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Effect of different connector designs on the fracture resistance of zirconia all-ceramic fixed partial dentures: In Vitro Study

Mai Hesham Abdelrahman [1,*], Ahmed Wagdy Hashim [2], Mahitab Mohamed Mansour [3], Faisal Safwat Hamza [4]

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Abstract

Background: This study aimed to evaluate and compare the fracture resistance of the zirconia frameworks with two different connector designs; concave gingival margin and convex gingival margins.

Methods: Epoxy resin second premolar and second molar duplicated from acrylic cast "el banna" were mounted in an acrylic resin base and prepared to receive full coverage zirconia restoration. A total of thirty six all-ceramic three-unit fixed partial dentures (FPDs) were fabricated using CAD/CAM technology, then they were divided in to two groups according the connector designs (concave and convex gingival margins) n=18. Framework trial fittings were conducted on the epoxy dies. Glass ionomer cement was employed for the cementation of all restorations. All samples were subjected to fracture resistance test. Results: notable difference in mean maximum load between the two connection types, with the convex connection type exhibiting a substantially higher mean load than the concave connection type.

Results: The fracture resistance values for the tested groups indicated that monolithic zirconia fixed partial dentures can withstand masticatory forces in the molar region, despite variations in connector design.

Conclusion: The fracture resistance of the full contoured monolithic zirconia is affected by the connector design.

* **Corresponding author**.

E-mail address: mhesham@msa.edu.eg

1 *Associate Professor of Dental biomaterials, Faculty of Dentistry, October University for Modern Sciences and Arts, Egypt.*

2 *Lecturer of Fixed Prosthodontics, Faculty of Dentistry, October University for Modern Sciences and Arts, Egypt.*

3 *Lecturer of Dental biomaterials, Faculty of Dentistry, October University for Modern Sciences and Arts, Egypt.*

4 *Lecturer of Fixed Prosthodontics, Faculty of Dentistry, October University for Modern Sciences and Arts, Egypt.*

1 Introduction

Improvements in mechanical characteristics combined with the production of new ceramic materials contributed in the widespread embracing of restorations free of metal. [1] The integration of yttrium-stabilized zirconia in the dental field has led to the expansion in its applications and design potentials. [2]

Zirconia displays exceptional mechanical characteristics, comprising high fracture strength and toughness, which can be accredited to its transformation toughening mechanism. [3] Moreover, zirconia is considered to exhibit higher biocompatibility than other materials such as ceramics, titanium, and metal alloys, enabling a positive soft tissues response. [3]

Numerous clinical studies have proven that zirconia retains adequate strength to function as a material used for abutments, proposing aesthetics and longevity equivalent to abutments fabricated from titanium. [1-3] Its outstanding characteristics have directed the clinicians to use it for fabrication of frameworks of posterior fixed partial dentures (FPDs). [3,4] Restorations fabricated from monolithic zirconia are regarded as an effective treatment choice, providing a number of benefits such as accurate fit with reduced need for occlusal amendments, besides being durable without the threat of porcelain veneer fracture, combined with satisfaction of the patients' concerns both functionally and aesthetically. [5] Furthermore, zirconia restorations that do not necessitate ceramic veneering provide restorations with exact margins. [5]

From the mechanical aspects, zirconia is categorized as a brittle material where its thickness plays a pivotal role in its fracture [2], pointing out that its design is of a major concern. Accordingly, the restorations design is considered a vital cause with a great influence on the fracture resistance of fixed partial dentures (FPDs). [1] Studies indicated that the most vulnerable area of FPDs is the connector region linking the pontic and the retainer. [1, 2] Thus, design mistakes, as inaccurate dimensions of the connector and insufficient axial walls reduction, are the prime contributors to these failures. [1,2]

Given the significance of connection design concerning the curvature of the gingival and occlusal embrasures, it was projected that the connector design is another key influence prompting the success of the framework. [2]

For augmenting the success of zirconia restorations, alterations in the framework design have been proposed for reinforcing the connection area, either in a direct or indirect ways. [2]

As a result, the current study was designed to evaluate and compare the fracture resistance of the zirconia FDPs with two different connector designs (concave and convex gingival margins).

The study's null hypothesis identified that connector design does not have an influence on the fracture resistance of monolithic zirconia FDPs.

2 Materials and Methods

2.1 Sample size calculation

To assess the impact of the connector size and design on the fracture resistance, Mann Whitney U test or independent t test was utilized for comparing the two groups. Rendering to a preceding study by Hafezeqoran *et al.* (2020) [6] the failure load in 12 mm two sized connectors varied between 1599.8±167.09 and 1440±159.05 for round and sharp connectors.

Depending on Hafezeqoran et al (2020) [6] and Using G power statistical power Analysis program (version 3.1.9.4) for sample size detection [7], A total sample size (n=36; partitioned to 18 in each group) was adequate to notice a large effect size (d) = 0.97, with an actual power (1-β error) of 0.8 (80%) and a significance level (α error) 0.05 (5%) for two-sided hypothesis test.

Table 1. Sample size calculation

	Effect size	**α error**	**Power (1-β error)**	**Calculated Total sample size**	**Calculated Sample size per group**
Size 12mm²	0.97	0.05	0.80	36	18

2.2 Samples preparation

Epoxy resin lower second premolar and lower second molar duplicated from acrylic cast "el banna". The second premolar and second molar were embedded in a base made of acrylic resin and adjusted to be restored by a full coverage zirconia restoration. A 1.5 mm thickness heavy chamfer finish line, 18 tapered axial walls, 1.8 mm occlusal reduction, and rounded axial lines. Prepared teeth were digitally scanned and epoxy duplicates were fabricated and digitally scanned

2.3 Grouping of samples:

A total of thirty six all-ceramic three-unit FPDs were fabricated using CAD/CAM technology , then divided into two groups (n=18) according the connector designs (concave and convex gingival margins).

One model was scanned by trios 4 3-shape and one design for each group designed by Exo Cad Version Elsefina was made, then milled by translucent zirconia, dimension of the connector design was 12 mm.

Group 1: convex connection

Group 2: concave connection

Following the sintering (Sirona HTC furnance) of the specimens, individual framework trial fittings were conducted on the epoxy dies. Restorations were cemented by glass ionomer cement (Medifil Promedica GmBh), using cementing device loaded by customized weights for applying a consistent load of 1.5 kg. All samples were then maintained in distilled water at room temperature for a period of 72 hours.

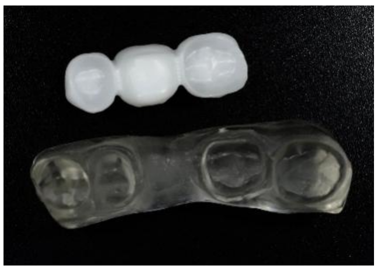

Figure 1. FPD

2.4 Fracture resistance testing

Each specimen was steadily fixed in the universal testing machine (Instron, model 3345, England) using a load cell of 5 KN, data were recorded using a computer software (Bluehill 3, v. 3.3). Fracture testing was completed by applying compressive load occlusally at the central fossa of the pontic, which was selected by following the standard anatomy of the lower molar, load was applied using a metallic rod having a spherical tip (5.6 mm diameter) attached to the upper mobile section of the testing machine roving at cross-head speed of 1 mm/min, tin foil sheet was placed in-between to attain uniform stress spreading and to minimize the transmission of local force peaks. The load at failure was expressed by an audible crack and was definite by a sharp drop at load-deflection curve documented using computer software (Bluehill Lite Software Instron Instruments). The load necessary for fracturing was recorded in Newton. [2,3]

Figure 2. Fracture resistance testing

2.5 Statistical Analysis

Statistical analysis was done using a commercially available software program (SPSS Chicago, IL, USA). Numerical data was designated as mean and standard deviation or as median and range as appropriate according to the normality of the data. Data was compared by Mann Whitney U test or independent t test depending on normality. The level of significance was set at P≤0.05. All tests were two tailed.

3 Results

In this study, the aim was to assess the influence of dissimilar connector designs concave and convex on fracture resistance. Shapiro-Wilk test (Shapiro and Wilk, 1965) was used to assess normality of the outcome and Levene test in car R package (Fox and Stanford, 2019) to check for homoscedasticity. Hence, independent sample t-test was utilized to compare the two independent groups as shown in **Table 2**.

Table 2. Summary Statistics for Maximum Load by Connection Type

Connection type		Mean	Standard deviation
1	Convex connection	3032.47	203.63
2	Concave connection	1914.99	198.12

The mean maximum load for the convex connector design was recorded as follows (3032.47±203.63), indicating some variability in load capacity. In contrast, the concave connector design type had a mean maximum load of (1914.99 ±198.12), reflecting similar variability within this group

Comparison and Interpretation

The summary statistics showed a notable significant difference in mean maximum load between the two connection types, with the convex connection type exhibiting a substantially higher mean load than the concave connection type. The relatively close standard deviations suggest that, while both connection types displayed similar levels of variability, the convex connection consistently supports a higher load on average

Table 3. Results of the independent sample T-test

Independent T-Test Results: Maximum Load by Connection Type	
Statistic	**Value**
t-statistic	11.125
Degrees of freedom	14
p-value	<0.001
Mean (Convex connection)	3,032.47
Mean (Concave connection)	1,914.99
Mean difference	1,117.48
95% CI Lower Bound	902.04
95% CI Upper Bound	1,332.92

An independent samples t-test was conducted to compare the mean maximum load between the two connection types: **Convex** and **Concave.**

- **Test Results**: The t-test revealed a significant difference in maximum load between the convex and concave connection types, with a t (14) = 11.125, p < .001.
- **Means and Confidence Interval**: The mean maximum load for the convex connection group was 3032.47, while the concave connection group had a mean of 1914.99. The 95% confidence interval for the difference in means was [902.04, 1332.92], indicating that the convex connection type generally had a higher maximum load than the concave connection.

Since the p-value is less than 0.05, we conclude that specifically, the convex connection type has a significantly higher maximum load than the concave connection.

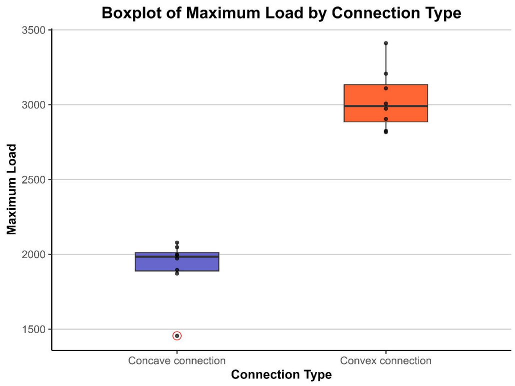

Figure 3. Maximum load by connection type

4 Discussion

The growing importance of aesthetics had led dentists to utilize all-ceramic prostheses for replacing lost tooth structure, combined with the stand out of zirconia as one of the most durable aesthetic materials on the market. [6] All-Ceramic Fixed Partial Dentures (FPDs) compromise superior aesthetics and exceptional biocompatibility when in contrast to other materials, although, their capacity for bearing loads is limited. [8]

In the current study, monolithic zirconia FPDs were utilized with reference to their considerably enhanced resistance to fracture, improved resistance to chipping, as well as superior flexural fracture properties in contrast to veneered substitutes. Zirconia based ceramic monolithics demonstrate higher failure resistance compared to lithium disilicate glass ceramics in terms of chipping and radial cracking. [9]

Monolithic zirconia fixed dental prostheses (FDPs) were fabricated without a porcelain veneer preventing any possible impact on standardization besides excluding the risk of chipping failures frequently accompanying zirconia-based ceramic-layered restorations. To ensure that only the connector's design of the all-ceramic restoration was the only variable, a Cercon CAD/CAM machine had been utilized for creating duplicate FDPs, in external and internal dimensions. This methodology permitted a precise fit over the resin models replicating the missing mandibular teeth. [8]

Besides the material itself, the shape, position and size of the connector have a great impact on the fracture resistance of the fixed partial denture (FPD). The most common region of the prosthesis fractures take place close or at the connector site, as this part is the most susceptible zone in all-ceramic FDPs, where most clinical failures are witnessed. [10,11]

It has been pointed out that the cross-sectional area of the connector should be exceeding 6.9 mm² for sustaining a maximum occlusal force surpassing 880 N, thus they can withstand forces produced by certain parafunctional behaviors.[12]

Standardizing the size of connectors poses significant challenges, complicating the testing of their biomechanical performance in relation to dimensions within clinical studies. Consequently, this study standardized the 3-unit fixed dental prosthesis (FDP) design with connector dimensions of 12 mm², in alignment with Hafezeqoran *et al.* (2020). [6] Moreover, two connector designs—concave and convex—were created.

The current study inspected the influence of connector design on the resistance to fracture of monolithic zirconia FDPs. Based on the results, variations in the connector design impacted the fracture resistance; as a result, the study's null hypostasis was rejected.

In this study, resin models were utilized because their modulus of elasticity, Poisson's ratio and flexural strength values are more comparable to those of dentin, which is approximately 20 GPa. [8, 9]

Results of the present study had shown a significant difference in mean Fracture resistance between the two connection types, with the convex connection type exhibiting a substantially higher mean load than the concave connection type. This was in accordance with Lotfy *et al.* in 2024 [10], they noted that the design of the framework in ceramic FDP, especially the pontic connector interface, plays a crucial role in how stress is distributed throughout the zirconia framework.

Furthermore, enhancing the dimensions of the connector will result in improved fracture resistance results. Once occlusal forces are exerted directly along the long axis of a ceramic fixed partial denture (FPD) compressive stresses of the connector, are generated on the occlusal side, though tensile stresses occur on the gingival aspect. These stresses can promote the spread of micro cracks at the gingival side, ultimately resulting in fractures. By increasing the connector's dimensions, this adverse effect may be reduced. [8]

Furthermore, Azmin *et al.* (2023) [11], supported the findings of the present study by noting that zirconia's weakness under tensile stress results in micro cracks propagation at the gingival aspect of the connector, spreading throughout the core material occlusaly and ultimately resulting in failure. Since the connector is the least section of a fixed partial denture (FPD), it experiences concentrated forces that can result in fracture. Consequently, the FPD connectors dimensions need to be sufficiently with appropriate dimensions to mitigate stress concentrations in the framework while still being small enough to facilitate proper hygiene and maintain aesthetics.

Finally, future research should integrate thermo-mechanical loading and more precisely simulate the oral environment.

Limitations of the study

- Only one type of restoration was studied, namely monolithic zirconia.
- The absence of occlusion force, magnitude, and nature.

5 Conclusion

Within the limitations of the present study:

1. The fracture resistance values of monolithic zirconia FPDs can withstand masticatory forces in the molar region, despite variations in connector design.

2. The use of a convex connector design in full-contoured monolithic zirconia FPDs demonstrates significantly higher fracture resistance values than the concave design..

Authors' Contributions

Ahmed wagdy, Faisal Safwat, Mahitab Mansour and Mai Hesham managed the methodology, review, editing, and supervision. Ahmed Wagdy managed the digital design part and Mai Hesham managed the resources and manuscript. All authors have read and approved the manuscript.

Conflict of interest

The authors declare that they hold no competing interests.

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