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Effect of Selective Proximal Wall Thickening on the Connector Fracture Resistance in Zirconia Short Span Fixed Partial Denture (In vitro study)

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ABSTRACT

OBJECTIVE: to compare the effect of abutments' proximal wall thickness adjacent to the connector on the fracture resistance of a three-unit fixed partial denture framework.

MATERIALS AND METHODS: twenty-eight FPD frameworks were divided into 4 groups according to the finish line thickness on the proximal wall adjacent to the connector (n=7): 0.4 (group I); 0.8 (group II); 1.0 (group III) and 1.2 mm (group IV). Preparations were scanned using EXOCAD software. Using Stereo-lithography technology, twenty- eight 3D resin models were printed simulating the maxillary left quadrant with missing tooth number 25 and prepared teeth 24 and 26 to receive a three-unit FPD.

Twenty-eight three-unit identical FPD frameworks with different proximal wall thicknesses were designed, milled using CAD/CAM, and cemented with resin cement to their corresponding models.

A thermal cycling regime was conducted to simulate intraoral temperature changes, corresponding to 10 months of clinical service with 1000 thermal cycles.

All specimens were tested for fracture resistance in a universal testing machine with a crosshead speed of 1 mm/min speed until failure, which was confirmed by a sudden drop in the measurements of the testing machine. Mode of failure was recorded for each specimen and visually investigated. Results were recorded, tabulated, and statistically analyzed.

Shapiro-Wilk and Kolmogorov-Smirnov normality tests were considered to evaluate the normality of data distributions. One-way ANOVA followed by Tukey's post hoc analysis tests was conducted to analyze the fracture resistance significant difference.

RESULTS: Descriptive analysis showed a greater mean value for Group IV (1191.9) followed by Group III (789.4), group II (702.3), and Group I (511.8) consecutively. One-way ANOVA revealed that there was a statistically significant difference between the four groups that were represented by ($P<0.001$).

CONCLUSIONS: Modifying the proximal finish line thickness adjacent to the connector affected the fracture resistance of the three-unit Zirconia FPD framework.

KEYWORDS: Zirconia, Connectors, 3-unit FPD, Fracture Resistance.

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INTRODUCTION

To achieve the highest level of esthetics, new materials, and techniques have been developed during the past ten years in response to the rising demand for cosmetic dentistry. As a result, metal-free restorations were used in both the anterior and posterior regions (1). Due to their superior aesthetic and biocompatibility qualities, ceramic-fixed dental prostheses have been strongly recommended over metal-based restorations (2).

Due to surface defects, ceramics are brittle and prone to fracture beyond critical stress (3). New ceramic core materials were introduced to strengthen the ceramics and increase the fracture resistance of posterior FPDS. This was achieved by increasing the radius of the gingival embrasure of the connector area to reduce stresses and strengthening the ceramics by adding residual compressive stresses to the material's surface or preventing crack propagation through the material (4).

On the other hand, contemporary ceramic materials provide an appropriate level of fit, mechanical, and fracture resistance. Additionally, due to ceramic materials' ongoing development, they are now used in posterior stress-bearing regions (5) Zirconia ceramics were used in dentistry as a frame work material for posterior FPDs fabricated easily with the help of CAD/CAM systems by milling a ZrO2-block. Zirconia, from a chemical standpoint, represents a metal oxide end owed with polymorphism and allotropy attributes, positioning it as an "all-ceramic" material within the realm of dentistry. Furthermore, zirconia occurs in three phases: monoclinic (m), cubic (c), and tetragonal (t). In pure ZrO_2 the monoclinic phase is stable up to 1170°C; but the transformation on cooling appear 100°C below 1170°C (6).

Lughi and Sergo in 2010, found that zirconia may remain stable at room temperatures by alloying it with other cubic oxides, called stabilizers. Until now the most used stabilizers to apply biomaterials are CaO, MgO, Y_2O_3 and CeO_2, but only ZrO_2-Y_2O_3 has a self ISO standard for surgical use (7).

The most important components of esthetic tooth appearance are: color, fluorescence, opalescence and translucency. One major drawback of full contour zirconia restorations is their opacity (8)

Zirconium is utilized for bridges in both the anterior and posterior regions, and it is even employed in full-arch rehabilitations involving implants or natural teeth (9)

Additionally, size, form, connector position, and span length are among the factors that affect fracture resistance in ceramic FPD. The law of beams, which states that a beam's deflection rises as a cube of its length, serves as the basis for properly designing connectors and pontics. It is inversely proportional to both the cube of its height and its width. The connector areas have the greatest impact on the failure of all structural components (5)

Furthermore, a faulty connector's 3D design could result in an early failure. In cases where short clinical crowns were present, connectors were designed to fulfill esthetic and functional demands. However, thin and short connectors showed failure at junctions between the abutment wall and the connector (4).

According to previous studies, the connector area is the weakest part of three-units posterior all-ceramic FPDs (10–12). This is because the height of the occlusal loads is higher in the posterior area. In three-unit FPDs, the connector areas reflect stress concentrations due to the complicated architecture of an FPD, which has multiple concavities and convexities depending on the teeth restored and their alignment (13,14)

To solve this issue, Manufacturers recommended 4mm BL x 4mm OG connectors size, which were aesthetically unpleasant and could lead to papillary recession. Lab technicians started following the manufacturer's recommendations for thickening the connector area to prevent fracture. This limited the uses of ceramic restoration to particular areas and patients (15).

Failure of the connector to withstand forces acting upon it is another problem with ceramic-fixed dental prostheses (16). Researchers tested various connector geometries (elliptical and circular) to increase fracture resistance in the connector area. Previous tests showed that elliptical cross-sections had higher fracture resistance than circular cross-sections, however, the connector area of the ceramic material had lower fracture resistance (17,18)

Finish line thickness varies from one restoration type to another. To create enough space for a bilayer ceramic restoration, the abutment preparation for receiving a ceramic fixed dental prosthesis may range from 0.5 to 1.5 mm. Finish line preparation can be as thin as 0.4 mm for teeth receiving zirconia crowns because of the material's exceptional strength (18)

The purpose of this study is to evaluate in vitro the effect of selective wall thickening on connector fracture resistance in zirconia-fixed dental prostheses.

The null hypothesis was that there would be no statistically significant difference between tested groups.

MATERIALS AND METHODS

In this in-vitro experimental study, the sample size was calculated to be 7 samples in each group according to a previous study (19), assuming a type-on error of 5% and a power of 80%.

Maxillary artificial model was used (Frasaco Dentoform, Dental Solutions German Manufacturers, Germany) to prepare three-unit FPDs covering the left 2nd premolar (missing),1st premolar, and 1st molar as abutments. Preparations were done according to a silicone index to control the cutting depth occlusally and axially, with a 0.4 mm chamfer finish line thickness and 1.5 mm occlusal reduction. And a taper of 6° axially.

Blue grit round taper diamond size 12 was used for teeth preparations, and red grit round taper diamond size 12 was used for finishing.

Confirmation of all preparations criteria, parallelism, and path of insertion checked virtually after scanning in a 3D scanner using (lab scanner, 3Shape EOS, Copenhagen,Denmark)

For standardization of tooth preparations, only one model was used starting from 0.4 mm all around and scanned to verify the wall thickness. Then the axial finish lines (distal of premolar and mesial of molar) were increased subsequently to 0.8, 1, and 1.2 mm and verified every time by scanning the model and measuring the finish line thickness using an EXOCAD software (3Shape EOS, Copenhagen, Denmark)

The four digital models were printed 7 times each (n = 28) with epoxy resin using the reference STL (Standard Tessellation Language) file by SLA technique (fig.1 & 2.)

Four different 3D printed models were scanned, (one model of each group) with an industrial desktop 3D scanner (3Shape EOS, Copenhagen, Denmark). Pre-sintered Polycrystalline Ceramic (White Peaks Dental Solution GmbH &Co.KG -GERMANY) zirconia FPDs frameworks were designed using CAD technique with connector area adjusted to be 16mm2 (4×4 mm) (fig.3)

Adhesive resin cement TOTAL C-RAM (itena Clinical, Villepinte, France) was used for the cementation of the FPD frameworks on the models (fig.2). Static load device was used for seating the FPD framework on the model with a load of 5 Kg for up to 10 minutes to produce a uniform thickness of the cement (20,21). A thermal cycling regime was conducted to simulate intraoral temperature changes, corresponding to 6 months of clinical service with 600 thermal cycles (22)

Then all specimens were loaded till failure in a universal testing machine (YLe Gmbh Germany) using a 3 mm diameter metal sphere indenter loading on the center of the occlusal surface of the pontic with a cross head speed of 1mm/min.

The load was raised gradually until a sudden sharp decrease of the force, which indicates the failure of the specimens. The maximum load before the sharp decrease of force was recognized as "failure load", and was determined for each specimen in Newton (fig. 4)

failure mode was determined subjectively by checking the fracture line location and propagation.

STATISTICAL 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 normal (parametric) distribution. Data were presented as mean and standard deviation (SD) values. One-way ANOVA test was used to compare the four groups. Tukey's 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. Mode of failure of all models was assessed visually, and Fisher's Exact Test was performed.

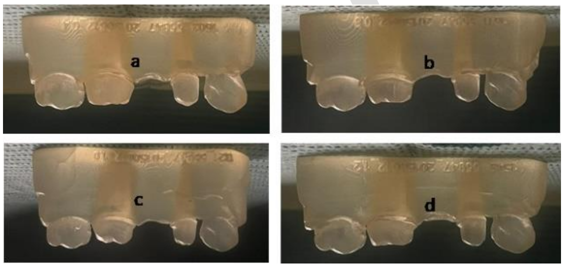

Figure 1: 3D printed epoxy resin models with different proximal finish line thickness (a: 0.4mm; b:0.8mm; c: 1mm; d:1.2 mm).

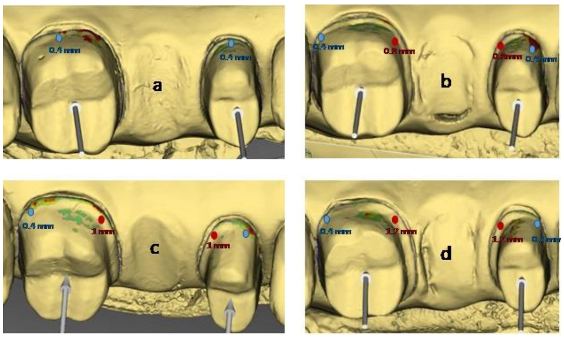

Figure 2: showing finish line thickness scan on 4 different groups (a: 0.4mm; b:0.8mm; c: 1mm; d:1.2 mm).

Figure 3: Milled Zirconia Framework.

Figure 4: Custom-made jig with the specimen during testing.

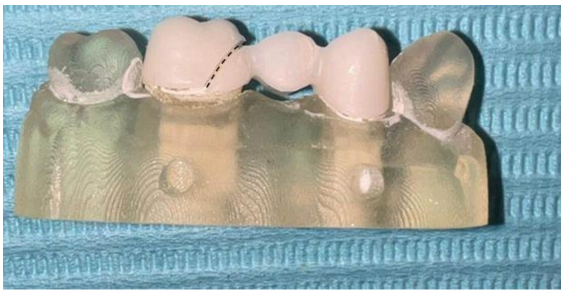

Figure 5: Group I (1 specimen) showing the buccal crack extension.

Figure 6: Group II palatal view showing the oblique distal crack.

Figure 7: Group IV palatal view showing mesio-palatal crack on molar.

RESULTS

The data passed the Shapiro-Wilk and Kolmogorov-Smirnov normality tests with P values greater than 0.05 for all groups; revealing that the data were normally distributed (table 1)

The mean value of fracture resistance in Newton (N) and One-way ANOVA revealed that there was a statistically significant difference between the four groups that were represented by P <0.001 (table 2)

There was a statistically significant difference between the mean fracture resistance values of the four groups (P-value <0.001, Effect size = 0.809). Pairwise comparisons between the groups using Tukey's test revealed that group IV recorded the highest fracture resistance with a statistically significant difference from all other groups (table 3). On the other hand, there was no statistically significant difference between groups I, II, and III; whereas all showed statistically significant lower mean values compared to group IV (fig.8)

Failure Mode Analysis

Fisher's exact test showed a statistically significant difference between the groups. Group III was the only group that had pontic fracture, Group I was the only group that had buccal extended fracture (fig.5) while Group II was the only group that had premolar fracture (fig.6). Groups II and IV showed the highest prevalence of palatal extended fracture. Groups I and III (fig.7) showed the highest prevalence of molar fracture (table 4).

Table 1: One-way ANOVA

Groups	Mean (N)	SD	*P*-value	Effect size(*Eta squared*)
Group I	511.8^{B}	108.7	<0.001*	0.809
Group II	702.3^{B}	139.9		
Group III	789.4^{B}	212.1		
Group IV	1191.9^{A}	263.8		

*: *Significant at P ≤ 0.05, Different superscripts are statistically significantly different*

Table 2: Results of Tukey's test (Pair-wise comparisons)

Tukey's test	Mean1	Mean2	P-value
0.4mm vs 0.8 mm	511.8	702.3	0.314
0.4mm vs 1 mm	511.8	789.4	0.074
0.4mm vs 1.2mm	511.8	1191.9	<0.001*
0.8 mm vs 1 mm	702.3	789.4	0.834
0.8mm vs 1.2 mm	702.3	1191.9	<0.001*
1mm vs 1.2mm	789.4	1191.91	<0.004*

*: *Significant at P ≤ 0.05*

Table 3: Percentage of failures based on fracture location and extension.

	Pontic fracture	Buccal extended fracture	Palatal extended fracture	Premolar fracture (wall adjacent to pontic)	Molar fracture (wall adjacent to pontic)
Group I	0	1	6	0	7
Group II	0	0	7	7	0
Group III	1	0	6	0	6
Group IV	0	0	7	0	7
P-value	<0.001*				

*: *Significant at P ≤ 0.05*

DISCUSSION

The present study investigated the effect of widening the connector toward the abutment tooth by increasing the depth of the finish line proximally (distal of premolar and mesial of molar) on the fracture resistance of the zirconia FPD framework. According to the results, changes in the size (surface area) of zirconia FPDs altered fracture resistance; therefore, the study's null hypothesis was rejected.

For standardization in this study, resin 3D printed models were used instead of natural teeth because human teeth as abutments add a new variable due to the different dimensions of teeth which may cause variability in fracture load results, possibly (23)

In the present study, attempts were made to simulate clinical conditions. Instead of the bar-like specimens used in previous studies (24,25), which had no relation to a fixed partial denture, the models for this study were created as three-unit FPD frameworks. Additionally, the resin was used as the specimen's supporting structure because it has an elastic modulus of 16.5 MPa, which is comparable to that of trabecular bone (26) and falls between the elastic modulus of cancellous bone and dentin (27)

Confirmation of all preparation criteria, finish line thickness, parallel walls, and path of insertion was checked virtually after scanning in a 3D optical scanner using (3Shape EOS) CAD/CAM software.

Tooth preparation design with 0.4 mm chamfer finish line thickness was done by Bahat et al, (2009) (18), who stated that teeth receiving zirconia crowns could have a conservative finish line thickness due to its exceptional strength, a total taper of 6 degrees, 1.5 mm occlusal reduction and smooth, rounded transitions from the axial to the occlusal surfaces was done, as it is recommended that an occlusal reduction of 1.5-2 mm and an occlusal angle of convergence not greater than 10 degrees be employed (10,28,29)

In this study, connector dimensions of 4x4 mm were used (30). As the maximum strain in FPDs is in the connector area .

To eliminate the impact of the veneering process on the flexural strength, whether pressed, layered or CAD/CAM, the Y-TZP-based framework was used without the addition of a porcelain veneer because the veneer layer could not be standardized (24)

Because the premolar's occlusal surface is smaller than the molar's, the contact of teeth with opposing teeth is an area rather than a point (0.5-3 mm in diameter), and failure mechanisms are influenced by the contact area and load applied, a small-diameter 3 mm steel ball was used in the present study to develop as clinically relevant an occlusal contact as possible (31)

Based on the results of the present study, zirconia FPD's capability to withstand loads is adversely affected by increasing the connector surface area of the framework (by widening the proximal finish line on retainers). On comparing the mean values of all the groups, group IV had the highest fracture resistance (1189,9 N), whereas group I had the lowest (511,8 N). The findings support earlier research on zirconia and other ceramic core materials (24,32–34)

The fracture resistance of an FPD framework should be high enough to bear the patient’s maximum bite force, which depends on the patient’s age, gender, dental status, and the like (18,35). The value varies from 216 to 847 in the posterior region (30), while the load-bearing threshold should be at least 500 N for posterior FPDs (32). Considering the repeated occlusal forces applied to FPDs in clinical conditions, fatigue fracture can play a major role in restoration survival. Since ceramics have an endurance limit of 40%–50% of their optimal strength, it is recommended that their fracture resistance be >1000 N for optimal clinical performance as a posterior FPD (27,30)

In groups I and II, the lowest fracture resistance was recorded (511.8; 702.3), indicating a potential for failure in the intraoral environment and under repetitive forces. Therefore, it is recommended that a finish line thickness > 1.2 mm be used with more caution despite the manufacturer's recommendations regarding the minimum thickness required for a zirconia restoration, whether a single crown or an FPD.

A statistically significant difference was reported between group IV and all other groups (I; II and III). These results can help the clinician choose a finish line of 1.2 mm thickness to enhance the restoration’s fracture resistance and clinical performance to an acceptable value.

In the present study, cracks propagated obliquely from the palatal wall of the retainer (molar) through the mesiobuccal surface in a perpendicular pattern without including the connector except for one specimen belonging to group I, at which the crack was propagated from the buccal surface towards the mesio- palatal surface. And another specimen in group III, where the crack propagated obliquely through the gingival embrasure to the buccal cusp tip of the pontic including connector fracture. This can be explained by the axial load created on the pontic which in turn generated initial compressive stress on the mesial occlusal embrasure of molar and tensile stress on the distal surface that caused a complete fracture of the mesial wall of molar.

Mode of failure in all groups revealed that specimens demonstrated a typical tensile or brittle fracture pattern.

Zirconia and ceramics are strong under compressive strain, however, they are brittle under tensile stress, according to Quinn (2007) (36). This results in typical fracture patterns, and further observation of these fractured surfaces gives rich information on the origin and direction of the fracture.

The fracture surface was smooth and the failure origin was more difficult to detect. (Oh and Anusavice (34) and Sundh et al. (37) reported results similar to those of this study. The greatest incidence of fractures was observed on the molar side.

The palatal propagation of the fracture line is maybe due to the difference in zirconia thickness between the mesial wall of the molar, which is thicker due to the widening of the finish line in that area.

Analysis of the fracture site revealed that the most of fractures recorded are at the distal connector of the frameworks in 3 groups (90.4%). Thus there was a tendency for fracture to occur at the distal connector including the mesial wall of 1st molar. This result is consistent with that of Tsumita et al., who attributed this tendency to the structural feature that the distance between the center of the distal abutment (molar) and the middle of the pontic is greater than the distance between the center of the mesial abutment (premolar) and the middle of the pontic(38)

Distal failure started from the margin of the retainer crossing obliquely through the junction between the connector and the mesial wall of molar, which might be due to the thin retainer's margin (0.4 mm thick). This mode of failure was in agreement with the results of Bömicke et al. (39) and Partiyan et al. (40). In their studies, the axial wall margin thickness of the retainer was 0.5 mm. The fracture also propagated from the thin margin of the retainer but towards the occlusal loading point. In this study, only one sample in Group III had a pontic fracture.

CONCLUSION

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

1. The fracture resistance of three- unit Zirconia FPD framework was affected by modification of the finish line thickness adjacent to the connector.
2. Using a finish line as thin as 0.4 mm could drastically weaken the fracture resistance of the Zirconia FPD framework.
3. A finish line of 1-1.2 mm is recommended when planning a 3-unit Zirconia FPD framework in the posterior region.

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