


Fracture load resistance of pontic with different connector designs: three-unit implant-supported fixed partial denture

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Aim: This in-vitro study aims to assess the fracture load resistance of the central pontic of two implant-supported zirconia fixed partial dentures (FPDs) using five alternative connector designs. **Methods:** The CAD/CAM production technique was used to mill the FPD of a three-unit zirconia prosthesis (from the mandibular second premolar to the second molar) (DDS, 3D White Zirconia). The STL file was generated for two implant-supported 3-unit bridges. The zirconia fixed partial substructure was designed with five types of connector designs. The pontic is connected to an implant-supported bridge with round, square, rectangular, triangular, and reverse-triangular shape connectors. This study was designed for a cementless-retained implant-supported fixed partial denture (FPD) of 50µm interface gap. The fracture resistance of a pontic of a 3-unit zirconia FPD was assessed under a crosshead speed of 1mm/min using an Instron universal machine. The study data were statistically analyzed using the ANOVA (post hoc Games-Howell) test with a significant interval of ($P \leq 0.05$). **Results:** The highest fracture resistance was using the reverse-triangular design, and the lowest fracture resistance was using the triangular connector design with a significant mean difference of ($P = .003$). **Conclusions:** It seems that the reverse-triangular connector design for implant-supported zirconia fixed partial substructure.

Keywords: Zirconium. Denture design. Materials testing. Dental implants. Denture, partial, fixed.



Introduction

Ceramics with improved physical characteristics are being developed along with the material's intrinsic properties, such as biocompatibility and superior aesthetics¹. Public demand for metal-free prostheses has increased the popularity and acceptance of all-ceramic FDP over metal ceramics in the dentistry community². Among ceramic materials, zirconia polycrystal (3Y-TZP) has a high fracture resistance and flexural strength (800-1500MPa), with 5-year (90.4%) and 10-year (91.3%) survival rates, it has become the material of choice for all-ceramic dental prosthesis, particularly in posterior regions³. Regardless of mechanical qualities, zirconia ceramics are typically opaque and might need veneer coating by glass ceramics to match the natural teeth. Newly developed Monolithic transparent zir has shown encouraging results with a high survival rate. Thus, this material is recommended for applications requiring strength and aesthetics. It has improved characteristics significantly, encouraging dentists to apply this material, particularly when a cautious approach is necessary. A few short-term studies on Zir restorations revealed excellent results, notably for implant-supported single crowns and FDPs⁴.

Dental implants seem to be a reliable treatment option for partial or complete restorations to help overcome some limitations associated with prosthetic alternatives. It has become the primary way of replacing lost teeth in partial or entire edentulous areas⁵. A meta-data analysis found that zirconia-ceramic used for implant-supported prosthesis (FDPs) have a 93% 5-year survival rate⁶, as the material composition, dimension, geometry, and design may all have an impact on the prosthesis's longevity and fracture risk. All-ceramic implant support under masticatory pressures, FDP functions as a ceramic beam on stiff supports, gingival tension is created by compressing the occlusal surface of the pontic, and such forces are necessary for all-ceramic restorations. Given that fractures frequently might begin in the gingival embrasure and progress occlusally. The design of the connections is one of the most important factors in ensuring the success of the all-ceramic FDP^{7,8}. According to various studies, the sharper the connections, the higher the stress concentrations formed in the gingival embrasure, reducing the fracture resistance of three-unit FDPs⁹⁻¹².

Some studies investigated the long-term prognosis of implant-supported restorations^{13,14}. Bridge load-bearing capacity is widely recognised to be reliant on ceramic material qualities. However, the span of the pontics, size, form, and position of the connectors, fabrication technique, surface polish of the crowns, and luting method all have a significant impact¹⁵.

The cross-sectional shape of connectors had a significant impact on the mechanical fatigue performance of an implant-supported FPD made of zirconia. When compared to the usage of a circular connector, the use of an oval connector resulted in higher strains and a higher failure probability¹⁶. The fatigue failure load (FFL) values of the round and trapezoid designs were higher than those of the square connectors¹⁵.

In general, regardless of the ceramic system, the radii of curvature of the gingival embrasure at the connecting area may influence the fracture resistance of three-unit FPD on load applications. Depending on the clinical scenario, increasing radii of curvature at gingival embrasure at the connector region can increase the fracture resis-

tance of full-contour monolithic posterior three-unit zirconia FPD. When the load was applied in the middle of the pontic, the gingival embrasure in the connector region of the three-unit zirconia FPD reflected the tensile stress concentration zones. Both zirconia systems and connector designs show no substantial difference in stress distribution or displacement stress⁹.

A prosthesis's stress distribution can be fairly complex. Bridge pontics must meet cosmetic, mechanical, and functional, along with hygienic standards in prosthodontics. Pontic designs were precisely established for circumstances where pontics were required in the fabrication of FPDs. Design is more essential than substance selection for cleanability and tissue health¹⁷. The pontic design of implant-supported all-ceramic bridges can be altered to vary the usual stress pattern.

Metal-free all-ceramic fixed restorations like ceramics are becoming more popular due to their superior properties, such as esthetic¹⁸, mechanical^{19,20} and biocompatible²¹. One of the most popular material combinations for tooth restoration is all ceramic prostheses²². Rehabilitation using implant-supported prostheses, which is a reliable treatment with a high survival rate, is the most frequently suggested therapy in a posterior edentulous mandibular region²³. However, in cases of substantial bone loss, particularly in height, this physical restriction influences the therapeutic option. Lengthy-term biomechanical hazards should be taken into account when considering Implant-supported Prosthesis (ISP)-based rehabilitation as a potential substitute for long cantilevers or the use of portable partial prostheses^{24,25}. The clinical choice to use ISP is misunderstood because clinical and experimental investigations use a variety of approaches and lack consensus^{26,27}. Additionally, the ISP may raise stress at the pontic because of the connection effect caused by design. Therefore, before advising its use in clinical settings, it is essential to have a solid understanding of rehabilitative biomechanics. Treatment with implant-supported cantilever FDPs frequently follows the idea of the shorter dental arch, which is agreeable to the majority of patients. The pontic occlusal table should be as small as feasible to minimize the leverage effect, more closely resembling a premolar than a molar²⁸. To perform a stiff FPD, the pontic must have reached its maximal occlusogingival height²⁹.

Cement retention is commonly associated with occlusal integrity; however, ensuring that cement is removed completely from the subgingival area is difficult³⁰. During the fabrication process, a precise fit between the implant crown and the abutment takes place due to the flowable composite resin that relined the inner surface of the implant crown. To distribute pressures uniformly over the occlusal surface, cementless fixation (CLF) is a recessed structure on the abutment occlusal surface. As a result, CLF has been introduced as a revolutionary retentive form for implant prostheses with no cement- or screw-required retention. Few studies investigated the biomechanical elements of the CLF implant crown³¹. The best design for reducing stress distribution on the CLF implant restoration has yet to be determined. The purpose of this research is to determine how different framework connector designs affected the fracture load resistance of all-ceramic FPD. In a study by Lee et al. 2019, the CLF implants' air group was as stable as or better than the standard cementation implant technique. Filling the air hole with resin in the CLF implant air group made no meaningful impact on stability. In addition, the air hole status and kind of relining resin had no significant effect

on cancellous bone stability. As a result, there were no biomechanical disadvantages to employing the CLF system instead of the usual cement resin (CR) system³². Therefore, The hypothesis proposed that different connector forms may affect the fracture load resistance of cementless zirconia FPD of 3-unit restorations.

Materials and Methods

In this study, a three-unit zirconia bridge for right lower 2nd premolar-1st molar- 2nd molar replacement in a specific clinical case was created using a CAD/CAM system (dental DB ver. 3.0, Galway 2021)..

The five study designs were all variations on the same missing tooth, but with different connector cross-section forms of round (6mm diameter); square (6mm²); rectangular (3×2mm height and width respectively); triangular and reverse-triangular (6mm²) minimum area.

Specimen Design and Preparation

Two screw implants (easy implant, TA6V ELI F136, France) with a diameter of 3.75mm and a length of 11.5mm were used. Two abutments of 6.5mm in both length and diameter were modified for this study. The abutment was 5.8mm in length and 4(±0.02)mm in diameter for a mandibular right second premolar, while for the molar region, the abutment was 5.6mm in length and 6(±0.02)mm in diameter. Scanning images of edentulous posterior mandibular sites with alveolar bone loss are created with short dental implants supporting three-unit FDP. A 3D shape lab scanner was used to scan the model (R1000, Denmark), and five different three-unit restorations were designed (Figure 1).

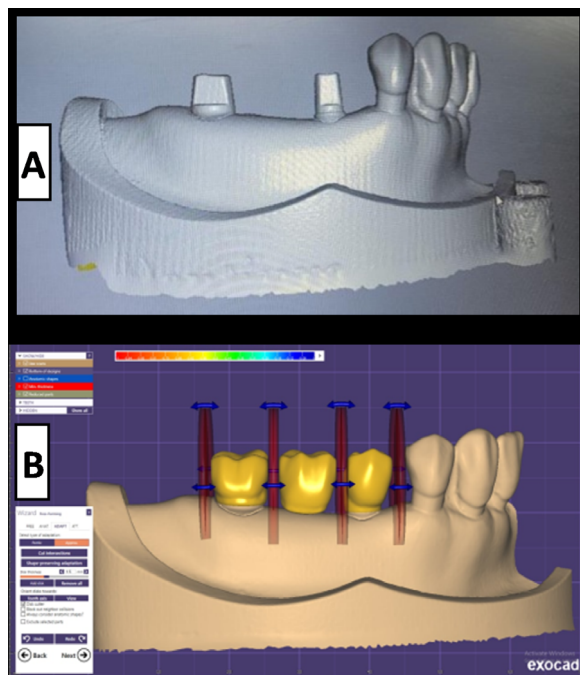


Figure 1. A, Scanned study model with two implant-supported abutments; and B, Mesial-distal dimension of the connectors for FPD

The cementless-retained design applied for biomechanical analysis of the prosthesis structure was designed with two crowns connected to one centred pontic with round, square, rectangular, triangular, and reverse-triangular shape connector design. The connectors were 6mm in dimension (Figure 2).

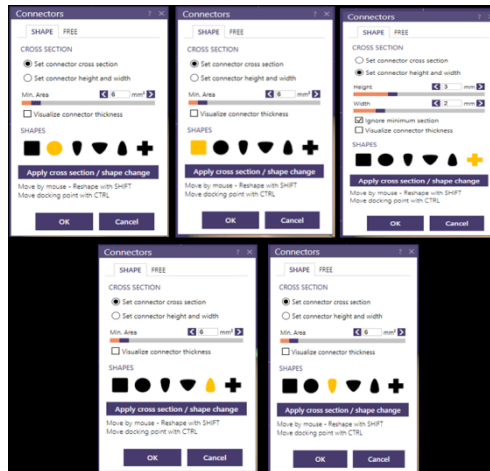


Figure 2. The five connector designs

The interface cement gap was 50µm, the minimum thickness of the framework was 0.5mm, and the border thickness was 0.2mm with a free-form margin without cement space.

The study model was fabricated by using the 3D printed DLP resin material (Asiga MAX™, SCHEU-DENTAL, Iserlohn, Germany). The FPDs zirconia prostheses (DDS 3D White Zirconia Blocks, Diamond Dental Supply, Canada) were milled using a CAM milling machine (X5-001, Dental Plus, South Korea), and the framework was sintered for 8h at 1600°C (zirconia sintering furnace, LD-B1700BT, China) (Figure 3).

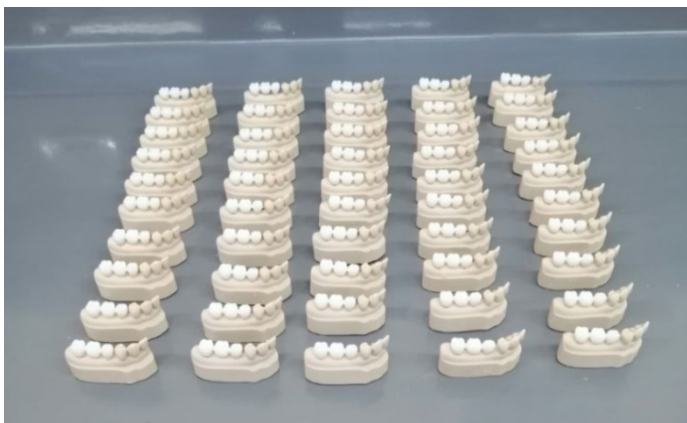


Figure 3. Zirconia FPDs of five connector designs

Fracture Resistance Testing Procedure

Each implant-supported zirconia framework specimen placed the uncemented model onto the abutments of the resin model. This study attempted to compare the fracture load of five distinct connector designs. Therefore, in this study, the central pontic of the implant-supported framework was analysed regarding cementless-retained restoration over ended abutments^{33,34}. According to this study pilot experiment, the three articulated spots on centric occlusion were located on the pontic occlusal surface. Over the three located points, the load was distributed in a vertical direction uniformly (central cross-section of the pontic) through a steel ball (8mm in diameter)^{35,36}. A universal testing machine was used to test the underload at a crosshead speed of 1mm/min with a maximum set load of 500N exerted on the occlusal surface of each pontic crown until the fracture^{34,37-39} (Figure 4). The maximal breaking load of each specimen was measured in Newton (N). To determine the statistical difference between the study groups of significant normality tests, the ANOVA (post hoc- Games-Howell) test was applied.

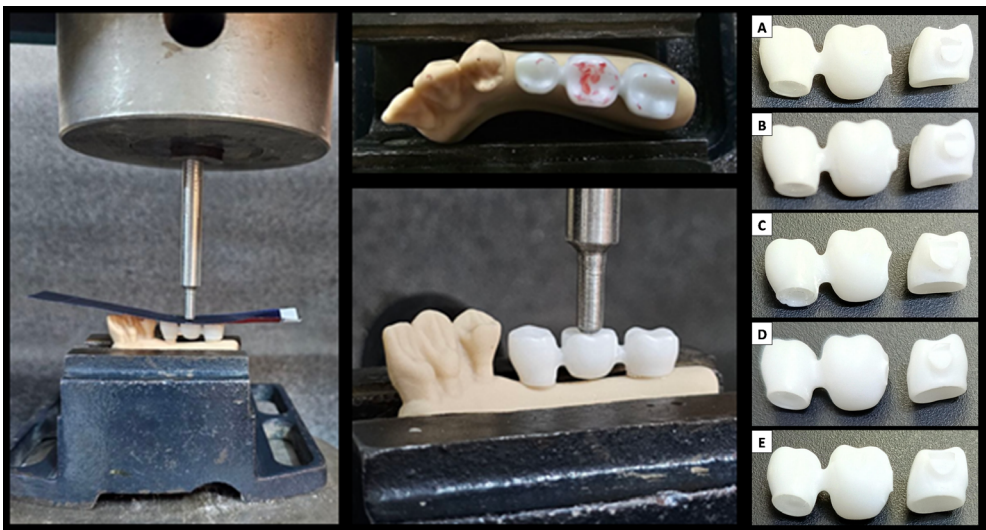


Figure 4. Zirconia FPDs under loads up to fracture (shaped connector designs: A, round; B, Square; C, Rectangular; D, Triangular; and E, Reverse-triangular)

Results

The findings of the study analysis of the central pontic implant-supported fixed partial denture performed to evaluate the load at fracture were presented in Table 1 and Figure 5.. Statistically, a non-significant difference in fracture resistance was noticed between all different connector designs ($P \geq 0.05$). However, a significant difference in fracture resistance was reported between that of round and triangular connector designs, reverse-triangular and rectangular, and that of reverse-triangular and triangular connector designs. Yet, the highest fracture load resistance was reported with the reverse-triangular connector design of $(1022 \pm 173)N$, and the lowest fracture load

resistance was with the triangular connector design of (740±67)N. Therefore, the reverse-triangular connector fracture starting point on the load-versus-chart-speed curve for zirconia implant-supported FPDs was determined by a significant loading curve (Figure 6).

Table 1. ANOVA (Games-Howell) test of the mean differences between the studied groups

FPD Connector Designs		Mean Difference	Standard Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Lower Bound
Round	Square	-8.5000	42.42019	1.000	NS	-146.8882	129.8882
	Rectangular	-77.0000	47.90442	.524	NS	-234.2342	80.2342
	Triangular	122.0000*	24.25215	.001	S	46.4453	197.5547
	Reverse-Triangular	-160.0000	55.96378	.098	NS	-344.8194	24.8194
Square	Rectangular	-68.5000	61.80278	.800	NS	-255.7082	118.7082
	Triangular	130.5000	45.96647	.084	NS	-13.3798	274.3798
	Reverse-Triangular	-151.5000	68.23998	.220	NS	-359.6210	56.6210
Rectangular	Triangular	199.0000*	51.07130	.014	S	37.4498	360.5502
	Reverse-Triangular	-83.0000	71.77782	.775	NS	-300.6420	134.6420
Triangular	Reverse-Triangular	-282.0000*	58.69744	.003	S	-469.9931	-94.0069

* = Significant

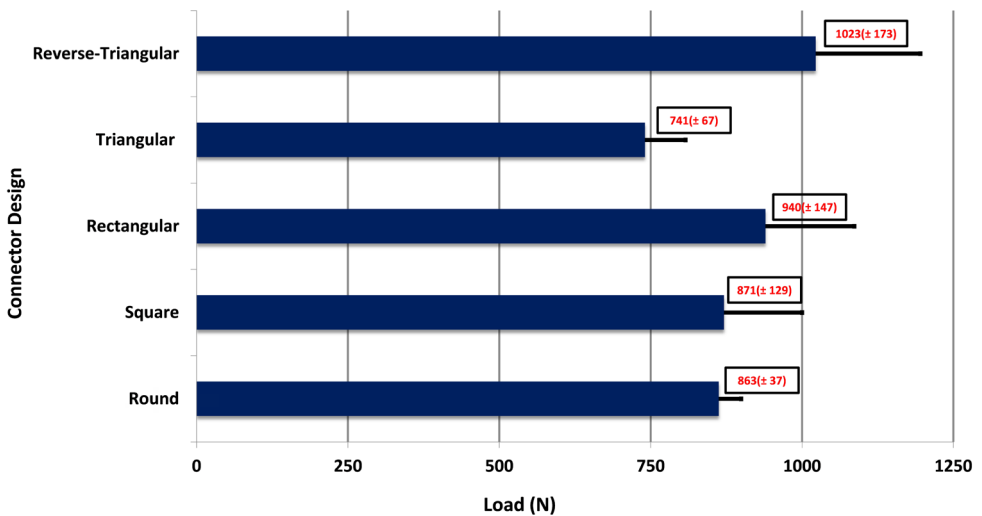


Figure 5. Bar-chart showing the fracture load at failure of FPDs of five different connector designs

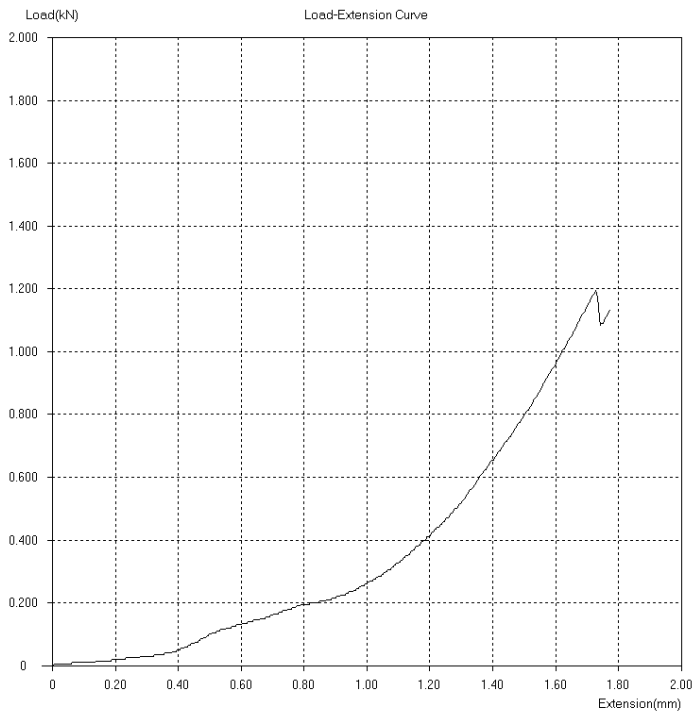


Figure 6. Load-strain diagram of FPD with reverse-triangular connector

Discussion

The objective of this study was to acquire a better knowledge of how to design an approach for parametric remodelling of FPD connector dimensions, as well as to investigate the effect of connector automated forms on fracture resistance inside a three-unit implant-supported FPD. Overall, the findings show that how a specific cross-sectional region is simulated has a significant impact on the final fracture resistance, depending on geometric details.

The form of the connector cross-section seems to influence the fracture load resistance of FPD. Experiment results revealed that the round, square, and triangular restorations failed at loads less than 900N, however, the rectangular and reverse-triangular cross-section connecting area frameworks failed at loads greater than 900N. A study by Almasi et al.¹⁶ showed that the 5mm diameter circular connector yielded lower stresses and failure probability than an oval connector, and Luft et al.¹⁵ stated that the round connectors presented higher fatigue failure load (FFL) values than the square one. Many studies suggested that sharper connectors may create higher stress concentrations, which reduce the fracture resistance of FDPs of three units⁹⁻¹². However, Luft et al.¹⁵, show a similar statement to the present study regarding that the trapezoid connectors presented higher fatigue failure load (FFL) values than the square one. Connector design and morphology are necessary for efficient load bearing, and stress concentrators like sharp edges should be avoided by creating rounded corners.

In the present study, the load seems more consistently distributed throughout the framework when using a reverse-triangular cross-section connector. This significantly lowers the loads concentrated in vital connector regions. In these specific circumstances, stress concentrations emerge where the roof meets the side wall of the restoration, considering simple support for the entire load taken by the framework. Given a normal loading during mastication, a two-caps supported bridge would meet mechanical criteria in this situation. Yet, under load, it appears that using a triangular connector of a 6mm² dimension was a poor choice.

The present study hypothesis has been validated by the outcome findings. Recent research suggests that the list of risk factors should be expanded to include material and FPD pontic design.

In this investigation, a reverse-triangular section was preferred, and using different connector cross-section form areas produced the best outcomes in what was deemed the worst loading-case scenario. Using the right restoration material and altering the framework design for strength, aesthetic, and functionality is still difficult to achieve. Y-TZP has good mechanical properties, and choosing an efficient design extends the operating life of the restoration. Recent research suggests that the list of risk factors should be expanded to include the connector designs, including prostheses under the thermocycling effect; therefore, additional research is advised.

Generally, the central pontic seems susceptible to high stresses, so it is recommended to avoid sharp connection connector region designs, particularly on the gingival side of the middle connector in a three-unit FPD. In addition to acceptable algorithms, a cost-effective automation approach is required to undertake a stress analysis of patient-specific FPDs.

Clinically, these findings support the use of alternative connectors in implant FPDs, especially when reducing micromotion is crucial to avoiding problems such as cementum damage and implant overload. These findings help to advance the creation of more effective and long-lasting dental prostheses, with the potential to improve patient outcomes in the setting of implant-supported restorations.

The current research has some limitations. The study models do not incorporate bonded material interfaces, which is a frequent simplification. However, this simplicity may result in the implant being less stiff and, hence providing less firm support. Furthermore, all of the material attributes used in this investigation were considered homogeneous. Another restriction is that the force was given directly to the pontic occlusal surface, resulting in simpler contact between the FPD and supported implants. The experimental and computational models utilized idealized vertical forces, whereas actual occlusal forces during mastication involve both axial and shear stresses. Although axial loading represents the majority of occlusal force during chewing. These simplifications were performed to lessen the study model's complexity. Nevertheless, the connector adjustment.

The purpose of this study was to determine the impact of a 3-unit FPD's connector cross-sectional area on subsequent automation stages. This goal was successfully met, increasing the level of automation in the field of dentistry. Automating the entire

FDP design process, including support, appears to be technically feasible with today's technology, but it remains a daunting issue.

Finally, this inquiry is simply the beginning of the complicated investigations that the authors aim to do in future years. When choosing the right connector design with implant-supported FPD, clinicians should consider the unique clinical circumstances and patient needs. The outcomes of this investigation validated the idea that the cross-sectional area of connections has a general effect on the fracture resistance of three-unit, implant-supported fixed partial dentures.

Within the limitations of this study and based on the data, this study investigates the effect of five different connector forms on the fracture load resistance of the central pontic of two implant-supported 3-unit FPDs. The following is a summary of the conclusions: 1) The fracture load resistance of the central pontic of two implant-supported 3-unit zirconia FPDs was reported with no difference after using automated round, square and rectangular connector designs; 2) The triangular connector should be avoided with two implant-supported 3-unit zirconia FPDs; 3) An automated reverse-triangular connector design recommended for the central pontic of two implant-supported zirconia fixed partial dentures.

Data availability

Datasets related to this article will be available upon request to the corresponding author.

Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Author Contribution

Enas Kareem Mohammed: The digital design and software data management. **Saja Ali Muhsin:** The academic writing and statistical analysis. **Ahmed Ali Mohammed:** The fabrication of zirconia fixed partial frameworks. **Khalid Bander:** The fabrication of implant-supported study solid model. All authors actively participated in discussing the manuscript's findings and have revised and approved the final version of the manuscript.

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