 DOI: 10.21608/ADJALEXU.2020.82697

MARGINAL PENETRATION IN ZIRCONIA INALY-RETAINED FIXED PARTIAL DENTURES: AN IN-VITRO STUDY

Mohamed T. El Halawani[1] *BDS, MSc, Yehia S. Aboushady [2] BDS, MSc, PhD, Sally M. Abdel Kader [3] BDS, MSc, PhD, Luca Solimei [4] DDS, Beatrice Morfi DDS [4], Stefano Benedicenti [5] DDS

ABSTRACT

INTRODUCTION: Inlay-retained fixed partial dentures (IRFPDs) have been proposed as a more conservative method for replacing missing dentition instead of the more destructive full crown preparation. Various studies have been conducted on the flexural strength of such restorations; however, there is a lack of evidence on their marginal integrity.
OBJECTIVES: Evaluating the marginal integrity of three IRFPD designs fabricated using monolithic translucent zirconia.
MATERIALS AND METHODS: Thirty IRFPDs were fabricated using a translucent monolithic zirconia (Katana STML) and divided randomly into 3 groups according to the cavity design. Group 1 received an inlay cavity preparation including a proximal box and a 2 mm deep occlusal extension, Group 2 received an inlay cavity preparation including a proximal box and a 1.5 mm deep occlusal extension, and Group 3 received only a proximal box cavity preparation without an occlusal extension. The restorations were fabricated and cemented using a dual cure resin cement (Panavia V5 system) and subjected to an equivalent of 5 years of ageing. A dye penetration test was performed on the specimens, and the values of marginal penetration were analyzed under a stereomicroscope.
RESULTS: During the whole 5-year ageing process, no specimens showed signs of cracking, fracture or loss of retention in any or the restorations. There was a significant difference between the marginal leakages values obtained in the 3 groups of the study (H=10.208, $p<0.05$). Comparing the groups of the study showed significant difference in marginal leakage between Group 1 and Group 3 ($p<0.05$).
CONCLUSIONS: The margins of inlay-retained fixed partial dentures performed well after ageing with recommended bonding protocols for zirconia. Inlay cavity design including a proximal box and an occlusal extension exhibited better marginal stability than proximal box without any occlusal extension.
KEYWORDS: Inlay-retained, FPD, dye penetration, marginal leakage
----

1 Assistant Lecturer of Fixed Prosthodontics, Conservative Dentistry Department, Faculty of Dentistry, Alexandria University; Champlion St. 21131, Alexandria, Egypt.
2 Professor of Fixed Prosthodontics, Conservative Dentistry Department, Faculty of Dentistry, Alexandria University; Champlion St. 21131, Alexandria, Egypt.
3 Professor of Dental Biomaterials, Department of Dental Biomaterials, Faculty of Dentistry, Alexandria University; Champlion St. 21131, Alexandria, Egypt.
4 Department of Surgical and Integrated Diagnostics, University of Genoa; Largo R. Benzi, 10 - 16132 Genoa, Italy.
5 Associate Professor, Dean of Laser Department Center, Department of Surgical and Integrated Diagnostics, University of Genoa; Largo R. Benzi, 10 - 16132 Genoa, Italy.

**Corresponding author:*
E-mail: mthalawani@gmail.com

INTRODUCTION

The increased demand for esthetic restorations in today's world has spurred a technological advance in the field of dental restorations aiming at producing durable restorations capable of withstanding the patients' intraoral environment and masticatory forces and at the same time striving for maximum esthetics for patient satisfaction (1).

The use of high-strength Yttrium stabilized zirconium oxide in fabricating dental restorations has been growing in recent years. The zirconium oxides are highly crystalline materials that possess excellent mechanical properties making them a candidate for use in fixed prosthodontics and extensive oral reconstructions (2, 3).

One of the main concerns with zirconium oxide restorations was their lack of translucency resulting in unesthetic and dull restorations. This resulted in their use being limited to the posterior regions or unesthetic zones of the oral cavity and/or their use as a core material to be veneered using ceramics. Even though the material had sufficient mechanical properties, a common problem with these restorations was their liability for chipping or loss of veneering material (4).

Translucent zirconia was introduced to avoid these issues, creating monolithic restorations that help in preservation of sound tooth structures since they do not require the addition of veneering ceramic thus limiting the need for the extra tooth preparation and eliminating chipping that occurred in veneered restorations (5, 6).

The inert nature of zirconia prevents it from being affected by hydrofluoric acid etching, and the lack of silica particles renders the use of silane for enhancing the bond with resin cement futile (7, 8). The use of airborne particle abrasion followed by resin cements containing 10-methacryloyloxy-decyl dihydrogen-phosphate (MDP) has showed to produce durable bonds with zirconia (9-11).

Inlay-retained fixed partial dentures have been proposed as a more conservative method for replacing missing dentition instead of the more destructive full crown preparation (12-16). Due to their high mechanical properties, zirconia exhibited higher survival rates in the literature when compared with other all-ceramic and fiber-reinforced composite after being used for constructing IRFPDs (17-19).

In this study, the marginal integrity of three IRFPD designs fabricated using monolithic translucent zirconia restorations was evaluated. The null hypothesis is that there is no difference between the three study groups with regards to marginal infiltration.

MATERIALS AND METHODS

Sixty extracted human teeth were used in this study; thirty maxillary human premolars and thirty maxillary human molars without cavitated carious lesions or restorations were selected. The extracted teeth were thoroughly cleaned from any calculus or debris using an ultrasonic scaler and stored in in a 4% formal saline solution at room temperature (20).

The roots of the extracted teeth were painted using a silicone spacer Erkoskin (Erkodent Erich Kopp GmbH, Pfalzgrafenweiler, Germany) to create a thin homogenous layer over the roots representing the periodontal ligament space (21). A copper mold with fixed dimension of 2 x 4 cm was filled with an autopolymerising acrylic resin, DEI Preceasy (Dei Italia, Mercallo VA, Italia). The teeth were mounted parallel on a metal rod with a fixed distance of 10 mm between them and then inserted into the autopolymerising acrylic resin block to replicate the condition of a patient with a missing 1st maxillary molar. The spacer was then removed and Light-body PVS impression material, Express STD (3M Espe, Seefeld, Germany), was then injected around the roots to replicate the periodontal ligament (Figure 1).

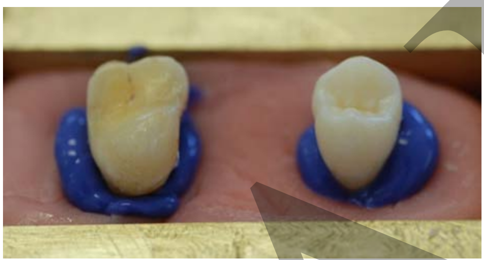

Figure (1): Finalized specimens with PVS replicating the PDL.

Grouping of the specimens

The specimen blocks were divided randomly into three groups (n=10) according to their preparation design.

Group 1: Inlay cavity with an occlusal extension of 2 mm depth. (Figure 2a)

Group 2: Inlay cavity with an occlusal extension of 1.5 mm depth. (Figure 2b)

Group 3: Proximal box without an occlusal extension. (Figure 2c)

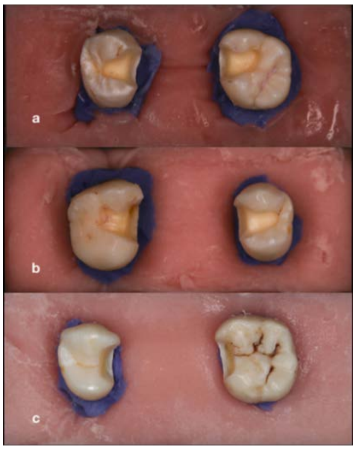

Figure (2): Preparation of specimens in different study groups a) Group 1, b) Group 2 and c) Group 3.

Preparation of the Specimens

All teeth cavity preparations were made using a high-speed contra-angled handpiece with diamond stones #2133 (Microdont, Monsey, New York, USA) having rounded cutting angles to have internal rounded cavity walls. After the preparations were cut, all walls and margins were finished using red grit diamonds #2133F (Microdont, Monsey, New York, USA) to ensure smooth surfaces and rounded line angles.

FPD Fabrication

The digital impressions were acquired utilizing a CAD/CAM 3D scanner, D800 extraoral scanner (3Shape, Copenhagen, Denmark) and the IRFPDs were then designed using the Dental Designer Premium software (3Shape, Copenhagen, Denmark) with a minimum connector thickness of 9 mm3. The finished design was milled from Katana STML zirconia disks shade A3 (Kuraray Noritake Dental Inc., Tokyo, Japan) using the imes-icore 450i milling unit (imes-icore® GmbH, Eiterfeld, Germany), and sintered to acquire full strength.

Cementation of the specimens

Before cementation, the restorations were tried in on the abutment teeth to check for proper seating. Then the fitting surface of the zirconia FPDs in all groups were air borne particle abraded using 50-μm aluminum-oxide (Al_2O_3) particles at 3 bar pressure for 10 seconds at a distance of 10 mm. The MDP containing Ceramic Primer Plus (Kuraray Noritake Dental Inc., Tokyo, Japan.) was placed on the fitting surface of the restorations and air dried according to manufacturer's requirements.

Selective etching of enamel margins in the tooth preparations was done using 37% phosphoric acid, K-Etchant (Kuraray Noritake Dental Inc., Tokyo, Japan.), for 15 seconds, which was then rinsed and gently dried. The Tooth Primer (Kuraray Noritake Dental Inc., Tokyo, Japan.) was then applied on the tooth preparation for 20 seconds, during which agitation of the surface was done using a microbrush, and after that it was thoroughly dried with mild air.

The bonding was done using an MDP containing self-adhesive resin cement, Panavia V5 (Kuraray Noritake Dental Inc., Tokyo, Japan.) according to manufacturer's recommendations. The resin cement was dispensed onto the fitting surface of the zirconia FPD, which was slowly seated on the abutment teeth allowing excess cement to seep out. The excess material was light cured for 2 seconds from each direction and the excess was removed using a dental explorer. Light curing of 40 seconds from each side was done and the FPD was left in place for 5 minutes to ensure complete polymerization of the resin (Figure 3).

Figure (3): Final Cemented restoration.

Testing

1. Cyclic Loading

The samples were subjected to cyclic loading in a masticator with a force of 50 N. The load was applied on the central fossa of the pontic using a metal rod with a spherical tip. Each sample was subjected to 1,200,000 cycles at a frequency of 2 Hz and thermocycled at 5°C to 55°C to 5°C for 5,000 thermal cycles to simulate 5 years of function inside the oral cavity (22).

2. Marginal Leakage

After cyclic fatigue, the specimens were immersed in a bath of laboratory-prepared 2% methylene blue solution at 37° C for 24 h. First the pontic was sectioned buccolingually to separate both abutments from each other. Each tooth was then sectioned longitudinally in the buccolingual and then crosssectionally with a diamond disc under dry conditions. The specimens were then viewed under a stereomicroscope at 4 predetermined points (2 points on the occlusal surface and 2 points along the axial wall). The extent of the dye penetration was scored according to the 5-point scale (23, 24)

0- No microleakage

1- Microleakage less than 1/3rd the axial wall length

2- Microleakage more than 1/3rd but less than 2/3rd the axial wall length

3- Microleakage all along the axial wall length

4- Microleakage reaching the pulpal floor

The value of the microleakage assigned to each specimen was the mean score of dye penetration recorded at all of the measurement points.

Statistical Analysis

The data obtained from each specimen was recorded and tabulated. Descriptive statistics were used to analyze the data, and the median, mean and standard deviation were calculated for each group. Comparison between the study groups was done using Kruksal Wallis test followed by a Post Hoc test (Dunn's for multiple comparisons) to compared between every two groups.

RESULTS

Thirty monolithic zirconia IRFPDs were fabricated on extracted teeth to resemble a single missing maxillary molar. During the whole 5-year ageing process, no specimens showed signs of cracking, fracture or loss of retention in any or the restorations.

The mean values and medians were obtained for the 3 groups and Kruksal Wallis test was used to compare between them as shown in table 1. There was a significant difference between the marginal leakage values obtained in the 3 groups of the study (H=10.208, p<0.05). Dunn's for multiple comparisons was used as a Post Hoc for comparing the groups of the study showing significant difference in marginal leakage between Group 1 and Group 3 (p<0.05).

No leakage was observed at the pulpal floor in any of the samples, therefore no Value 4 dye penetration was reported. The highest number of points with a Value 3 dye penetration was seen in Group 3 of the study. On the other hand, no Value 3 dye penetration was recorded in any of the samples in Group 1. Examples of different dye penetration values observed are shown in figures 4-6.

Table (1): Comparison between the three studied groups according to leakage value.

	Group I (n = 10)	Group II (n = 10)	Group III (n = 10)	H	p
Leakage value					
Min. – Max.	0.0 – 1.0	0.25 – 1.0	0.38 – 1.88		
Mean ± SD.	$0.45^{b} \pm 0.27$	$0.64^{ab} \pm 0.24$	$1.06^{a} \pm 0.44$	10.208^{*}	0.006^{*}
Median	0.50	0.63	1.06		

H: H for **Kruskal Wallis test,** Pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Dunn's for multiple comparisons test)** and was expressed by small letter

p: p value for comparing between **the three studied groups**

Means with **Common letters** in the same **row** are not significant (i.e. Means with **Different letters** are significant)

*: Statistically significant at $p \leq 0.05$

Figure (4): Specimen with no dye penetration at the two margins in occlusal extension box.

Figure (5): Specimen with Value 1 dye penetration at both margins in occlusal extension box.

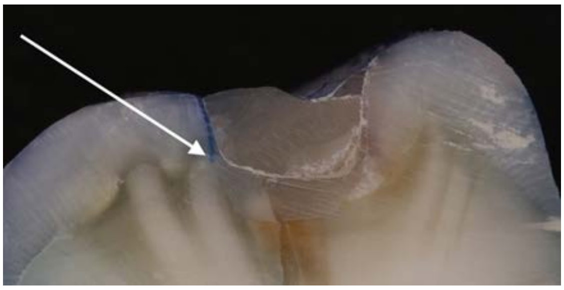

Figure (6): Specimen with Value 2 dye penetration in one margin in occlusal extension box.

DISCUSSION

The current study was an attempt to validate whether monolithic zirconia could be used as an IRFPD and to evaluate its short-term to medium-term survival in function. The study also aimed at studying the marginal integrity of such restorations to be able to understand their mechanism of failure. The null hypothesis of the study was rejected.

Multiple finite analysis studies of IRFPDs have shown that IRFPDs are subject to higher forces of mastication compared to the FPDs with full coverage retainer, as the full coverage retainer has a more favorable stress distribution pattern due to the added bulk of material (25). This might explain the low survival rates of IRFPDs constructed from lithium disilicate in the clinical trial conducted by Harder et al, with only 57% and 38% survival rates after 5 years and 8 years respectively with fracture of the restorations reported as one of the main causes of failure (12). In-vitro studies conducted on IRFPDs point to a significant difference in fracture resistance of restorations constructed from lithium disilicate and zirconia, with the lithium disilicate restorations showing lower fracture strengths (15, 18).

In the current study, 3Y-TZP zirconia was chosen as the material for constructing the inlay-retained FPDs due to its high strength and fracture resistance of around 1200 MPa, which is much higher than the forces found inside the oral cavity (16). The in-vitro studies reporting on zirconia IRFPDs showed promising results with high flexural strengths which are enough to withstand the forces of chewing in the patient’s mouth (15, 16).

Translucent zirconia was introduced to match patient esthetic expectations, especially in the posterior zone, without compromising its flexural strength by utilizing the better translucency of a smaller grain size (5, 6). Therefore, in the current study it was decided to use monolithic translucent zirconia for the construction of the IRFPDs to eliminate the possibility of failure due to chipping or delamination in the restorations.

The use of airborne abrasion with Al2O3 particles followed by bonding with an MPD containing resin cement has proven to provide a durable bond to zirconia as the MDP can bond strongly to sandblasted zirconia through hydrogen bonds that may be formed between hydroxyl groups in the MDP monomer and hydroxyl groups on the zirconia ceramic surface (10, 11).

In the current in-vitro study all specimens (100%) survived the 5 years ageing procedures without any cases of fracture or loss of bonding. This result was in accordance with the study conducted by Wolfart et al (15) on fracture strength of IRFPDs, were none of the zirconia specimens fractured during the fatigue testing procedures. Another in-vitro study by Puschman et al (19) also reported a high success rate with a failure of only one zirconia IRFPD during the ageing procedures.

Group 1 showed the best results for marginal leakage with 95% of the points observed had either no penetration at all or showed superficial penetration only in the outermost third of the margin. In Group 2, this dropped to 81.25%, with some points exhibiting deeper dye penetration including most of the axial wall (6.25%). Group 3 showed the highest dye penetration values with 16.25% reaching the last third of the axial wall. This might indicate that the presence of longer axial walls in Group 1 provide more area for cementation, which might help the diffusion of the stresses along them, decreasing the potential of surface marginal cracks from progressing inwards.

The results obtained from Group 1 of the current study are in accordance with those obtained for single indirect inlays in a study conducted by Duquia et al in which the authors reported that the marginal penetration in the indirect inlays were restricted to outermost third of the margin (24). Another study by Hahn et al, reported average penetration values of less than 200μm (which can safely be assumed is less than 1/3 of the axial wall) for ceramic inlays with clinically acceptable marginal gaps (26).

This points to the fact that when using a more retentive cavity design including an occlusal extension (as in the case of Groups 1 and 2), which might have decreased the forces transmitted at the margins of the restoration resulting in less micro-gap formation and thus less penetration of the dye.

CONCLUSION

Within the limitations of this study on the marginal leakage of IRFPDs, the following conclusions can be drawn:

- The margins of inlay-retained fixed partial dentures performed well after ageing with recommended bonding protocols for zirconia.
- Inlay cavity design including a proximal box and an occlusal extension exhibited better marginal stability than proximal box without any occlusal extension.
- Further studies are needed to assess the marginal integrity of IRFPDs to understand how they perform in function.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1- Thompson M, Thompson K, Swain M. The all-ceramic, inlay supported fixed partial denture. Part 1. Ceramic inlay preparation design: a literature review. Australian dental journal. 2010;55:120-7.
2- Manicone PF, Iommetti PR, Raffaelli L. An overview of zirconia ceramics: basic properties and clinical applications. J Dent. 2007;35:819-26.
3- Sundh A, Molin M, Sjögren G. Fracture resistance of yttrium oxide partially-stabilized zirconia all-ceramic bridges after veneering and mechanical fatigue testing. Dent Mater. 2005;21:476-82.
4- Tara MA, Eschbach S, Wolfart S, Kern M. Zirconia ceramic inlay-retained fixed dental prostheses–first clinical results with a new design. Journal of Dentistry. 2011;39:208-11.
5- Klimke J, Trunec M, Krell A. Transparent tetragonal yttria-stabilized zirconia ceramics: influence of scattering caused by birefringence. Journal of the American Ceramic Society. 2011;94:1850-8.
6- Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater. 2014;30:1195-203.
7- Chaiyabutr Y, McGowan S, Phillips KM, Kois JC, Giordano RA. The effect of hydrofluoric acid surface treatment and bond strength of a zirconia veneering ceramic. J Prosthet Dent. 2008;100:194-202.
8- Amaral R, Özcan M, Bottino MA, Valandro LF. Microtensile bond strength of a resin cement to glass infiltrated zirconia-reinforced ceramic: the effect of surface conditioning. Dent Mater. 2006;22:283-90.
9- Blatz MB, Chiche G, Holst S, Sadan A. Influence of surface treatment and simulated aging on bond strengths of luting agents to zirconia. Quintessence Int. 2007;38:745-53.
10- Yoshida K, Tsuo Y, Atsuta M. Bonding of dual-cured resin cement to zirconia ceramic using phosphate acid

ester monomer and zirconate coupler. Journal of Biomedical Materials Research Part B: Applied Biomaterials. 2006;77B:28-33.
11-Kern M. Bonding to oxide ceramics—laboratory testing versus clinical outcome. Dent Mater. 2015;3:8-14.
12-Harder S, Wolfart S, Eschbach S, Kern M. Eight-year outcome of posterior inlay-retained all-ceramic fixed dental prostheses. Journal of Dentistry. 2010;38:875-81.
13-Magne P, Perakis N, Belser UC, Krejci I. Stress distribution of inlay-anchored adhesive fixed partial dentures: a finite element analysis of the influence of restorative materials and abutment preparation design. J Prosthet Dent. 2002;87:516-28.
14-Iglesia-Puig MA, Arellano-Cabornero A. Inlay fixed partial denture as a conservative approach for restoring posterior missing teeth: a clinical report. J Prosthet Dent. 2003;89(5):443-5.
15-Wolfart S, Ludwig K, Uphaus A, Kern M. Fracture strength of all-ceramic posterior inlay-retained fixed partial dentures. Dent Mater. 2007;23:1513-20.
16-Ohlmann B, Gabbert O, Schmitter M, Gilde H, Rammelsberg P. Fracture resistance of the veneering on inlay-retained zirconia ceramic fixed partial dentures. Acta Odontol Scand. 2005;63:335-42.
17-Chen J, Cai H, Suo L, Xue Y, Wang J, Wan Q. A systematic review of the survival and complication rates of inlay-retained fixed dental prostheses. Journal of dentistry. 2017;59:2-10.
18-Kılıçarslan MA, Kedici PS, Küçükeşmen HC, Uludağ BC. In vitro fracture resistance of posterior metal-ceramic and all-ceramic inlay-retained resin-bonded fixed partial dentures. J Prosthet Dent. 2004;92:365-70.
19-Puschmann D, Wolfart S, Ludwig K, Kern M. Load-bearing capacity of all-ceramic posterior inlay-retained fixed dental prostheses. European journal of oral sciences. 2009;117:312-8.
20-El-Mowafy O, Rubo MH. Retention of a posterior resin-bonded fixed partial denture with a modified design: an in vitro study. Int J Prosthodont. 2000;13:425-31.
21-Brito-Junior M, Braga NMA, Rodrigues DC, Camilo CC, Faria-e-Silva AL. Effect of the simulated periodontal ligament on cast post-and-core removal using an ultrasonic device. J Appl Oral Sci. 2010;18:528-32.
22-Monaco C, Krejci I, Bortolotto Ibarra T, Perakis N, Ferrari M, Scotti R. Marginal adaptation of 1 fiber-reinforced composite and 2 all-ceramic inlay fixed partial denture systems. Int J Prosthodont. 2006;19:373-82.
23-Tjan AH, Dunn JR, Grant BE. Marginal leakage of cast gold crowns luted with an adhesive resin cement. J Prosthet Dent. 1992;67:11-5.
24-Duquia R, Osinaga P, Demarco F, Habekost L, Conceição E. Cervical microleakage in MOD restorations: in vitro comparison of indirect and direct composite. Operative dentistry. 2006;31:682-7.
25-Thompson M, Field C, Swain M. The all-ceramic, inlay supported fixed partial denture. Part 2. Fixed partial denture design: a finite element analysis. Australian dental journal. 2011;56:302-11.
26-Hahn P, Attin T, Gröfke M, Hellwig E. Influence of resin cement viscosity on microleakage of ceramic inlays. Dent Mater. 2001;17:191-6.