = 0.994). For group II (inlay-box design), there was no statistically significant difference between Cojet and Laser; both showed significantly the lower mean fracture resistance values than sandblasting (p = 0.002). While, for group III (Butterfly wing design), there was no statistically significant difference between sandblasting and Cojet; both showed significantly the higher mean fracture resistance values than Laser radiation p < 0.001 (table II, figure 3).

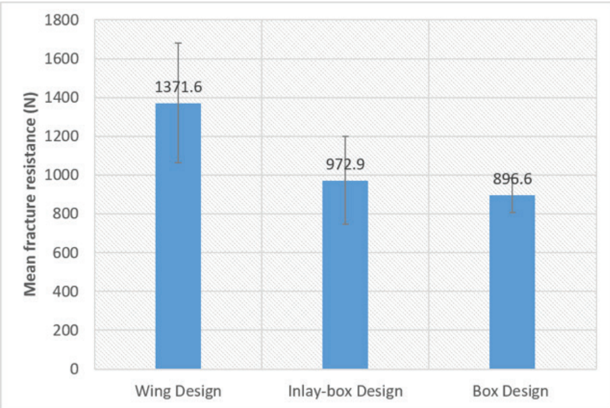

Figure 3 - Bar chart representing comparison between the fracture resistances values of zirconia IRFDPs with different preparation designs and different surface treatment protocols.

Table II - The mean, standard deviation (SD) values and results of two-way ANOVA test for comparison between fracture resistance values of the different interactions

Surface treatment	Wing Design		Inlay Design		Box Design		*P*-value (Between designs)	Partial Eta Squared (Effect size)
	Mean	SD	Mean	SD	Mean	SD		
Sandblasting	1566.9^{AD}	61.3	1159.5^{BD}	319	874.6^{C}	76.9	<0.001*	0.651
Cojet	1582.2^{AD}	41.8	860.7^{BE}	42.6	869.3^{B}	134	<0.001*	0.725
Laser	965.7^{E}	128.8	898.4^{E}	93.5	864.9	63.4	0.489	0.039
P-value (Between treatments)	<0.001*		0.002*		0.994			
Partial Eta Squared (Effect size)	0.656		0.290		0.001			

*: Significant at P ≤ 0.05,
A, B, C superscripts in the same row indicate statistically significantly difference between designs
D, E, F superscripts in the same column indicate statistically significantly difference between designs

While, comparing between the groups (preparation designs), Two-way Analysis of Variance (ANOVA) showed that with sandblasting surface treatment protocol, group III (Butterfly wing design) showed significantly the highest mean fracture resistance values followed by group II (inlay-box design). While, group I (box design) showed significantly the lowest mean fracture resistance values (p = 0.651). While, by using Cojet protocol, group III (butterfly wing design) showed significantly the highest mean fracture resistance values followed by group II (inlay-box design) and group I (box design) with no significant difference between them (p = 0.725). As regard to Laser irradiation, there was no significant difference between the mean fracture resistance values of the three designs (p = 0.039) (table II).

The initial fracture site of all the fractured specimens was either in the isthmus portion or the connector area (figure 4) which had extended to reach the wing extension in group III (wing design) (figure 4e and 4f). Fractures in the connector area occurred either next to the molar or premolar.

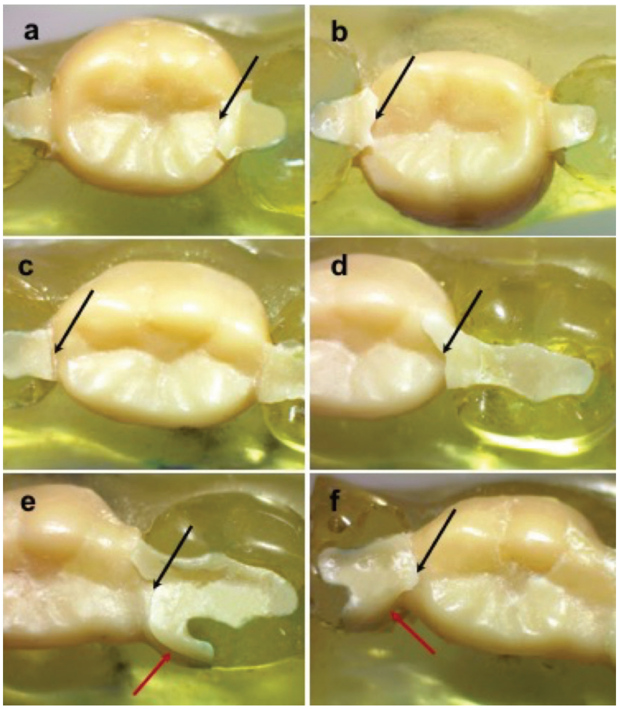

Figure 4 - Photomicrographs of fractured monolithic zirconia IRFDPs with three different designs: a and b; box design. c and d; inlay-box design. e and f; butterfly wing design. black arrows represent the initial fracture site in the zirconia either in the isthmus portion or the connector area. Red arrows represent extension of the fracture to reach the wing part of butterfly wing design.

DISCUSSION

The aim of the present study was to evaluate the effect of different preparation designs and different surface treatment protocols on the fracture resistance of monolithic zirconia IRFDPs for restoring mandibular missing first molar. According to the result of the present study, the null hypothesis was rejected as both preparation designs and different surface treatment protocols significantly affect the fracture resistance.

The mean fracture resistance values of the present study were ranged between 699 -1600 N which were in accordance with many previous studies. [9,39,40] They clarified that posterior FDPs must be strong enough to withstand a load of 500 N at the first molar region. Also, many researchers [12,15,19] concluded that zirconia is considered the material of choice for restoring missing teeth in the posterior region of the mouth.

The new design of IRFDPs (butterfly wing) used in the present study addressed the main weak points found in the box and inlay-box designs i.e. fracture at the ismuthus portion. Reviewing the literature, CAD/CAM manufactured zirconia framework was used for the newly designed IRFPDs resulted in a significantly high static and fatigue fracture strength of 3-unit inlay retained posterior FDPs [9]. Edelhoff et al. [41] reported that zirconia IRFDPs provides excellent esthetics and reduced invasiveness compared with full-coverage FDPs. As well as, addition of a wing as a retentive preparation design should be considered to provide mechanical support.

According to the findings of the present study, the higher fracture resistance of inlay design supported by the extra butterfly wings (averaging 1500 N) compared to the other two designs [box design 874 N, box-inlay design 874 N] could be attributed to the fact that the wing-inlay design may have provided greater surface area for bonding and resist the forces than the other two tested designs. These findings were consistent with those of previous studies [5,6,41] who reported that the new design of the IRFDP with retainer wings increased the size of the enamel adhesive bonding area, and therefore the bond strength of the IRFDP improved significantly. Also, they assumed that the new design improved the inlay-retained FDP at their weakest points; the adhesive bonding interface and the connection between the occlusal part and the proximal box of the inlay. On the contrary, Wolfart and kern [11] clarified some of the disadvantages of the butterfly wing which might be related to the fragile parts of the IRFPD. In addition, because of a suggested minimum thickness for the oral retainer wings and very thin preparation in this area, the wings might get oversized and bulge out slightly at the tooth contour [9].

The higher fracture resistance of air-particle abrasion and Cojet system could be attributed to the modification of the surface topography of zirconia through increasing its irregularities and wettability by air-particle abrasion with Al2O3 particles thereby, improving bond strength through micromechanical interlocking. Silica deposition by air-abrasion (Cojet system) might produce a more silane reactive surface which may enhance chemical bonding to resin cement. Previous studies [25,26,42] reported that adhesive bonding to zirconia mainly promoted by chemical bonds, either through hydrogen bonds between MDP functional groups in the resin cement and the hydroxyl groups available on zirconia surface or between siloxane bonds on zirconia silica-coated surfaces. Therefore, the main role of the abrasive process is to clean and increase the surface area creating circumstances for chemical bonding.

On the contrary, these findings disagreed with those reported by Rashad et al. [12] They found that zirconia surfaces treated with sandblasting showed higher bond strength than the silica coating group. They claimed that the increase in the surface area created by sandblasting allowing acceptable roughness facilitating resin/ceramic micromechanical interlocks formation. Beside, silica deposition by air-abrasion might produce a more silane reactive surface [34], but it also tends to reduce the surface roughness and consequently lower possibility of mechanical interlocking with resin cement [43,44].

In the present study, Er, Cr: YSGG laser irradiation was not efficient in modifying the surface topography of zirconia and improving the bond strength with resin cement thereby showed the least fracture resistance compared to the other protocols. These findings concurred with those reported by Ghasemi et al. [45] They concluded that the pre-sintered zirconia treatment with laser is not recommended to increased bond strength to resin cement. Lui et al [46] claimed that the lower bond strength could be due to the fact that zirconia ceramic does not contain any water molecules which affect laser absorption negatively. Also, many studies proposed that treating zirconia with laser should be carried out while the zirconia in the pre-sintered stage [47-49]. They assumed that after sintering procedure, all crystals would remain in the tetragonal form, avoiding unwanted phase transformations at the material surface. In the present study, treating zirconia with laser was carried out after sintering process.

On the other hand, the findings of the present study disagreed with those of Kirmali et al [50] who found that no significance difference in the bond strength between zirconia and resin cement when the zirconia surfaces treated with Er:Cr YSGG laser and tribochemical silica coating. Several previous studies [49,51,52] high-lightened the effect of different power settings of on the bond strength between zirconia and resin cement and compare with air-particle abrasion, tribochemical silica coating and other types of laser irradiation. Zeidan et al. [51] evaluated the effect of different output powers (2.0 W, 2.5 and 3W) of Er,Cr:YSGG laser and the association with tribochemical silica coating on the bond strength between zirconia ceramic and two resin cements. They concluded that the lowest power output tested was suitable and showed bond strength values similar to those of tribochemical silica deposition.

On the other hand, Zanjani et al. [52] concluded that air abrasion has a greater effect than CO_2 and Er,Cr:YSGG lasers in treating zirconia surfaces to enhance the bonding strength of resin cement to zirconia which is consistent with the results of the present study. Also, CO_2 laser at 4W and Er,Cr:YSGG laser at only 3-W output power can be regarded as surface treatment options for roughening the zirconia surface to establish better bond strength with resin cements. They claimed that 3 W sufficient texture on zirconia surface for resin bonding. Kirmali et al [49] reported that Er, Cr: YSGG laser irradiation with 4-6 W/20 Hz has significant effect in surface roughness changes of zirconia than non-treated, sandblasted and irradiated zirconia with 1-3 w power output. Accordingly, the effect of Er, Cr: YSGG laser irradiation is still controversial which requires further investigation.

In the present study, the initial fracture sites of the three designs with different surface treatment protocols were either in the isthmus portion or the connector area (figure 4). This may be due to the fact that the weakest parts of IRFDPs are the connectors [4] and the isthmus portion is the narrowest area of the restoration even with the use of 3 x 4 mm connecter area and the addition of the wing.

The general outcome of the present study suggests that adequate evidence about long -term safety and efficacy of the new design of monolithic zirconia inlay-retained FDPs is required before acceptance as a routine clinical practice. Airborne particle abrasion with aluminum oxide or aluminum oxide particles modified with silica remain the most suitable, easier and feasible method for enhancing the bond strength between zirconia ceramics and resin cement. Application of laser before sintering process of zirconia with different laser parameters require further investigations which may promote the desired outcomes.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Different preparation designs positively influence the fracture resistance of zirconia inlay-retained FPDs. The butterfly wing preparation design increased the fracture resistance of the Zirconia IRFDPs compared to box and inlay designs;

2. Sandblasting and tribochemical silica coating had a greater effect than Er, Cr: YSGG laser for treating monolithic zirconia surfaces to gain higher fracture resistance of IRRDPS.

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