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THE EFFECT OF CYCLIC LOADING AND SURFACE TREATMENT TECHNIQUES ON THE MARGINAL GAP OF ZIRCONIA INLAY RETAINED FIXED PARTIAL DENTURE WITH THREE DIFFERENT DESIGNS

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ABSTRACT

Statement of Problem With the rise of an esthetic demand for a more natural mimic appearance zirconia bridges and frame works are becoming more and more recommended. Having an esthetic strong restoration as zirconia IRFPD is a better option than the aggressive full coverage restoration or a long, painful and expensive procedure as implant retained restoration.

Aim of the study is to examine the impact of cyclic loading and two distinct surface treatments modalities on the marginal fit of different designs of Inlay retained fixed partial denture cemented with an MPD containing resin cement.

Materials and methods 30 IRFPD were constructed from zirconia with three designs [box, inlay box and winged inlay box] n=10. The samples were split into two subgroups within each group based on the type of surface treatment they received. [sandblasting, Air borne salinization] n=5. IRFPD's were cemented and examined by stereomicroscope for marginal adaptation before and after cyclic loading.

Results surface treatments and cyclic loading had significant effect on marginal adaptation of IRFPD's whereas the different design had no significant effect.

Conclusion IRFPD is a good alternative to restore missing posterior teeth with application of surface conditioning to zirconia and the use of MDP containing cement.

KEYWORDS: Marginal gap, zirconia, inlay retained fixed partial denture, fixed prosthodontics

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INTRODUCTION

When restoring a missing posterior tooth, both treatment options, Dental implants or full coverage three-unit fixed prosthesis might be some how aggressive or expensive treatment plans for the patient. Losing too much of to prepare the abutment, around 63-73% of the coronal structure is eliminated.[1]. Consequently, there is a significant risk of compromising pulp vitality and causing irreversible pulp damage during this invasive preparation, which can be unavoidable at times.[2,3]. Therefore, there is a growing need to modify the abutment preparation design in order to minimize the tooth structure extensive loss when preparing fixed dental prostheses (FDPs) as a viable alternative. to the more expensive and much longer procedure of the dental implants.

Metal ceramic restorations indeed blend the aesthetics of ceramics with strength of metals. But certain metals cause issues like allergies or gum staining. [2,3]. Research in more aesthetic metal-free ceramic systems has been motivated by these concerns for both patients and dentists

So In general, An (IRFPD) made up entirely of ceramic would serve as a method that provides a more conservative and more esthetic approach that allergy-hazard free, especially if adjacent teeth exhibit fillings or carious lesions.[4]

Dental ceramics had some disadvantages that rotate around their inherent low mechanical properties that renders them struggling to withstand forces in areas like premolar and molar, but advancements have expanded their use in long-span fixed partial prosthetics and dental implant superstructure. Compared to metals, dental ceramics generally have lower fracture toughness but have seen development in their properties over time. [5]

Partially stabilized zirconia's high stiffness and mechanical reliability enable thinner core layers, longer bridge spans and the utilization of all ceramic restorations in the posterior regions of the mouth.[5]

Veneering porcelain to metal, lithium disilicate, or zirconia have always proposed a week link of the restoration. It is at this junction where the potential for failure is the highest.[6-11] and so the monolithic concept was born, with less opaque colored zirconia. With the following advantages 1. Proper mechanical properties 2. Acceptable aesthetics 3. Conservation of tooth structure 4. Could be digitally executed 5. Could be cemented either with resin-based or conventional cements, monolithic zirconia has proven to be a promising material with a lot to offer. [12]

Concluding much research, the early attempts of all-ceramic Inlay retained prosthesis could not withstand posterior mastication forces. However, by employing densely sintered yttria-tetragonal zirconia polycrystal (Y-TZP), which possesses the capability to inhibit crack propagation, it has become feasible to fabricate durable inlay-anchored bridges. [13-15]

Research have concluded that when considering partially stabilized zirconia yttria based (YPSZ) as a material for IRFPDs in the molar region, the connector size should be between 9 and 16 mm to endure the maximum chewing forces. [16-18]

To enhance the retention of dental restorations, Wolfart and Kern conducted experiments to incorporate an additional feature into the inlay/box cavity design. Specifically, they introduced a wing-like structure exclusively in the enamel on the lingual surfaces of premolars and molars, thereby increasing the overall surface area. As a result, if a patient is unable to undergo implant treatment due to financial constraints, it is recommended to consider restoring a missing tooth using an inlay-retained fixed partial denture (IRFPD) rather than a crown-retained fixed partial denture, on the condition that there is sufficient healthy tooth structure available. [19]

The challenges in achieving adhesion to zirconia arise from its chemical inertness. Despite the use of aggressive chemical agents such as hydrofluoric acid that have no impact on zirconia frameworks. [20]

Numerous efforts were undertaken to improve the creation of chemical bonds with zirconia, and only coating agents containing a phosphate monomer (MDP) proved successful in forming a dependable bond with zirconia structures. [21,22]

A research compared the bond strength via micro tensile test of three resin cements [panavia f, Multilink, Unicem rely X] each containing a different phosphate monomer. His conclusion was that the MDP monomer led to the highest tensile bond strength values with zirconia and yielded greater bond strength in comparison to the other two phosphate monomers. [23]

To achieve a more robust bond with zirconia, surface conditioning strategies such as micromechanical roughening (involving mechanical, chemical, and laser irradiation) or chemical methods (utilizing silicon coatings and coupling agents) need to be pursued. [24-29]

Micromechanical conditioning theories operate by eliminating the loose contaminants off the substrate surface, producing micro-retentive cracks, This leads to an increase in roughness and improved wettability, facilitating the formation of micromechanical interlocking between the substrate and the adherent [30,31]

Eldafrawy has explained that to increase hydrophilicity for better adhesion, micro surface roughness achievement is a must. [31]

Silica coating, as chemical conditioning strategy, has proven clinically to provide the zirconia surface with the needed silica matter [32] and After undergoing silanization with a silane coupling agent [33,34], zirconia becomes responsive to subsequent treatment with traditional adhesive resins.

Heikkinen et al stated in 2007 that the CoJet system sandblasting the zirconia surface, utilizing a specially formulated silica-modified aluminum trioxide, which furnishes the ceramics with a reactive silica-rich outer surface prepared for silanization and then follows the adhesion with suitable resin composites. [35]

Zhu et al in 2009 attempted to evaluate four different surface treatment methodologies to zirconia surface and their effect on the bond strength to resin cement by the tensile bond strength test. He used a control group with no treatment, an air abrasion group [110 μm Al_2O_3] , air abrasion with silica [110 μm Al_2O_3 + 30 μm silica modified Al_2O_3] and a last group of silica-based porcelain coating. Bond strength results of the Silica abrasion and salinization were greater than sandblasting only. They also stated that the three treatments gave considerably good results, better that no treatment. [36]

Inadequate marginal fit reduces the long-term resilience of all types of restorations, leading to various issues such as microleakage, secondary caries, gingival inflammation, and cement dissolution. Additionally, insufficient internal fit raises the likelihood of prosthesis fracture [37-39].

Various methods are accessible for evaluating marginal and internal fit, primarily classified as destructive or non-destructive, or 2D and 3D methods [40,41].

Thus, this study aims to examine cyclic loading effect with two different surface conditioning on the marginal gap of the translucent zirconia inlay-retained fixed partial denture (IRFPD) with three alternative designs : 1. Proximal box design. 2.Occlusal & Proximal box design. 3.Butterfly wing [Modified inlay] design

MATERIALS AND METHODS

30 translucent zirconia IRFPDs were constructed. They were split into three groups based on the cavity outline.

Group A: Proximal box design. [n=10]

Group B: Occlusal & Proximal box design. [n=10]

Group C: Butterfly wing design[n=10]

Each group was further divided into two subgroups based on the method of surface treatment.

Subgroup I : Sandblasting

Subgroup II: Air borne salinization

Three typodonts (one for each design) was utilized. Acrylic teeth specifically the mandibular second premolar and the mandibular second molar, were chosen as abutments being 11 mm apart, equivalent to the approximate dimensions of a absent mandibular first molar. [42]

Design I : Inlay Box

The preparation procedures were carried out following the standard principles for ceramic inlay restorations [43] and was standardized using CNC milling machine. (fig.1)

The perfect inlay preparation design is recommended to have a cavity depth of between 1.5 and 2 mm with an isthmus cavity width greater than or equal to one third of the intercuspal width. This helps balance preserving of tooth structure and maintaining material strength.

Design II: (Occlusal & Proximal),

Involving the occlusal cavity with the previous box design, The premolar was prepared Ocluso-Distally and the molar would receive a Ocluso-Mesially restoration. (fig 2)

Design III: (Butterfly Wing),

Preparations will be conducted similar to the second design, featuring wings resembling those of resin-bonded bridges, prepared on the palatal walls of the molar and the premolar. (fig 3)

Impressions of the prepared dies were made from Poly vinyl siloxane rubber base material [addition silicon]. The impressions were poured using an epoxy resin material.

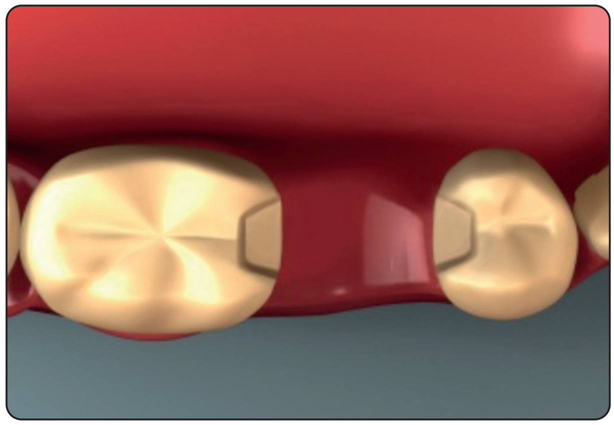

Fig (1) Proximal box design

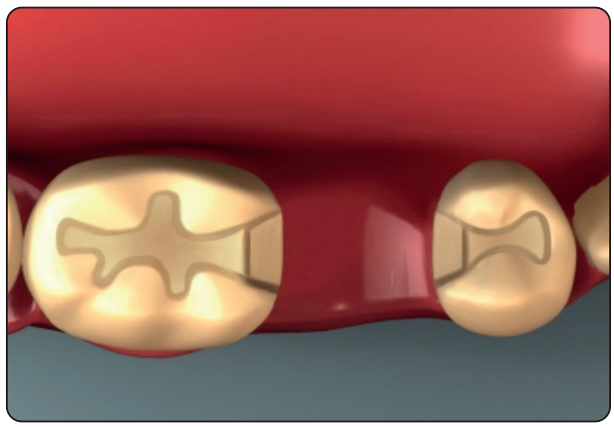

Fig (2) Occluso- proximal Design

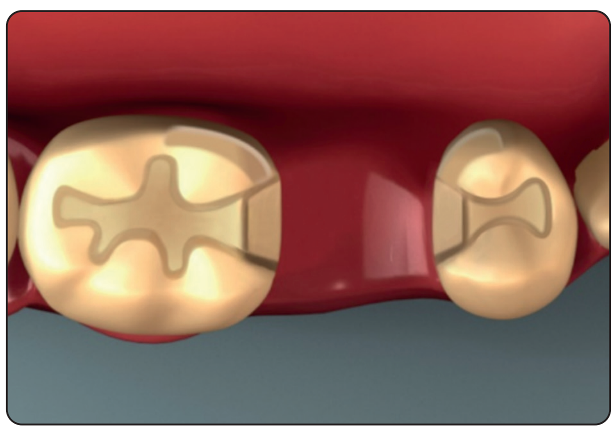

Fig (3) Wing design

IRFPD production

All Ceramic IRFPDs were constructed from translucent monolithic zirconia using CAD/CAM. The Abutments were scanned by a Omnicam scanning system. After starting the inlab software, an interface for a new restoration was initiated, prompting a dialog box for inputting data related to the new restoration. Powder free Scanning for each epoxy dies was done using Omni Cam chairside optical scanner. Continuous shots were taken for the dies from all aspects to create a 3D model on the designing software. IRFPD's the crowns were created on the scanned dies utilizing the Inlab 3D* software (V4.2). Various crucial parameters were configured, encompassing insertion axis, margin placement, occlusal and wall thickness. The crown insertion axis denotes the alignment of the preparation axial walls into the milling chamber. Prior to milling, the suitable blank size (Incoris TZI C 18 mm) for milling IRFPD's is chosen based on the inlay's final size. The software compensates for the sintering shrinkage of the material (24.7%). The exact shrinkage data of the respective block are stored in a barcode on the block itself. The barcode was automatically read prior to milling by the laser scanner built inside the MC X5 unit. Milling is performed by means of burs (cylinder pointed 20, step bur 20). When milling is complete, separation of the crown and cleaning by steam was done, to clean off the milling debris and the lubricant remnants.

Sintering

Tabeo furnace was used to complete the sintering process of monolithic Zirconia crowns following the manufacturer's instructions. The program ran for about 90 minutes. The IRFPD's underwent sintering at a temperature of 1540˚C.

Sandblasting

According to manufacturer instructions conventional Sandblasting was carried out to 30 specimens [10 of each design] using 110μm sized particles using 0.2 MPa pressure for 5 minutes with 10mm distance between the nozzle and the surface.

Airborne particle salinization (Tribochemical silica coating)

According to the CoJet system instructions, air pressure sandblasting with silica-coated aluminum trioxide particles was carried out to 30 specimens. The surfaces were treated with 30μm Silica Modified Alumina for 10 seconds at 0.2 MPa. The nozzle was positioned perpendicular to the surface at a distance of 10 mm. The inner surfaces of the IRFPD's was salinized with a fresh, unopened silane coupling agent. One coat of silane was applied as recommended by the manufacturer.

Cementation

Rely X U200 Self-adhesive resin cement is used to cement all the IRFPD. As it is indicated to cement a 3 unit inlay/onlay retained bridges.

The IRFPD's are cleaned, and a copious amount is placed on the restoration surface. Restorations are then seated on the epoxy models. A 3-second light cure is administered, followed by the removal of any excess. Subsequently, an additional 20 seconds of light curing is applied to ensure the complete setting of the cement. (Fig 4)

Marginal Fit measurement

Following the cementation process, each sample was inspected under a stereomicroscope (SZX12, Olympus, Tokyo, Japan), and images of the occlusal, mesial, and distal surfaces were captured at 10× magnification using a digital camera (DPR, Olympus, Tokyo, Japan) and transferred to a computer (Fig 5). Subsequently, the marginal gap (the distance between the dental wall and the restoration) was measured using a screen ruler (JRScreen Ruler PRO 3.0) in pixels at a minimum of six locations on the occlusal margins and six locations on each proximal surface. [44]

Cyclic mechanical loading

Cyclic loading was conducted to replicate conditions similar to those experienced in the oral cavity.

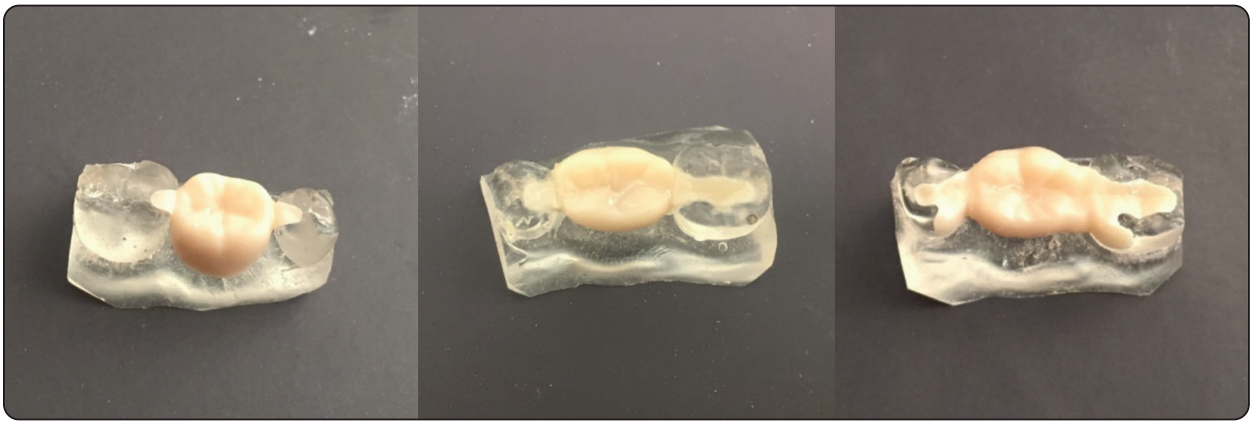

Fig (4) Cemented samples

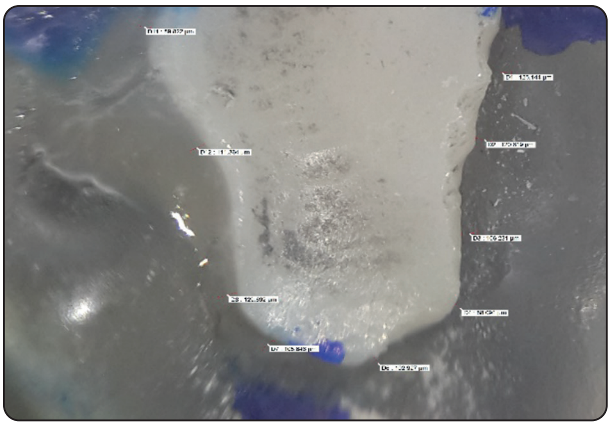

Fig (5) Margin gap measurement

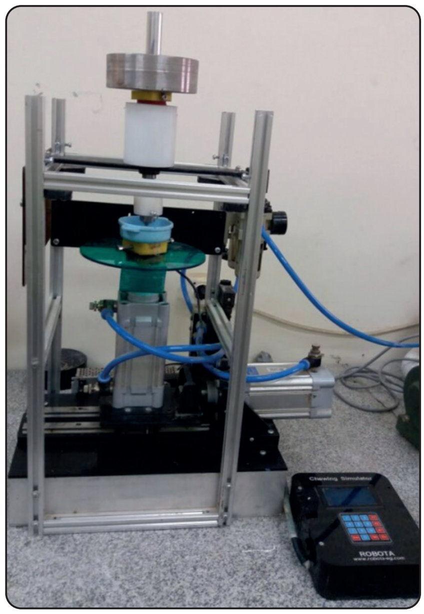

Fig. (6) Cyclic loading machine

A cyclic load of (5 Hz) was applied to the center of the IRFPD surface using a tungsten carbide sphere of (radius r=3 mm) using a maximum compressive load of 200 N (R=0.1) for a total of 300,000 cycles (see fig 6).

To provide further detail, a metallic plunger affixed to a cyclic loading machine was positioned in the middle of the restoration, and a consistent cyclic axial load was applied at a frequency of 2-3 cycles per second. It has been suggested that the application of a load for 500,000 cycles is equivalent to six months, and 1,000,000 cycles is equivalent to one year of in vivo mastication.

Measurements of marginal fit were repeated before and after cyclic loading.

Statistical Analysis

Data were presented as mean and standard deviation (SD) values. Repeated measures ANOVA test was used to study the effect of design, surface treatment, cyclic loading, and their interactions on marginal gap distance. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY:IBM Corp.

RESULTS

The findings indicated that the design (irrespective of surface treatment and cyclic loading) did not have a statistically significant impact on the average marginal gap distance (P-value = 0.448, Effect size = 0.065). Surface treatment (irrespective of design and cyclic loading) had a statistically significant influence on the average marginal gap distance (P-value <0.001, Effect size = 0.553). Cyclic loading (irrespective of design and surface treatment) also had a statistically significant effect on the average marginal gap distance (P-value <0.001, Effect size = 0.452). The interaction between the variables did not have a statistically significant effect on the average marginal gap distance (P-value = 0.101, Effect size = 0.174). As the interaction between the variables is not statistically significant, it can be inferred that the variables are independent of each other.

Effect of design regardless of surface treatment and cyclic loading

Irrespective of surface treatment and cyclic loading, there was no statistically significant variance in the mean marginal gap distance among different designs (P-value = 0.448, Effect size = 0.065).

TABLE (1) Repeated measures ANOVA results for the effect of different variables on mean marginal gap distance (μm)

Source of variation	Type III Sum of Squares	df	Mean Square	*F*-value	*P*-value	Effect size *(Partial eta squared)*
Design	2396.502	2	1198.251	0.831	0.448	0.065
Surface treatment	42896.238	1	42896.238	29.744	<0.001*	0.553
Cyclic loading	4093.728	1	4093.728	19.807	<0.001*	0.452
Design ´Surface treatment´ cyclic loading interaction	1046.080	2	533.040	2.531	0.101	0.174

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

TABLE (2) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between marginal gap distance (μm) of different interactions of variables

Cyclic loading	Surface treatment	Proximal box (n = 5)		Inlay (n = 5)		Modified Inlay (n = 5)		*P*-value	Effect size
		Mean	SD	Mean	SD	Mean	SD		
Before cyclic Loading	Sandblasting	132.9	50.2	146.3	46.4	139.8	26	0.799	**0.019**
	Airborne salinization	108.4	13.3	88.5	6.9	83.9	19	0.438	**0.066**
	P-value	0.230		0.008*		0.010*			
	Effect size	0.060		0.260		0.248			
After Cyclic Loading	Sandblasting	163.4	44.9	183.3	27.4	144	26	0.073	**0.196**
	Airborne salinization	116.6	12	95.1	4.3	96.4	18.5	0.348	**0.084**
	P-value	0.008*		< 0.001*		0.007*			
	Effect size	0.257		0.551		0.264			
Effect of cyclic loading		*P*-value	Effect size	*P*-value	Effect size	*P*-value	Effect size		
	Sandblasting	0.003*	0.320	<0.001*	0.409	0.650	0.009		
	Airborne salinization	**0.373**	**0.033**	**0.476**	**0.021**	**0.181**	**0.073**		

**: Significant at P ≤ 0.05, Effect size: Partial eta squared*

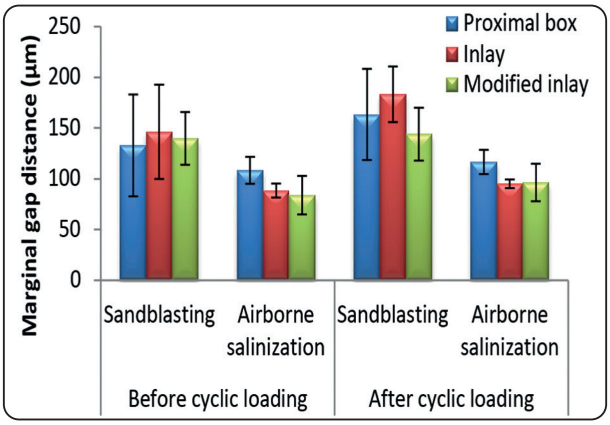

Fig. (7). Bar chart representing mean and standard deviation values for marginal gap distance with different interactions of variables.

Surface treatment impact regardless of design and cyclic loading

Regardless of design and cyclic loading, sandblasting showed statistically significantly higher mean marginal gap distance than airborne salinization (*P*-value <0.001, Effect size = 0.553).

Effect of cyclic loading regardless of design and surface treatment

Regardless of design and surface treatment**,** A statistically significant rise in the mean marginal gap distance was observed following cyclic loading (P-value <0.001, Effect size = 0.452).

DISCUSSION

For this study three designs were proposed a box preparation, an inlay preparation, and a newly introduced inlay preparation with an extended lingual wing.

Edelhoff and Yildirim proposed in 2004 that IRFDPs. Superb aesthetics and decreased invasiveness in comparison to complete crown-retained FPDs. Additionally, a wing as a retentive preparation design should be taken into consideration to offer mechanical support. [18]

As stated by many literatures, preserving tooth structure is the ultimate goal and It contributes to the overall health of the tooth and periodontal tissues. The utilization of minimally invasive bonded restoration consistently results in less trauma and a superior prognosis. [45-49] When designing a tooth preparation, whether for restorative or prosthetic purposes, it is crucial to balance various factors like aesthetics, preserving tooth structure, complexity of the periodontal structure and ensuring the restoration's strength. It's a delicate sequence of decisions that is made possible nowadays [50]

In a study by Mohsen C. in 2010 comparing different designs of inlay retained fixed partial dentures (IRFPD's) for replacing either molar or premolar, zirconia IRFPD's replacing molar showed fracture resistance values lower compared to short-span IRPFDs constructed for the replacing premolar across all three tested designs and so we have investigated a missing lower first molar simulation in shadow of his findings. He also noted that IRPFDs with inlay-shaped retainers exhibited the highest fracture resistance values, followed by IRPFDs with tube-shaped retainers, and finally IRPFDs with box-shaped retainers. [51]

In this study Monolithic translucent Zirconia have been utilized as in 2012 Monaco et al who were one of the first attempts to use it, Due to the superior mechanical properties of zirconia, particularly its stiffness, it could aid in preventing failures associated with lithium disilicate and high-strength pressed ceramics in the posterior region. Zirconia described could reduce phenomena like fracture of lithium dislocate or debonding due to the rigidity of the zirconia and the possibility of being adhesively cemented offered when using MDP containing resin cements has elevated the game to whole new level. [52]

Air borne salinization and sandblasting was utilized in this study to improve the bond of the zirconia restorations to the resin cement and thus securing a better bond to the epoxy dies. The resistance of zirconia to etching by hydrofluoric acid is well-established because of the inability of this acid to degrade a compact ceramic surface with a high alumina-zirconia content. [52]

Concurring to the results of this paper, the airborne salinization gave a smaller gap margin than sandblasting.

As dental ceramics with high crystalline content, like alumina and zirconia, lack an etchable glassy phase, they need to be silica-coated before salinization. [53]

To increase wettability and surface energy for bonding, zirconia must undergo either air abrasion with alumina particles or be treated with silica-coated alumina before salinization. Zirconia lacking surface treatments or salinization exhibited low bond strength of 7.6±3.0 MPa. However, after employing 30 µm alumina air abrasion followed by silanization, a high bond strength of 18.6±5.9 MPa was achieved [53].

It is the presence of silica left behind that causes the more intimate bonding of the restoration thus resulting in better marginal gap readings.

Most research has presented direct view analysis as reliable method of investigation for margin gap measurement, more practical and non-invasive 2D measurement method is enabled, utilizing either a traditional or digital optical microscope, a stereomicroscope, or a scanning electron microscope (SEM) to directly observe specific points and measure linear distances between them. The SEM provides a more detailed and precise image compared to an optical microscope due to its higher resolution, ranging from 100× to 1000×. Furthermore, in addition to its magnification capabilities, it can also be used for indirect viewing analysis, as described by Soliman et al. and Frankenberger et al. [54,55].

The majority of research has established 120 microns as the clinically acceptable limit for marginal gap, as initially proposed by Mclean and Fraunhofer [56]. However, some studies suggest values up to 200 microns [57,58]

The cyclic loading had a significant effect on increasing the gap margin between the tooth structure and the IRFPD's especially with the sandblasting groups.

Supporting our findings in this study, several in vivo studies have demonstrated that the marginal quality of ceramic restorations deteriorates over the years following adhesive cementation [59-62]. The widening of the marginal gap after thermal cycling and artificial aging can be attributed to hydrolytic and mechanical stresses. The luting composite may absorb water, causing an increase in volume and subsequently widening the marginal gap. However, even after masticatory simulation, the median marginal gaps of the test groups were slightly below the clinically acceptable marginal gap of 120 μm.

CONCLUSION

The inlay retained partial denture with any of the designs is a great option especially when intact teeth are serving as the abutments to preserve tooth structure as much as possible. Cyclic may have an adverse effect on the margin gap but in this study the results were still within acceptable range. Surface treatment is a must when it comes to the use of zirconia restorations.

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