Keywords:
Zirconia; 3Y-TZP; 5Y-PSZ; Fixed Dental Prosthesis; Connector Design; Fracture resistance.

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Influence of Connector Dimensions on the Flexural strength of Three-Unit Monolithic Fixed Dental Prostheses Fabricated from 3Y-TZP and 5Y-PSZ Zirconia: An In Vitro Study

Abstract

Purpose: Connector dimensions are one the key determinants of Fracture resistance in zirconia fixed dental prostheses (FDPs). In this in vitro study the influence of three connector dimensions on the Fracture resistance of three-unit monolithic FDPs fabricated from 3Y-TZP and 5Y-PSZ zirconia is evaluated.

MATERIALS AND METHODS: Sixty-three-unit monolithic zirconia FDPs were fabricated and divided into six groups (n=10). Thirty specimens were fabricated from 3Y-TZP zirconia and thirty from 5Y-PSZ zirconia. Three connector dimensions were evaluated: 3×3 mm, 2×6 mm, and 4×2 mm. Following CAD/CAM fabrication, sintering, polishing, and glazing, specimens were subjected to compressive loading in a universal testing machine until fracture occurred. Fracture loads were recorded and analyzed using one-way ANOVA and independent t-tests ($\alpha=0.05$).

RESULTS: The highest fracture load was observed in 3Y-TZP FDPs with 3×3 mm connectors (2394.2 ± 250.45 N), followed by 4×2 mm connectors (2099.0 ± 79.98 N) and 2×6 mm connectors (1728.2 ± 204.05 N). For 5Y-PSZ FDPs, the highest fracture load was observed with 3×3 mm connectors (2098.8 ± 309.82 N), followed by 2×6 mm connectors (1676.2 ± 314.43 N) and 4×2 mm connectors (1332.4 ± 60.94 N). Significant differences were identified among connector dimensions within both zirconia groups.

CONCLUSIONS: Connector dimensions significantly influence Fracture resistance. The 3×3 mm connector configuration demonstrated the highest Fracture resistance in both zirconia systems. Although 5Y-PSZ exhibited lower Fracture resistance than 3Y-TZP, all fracture loads exceeded normal posterior masticatory forces, indicating potential clinical applicability.

Introduction

The increasing demand for metal-free restorations has led to widespread adoption of zirconia-based fixed dental prostheses (FDPs). Zirconia possesses excellent biocompatibility, high strength, fracture toughness, and favorable long-term clinical performance compared with other ceramic systems. Conventional 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) has become the benchmark material for posterior FDPs because of its transformation toughening mechanism and superior mechanical properties.1–6

The connector is the component that joins retainers and pontics within a fixed dental prosthesis and is considered the most critical region with respect to fracture initiation. Connector dimensions, shape, embrasure radius, and cross-sectional geometry significantly affect stress distribution and Fracture resistance .7–9 Several investigators have demonstrated that connector size is directly related to the survival and mechanical performance of all-ceramic FDPs.10–24

Previous studies have shown that increasing connector dimensions improves Fracture resistance, whereas unfavorable connector designs increase tensile stress concentration at the gingival embrasure.8,9,20–24 Finite element analyses have similarly demonstrated the importance of connector dimensions and geometry in reducing stress concentration within zirconia frameworks.16,18,21–23,26–32

The introduction of highly translucent zirconia has improved esthetics but raised concerns regarding mechanical performance. 5Y-PSZ zirconia contains a greater cubic phase content than conventional 3Y-TZP, resulting in improved translucency but reduced transformation toughening and Fracture resistance .41,47,50,54 Consequently, clinical evidence regarding the suitability of 5Y-PSZ for posterior FDPs remains limited.

Therefore, the purpose of this in vitro study was to compare the Fracture resistance of three-unit monolithic FDPs fabricated from 3Y-TZP and 5Y-PSZ zirconia with three different connector dimensions.

Null Hypothesis

Connector dimensions would not significantly influence the Fracture resistance of monolithic zirconia FDPs fabricated from either 3Y-TZP or 5Y-PSZ zirconia.

Materials And Methods

A stainless-steel master die representing a three-unit posterior FDP was fabricated (fig:1). Digital impressions were obtained using a laboratory scanner and restorations were designed using CAD software (fig 2,3,4,5,6).

The present investigation demonstrated that connector dimensions significantly influence the Fracture resistance of monolithic zirconia FDPs. Therefore, the null hypothesis was rejected.

The 3×3 mm connector demonstrated the highest Fracture resistance for both zirconia systems. These findings agree with previous investigations by Oh and Anusavice, Plengsombut et al., Bahat et al., and Onodera et al., who reported that connector geometry and cross-sectional dimensions strongly influence stress distribution and fracture behavior.8,9,20,24

Onodera et al. reported that connector configurations with a balanced 1:1 ratio demonstrated superior Fracture resistance compared with elongated connector designs.24 Similarly, Hamza et al. reported that rounded connectors with adequate dimensions significantly improved flexural performance.39

Finite element studies have consistently shown that increased connector dimensions reduce tensile stress concentration within the connector region.16,21–23,26–32 Reimann et al. demonstrated that reducing connector cross-sectional area increased stress levels within zirconia frameworks, supporting the present findings.40

The greater Fracture resistance of 3Y-TZP observed in the present study is consistent with its predominantly tetragonal microstructure and transformation toughening mechanism.49,51 In contrast, 5Y-PSZ contains a larger proportion of cubic phase crystals, resulting in improved translucency but reduced strength and toughness.41,50,54

Although 5Y-PSZ exhibited lower Fracture resistance, all measured fracture loads exceeded average posterior bite forces reported in the literature.60 Consequently, highly translucent zirconia may be considered for posterior FDP applications when adequate connector dimensions are maintained.

The fracture loads obtained in this study were considerably greater than those reported for lithium disilicate FDPs and comparable to previous investigations involving monolithic zirconia restorations.10,17,36,43

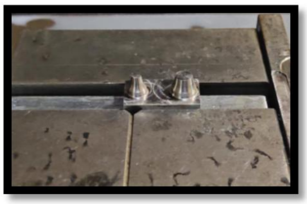


Fig:1 Fabrication of stainless steel metal die

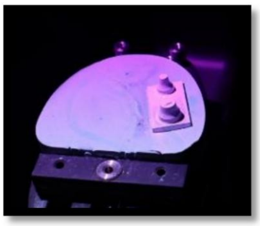


Fig:2 scanning of metal die in 3D scanner rainbowTM by using contrast spray

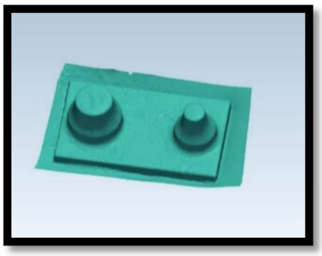


Fig:3 Scanned metal die in exocad software

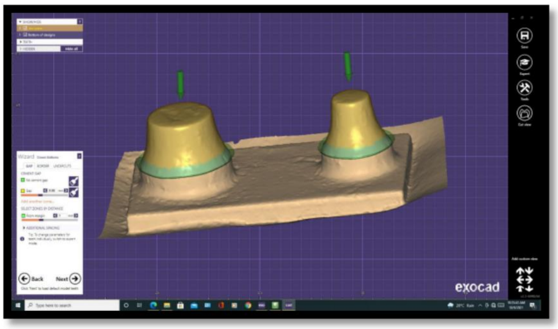


Fig:4 3D image of metal die

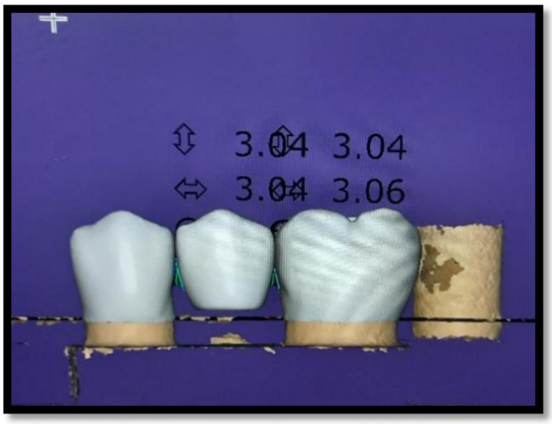


Fig:5 CAD designing of 3-unit monolithic bridge connector dimension of 3(H) mm*3(W)mm

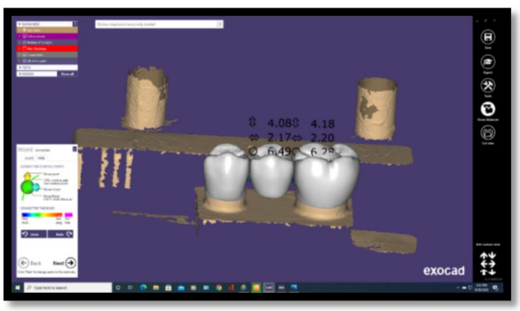


Fig:6 CAD designing of 3-unit monolithic bridge connector dimension of 4(H) mm*2(W)mm

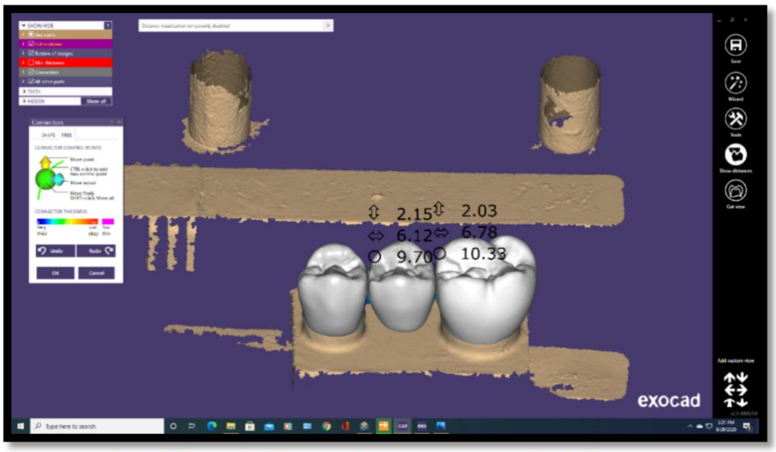


Fig: 7 CAD designing of 3-unit monolithic bridge connector dimension of 2(H) mm*6(W)mm

Fig:8 Milling of 3-unit monolithic bridges

Sixty monolithic zirconia FDPs were fabricated and divided into six groups (n=10):

Table 1. Distribution of Experimental Groups According to Zirconia Material and Connector Dimensions

Group(n=10)	Zirconia Material	Connector Dimension (Height × Width)
I	3Y-TZP	3 mm × 3 mm
II	3Y-TZP	2 mm × 6 mm
III	3Y-TZP	4 mm × 2 mm
IV	5Y-PSZ	3 mm × 3 mm
V	5Y-PSZ	2 mm × 6 mm
VI	5Y-PSZ	4 mm × 2 mm

Specimens were milled using CAD/CAM technology, sintered according to manufacturer recommendations, polished, and glazed(fig:8).57

Fracture testing was performed using a universal testing machine. Vertical compressive load was applied at the center of the pontic until fracture has occurred. Maximum fracture load was recorded in Newtons. (fig: 10). The fractured surfaces are seen in the scanning electron microscope (fig: 11,12)

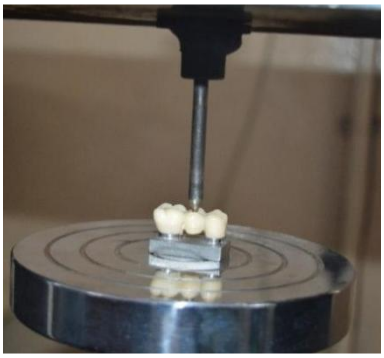


Fig:9 Specimens are loaded at middle of the pontic in a universal testing machine

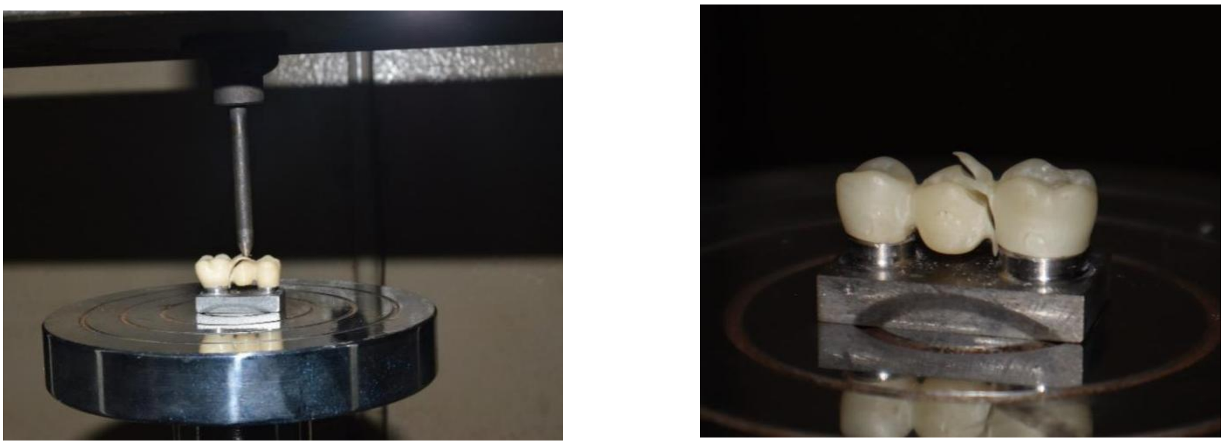


Fig:10 - Oblique orientation of fracture extending from gingival embrasure to the occlusal area and note that occlusal embrasure is not included in fracture.

A B

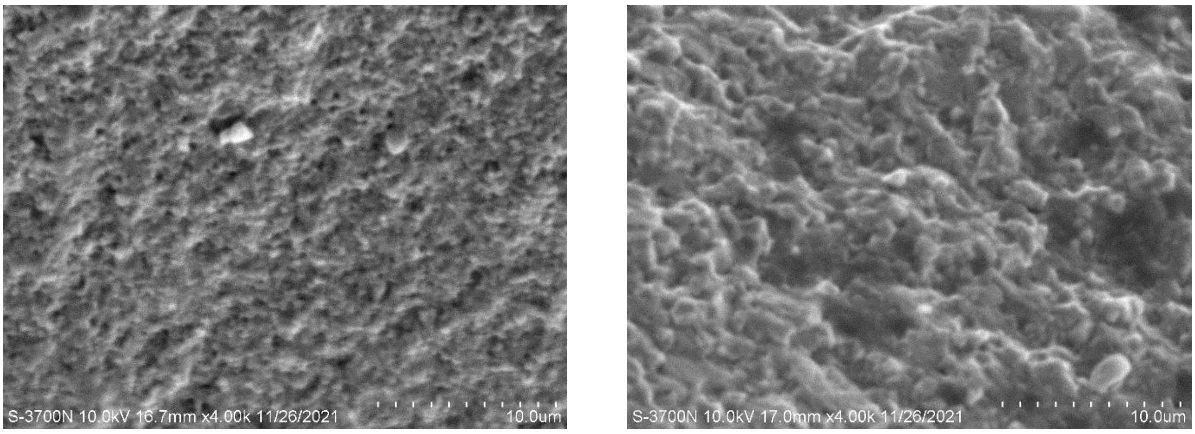
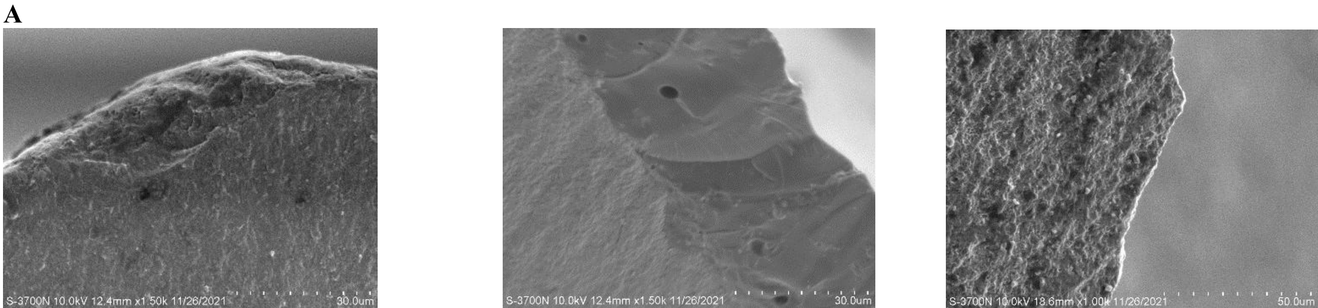


Fig:11- Scanning electron microscopy (SEM) images of fracture surfaces in a higher magnification (A) 3Y-TZP (B) 5Y-PSZ

A



B

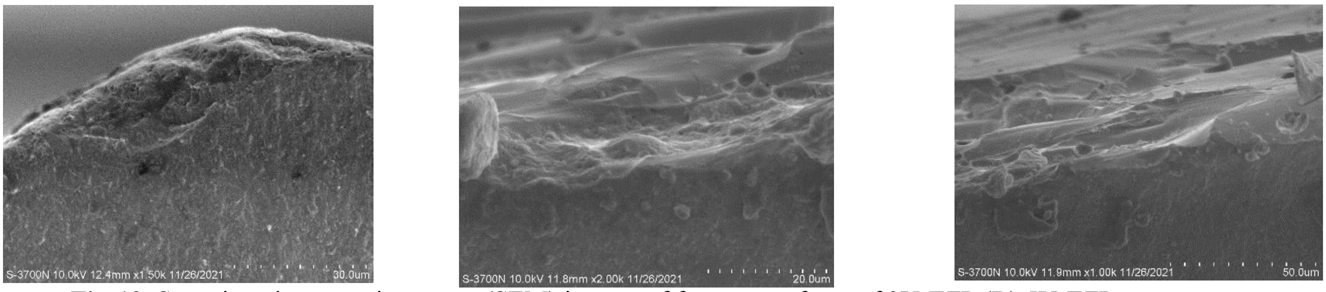


Fig:12 Scanning electron microscope (SEM) images of fracture surfaces of 3Y-TZP (B) 5Y-TZP

Data were analyzed using one-way ANOVA and independent t-tests with statistical significance established at $p<0.05$.

Results

The null hypothesis stated that connector dimensions (3×3 mm2, 2×6 mm2, and 4×2 mm2) would not significantly influence the fracture resistance of 3-unit monolithic bridges fabricated from 3Y-TZP and 5Y-PSZ zirconia

Table 2. Mean Fracture Load Values of Experimental Groups

Group	**Zirconia Material**	**Connector Dimension (mm)**	**Mean Fracture Load N) ± SD**
I	3Y-TZP	3 × 3	2394.2 ± 250.45
II	3Y-TZP	2 × 6	1728.2 ± 204.05
III	3Y-TZP	4 × 2	2099.0 ± 79.98
IV	5Y-PSZ	3 × 3	2098.8 ± 309.82
V	5Y-PSZ	2 × 6	1676.2 ± 314.43
VI	5Y-PSZ	4 × 2	1332.4 ± 60.94

SD = Standard Deviation; N = Newtons.

Table 3. Pairwise Comparison Within 3Y-TZP

Comparison	**Difference**	**p value**
3×3 vs 4×2	295.20	0.005
3×3 vs 2×6	666.00	0.001
4×2 vs 2×6	370.80	0.001

Table 4. Pairwise Comparison Within 5Y-PSZ

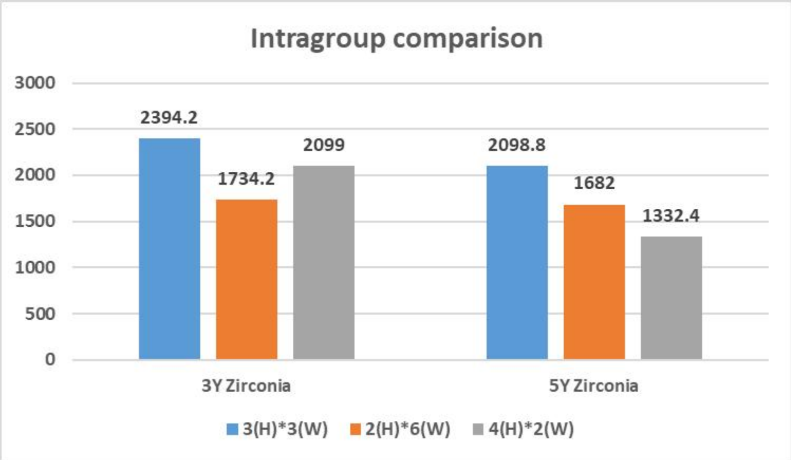
Comparison	**Difference**	**p value**
3×3 vs 4×2	766.40	0.001
3×3 vs 2×6	422.60	0.003
4×2 vs 2×6	343.80	0.016

Table 6: Intergroup comparison of flexural strength between 3Y and 5Y Zirconia

Groups		Mean	SD	Difference	t value	p value
3Y	3*3	2394.20	250.45	295.40	2.345	0.031*
5Y	3*3	2098.80	309.82			
3Y	4*2	2099.00	79.98	766.60	24.110	0.001*
5Y	4*2	1332.40	60.94			
3Y	2*6	1728.20	204.05	52.00	0.439	0.666 (NS)
5Y	2*6	1676.20	314.34			

Independent t test; * indicates significant difference at p≤0.05

Table 5. Intragroup Comparison



Within-group analysis revealed significant differences among connector dimensions in both zirconia systems ($p<0.001$). Intergroup comparisons demonstrated significantly greater Fracture resistance for 3Y-TZP than 5Y-PSZ for the 3×3 mm and 4×2 mm connector designs.

Table 7. Comparison of Fracture Resistance Within 3Y-TZP and 5Y-PSZ Groups Using One-Way ANOVA

Zirconia Material	Connector Dimension	Mean Fracture Load (N) ± SD	F Value	p Value
3Y-TZP	3 × 3 mm	2394.20 ± 250.45	30.165	0.001*
	4 × 2 mm	2099.00 ± 79.98		
	2 × 6 mm	1728.20 ± 204.05		
5Y-PSZ	3 × 3 mm	2098.80 ± 309.82	22.270	0.001*
	2 × 6 mm	1676.20 ± 314.34		
	4 × 2 mm	1332.40 ± 60.94		

One-way ANOVA test; * indicates statistically significant difference at p ≤ 0.05.

Discussion

The present investigation demonstrated that connector dimensions significantly influence the Fracture resistance of monolithic zirconia FDPs. Therefore, the null hypothesis was rejected.

The 3×3 mm connector demonstrated the highest Fracture resistance for both zirconia systems. These findings agree with previous investigations by Oh and Anusavice, Plengsombut et al., Bahat et al., and Onodera et al., who reported that connector geometry and cross-sectional dimensions strongly influence stress distribution and fracture behavior.8,9,20,24

Onodera et al. reported that connector configurations with a balanced 1:1 ratio demonstrated superior Fracture resistance compared with elongated connector designs.24 Similarly, Hamza et al. reported that rounded connectors with adequate dimensions significantly improved flexural performance.39

Finite element studies have consistently shown that increased connector dimensions reduce tensile stress concentration within the connector region.16,21–23,26–32 Reimann et al. demonstrated that reducing connector cross-sectional area increased stress levels within zirconia frameworks, supporting the present findings.40

The greater Fracture resistance of 3Y-TZP observed in the present study is consistent with its predominantly tetragonal microstructure and transformation toughening mechanism.49,51 In contrast, 5Y-PSZ contains a larger proportion of cubic phase crystals, resulting in improved translucency but reduced strength and toughness.41,50,54

Although 5Y-PSZ exhibited lower Fracture resistance, all measured fracture loads exceeded average posterior bite forces reported in the literature.60 Consequently, highly translucent zirconia may be considered for posterior FDP applications when adequate connector dimensions are maintained.

The fracture loads obtained in this study were considerably greater than those reported for lithium disilicate FDPs and comparable to previous investigations involving monolithic zirconia restorations.10,17,36,43

Limitations

This investigation was limited by its in vitro design. Thermocycling, fatigue loading, aging, and oral environmental factors were not simulated. Future clinical studies are required to validate these findings under functional conditions.

Conclusions

1.Connector dimensions significantly influence the Fracture resistance of monolithic zirconia FDPs.

2.A 3×3 mm connector configuration demonstrated the highest Fracture resistance for both 3Y-TZP and 5Y-PSZ zirconia.

3.3Y-TZP exhibited significantly greater Fracture resistance than 5Y-PSZ.

4.Alterations in connector height-to-width ratio reduced Fracture resistance.

5.Although 5Y-PSZ demonstrated lower Fracture resistance, all fracture loads exceeded reported posterior bite forces, suggesting potential clinical applicability in posterior FDPs.

Clinical Significance

Connector dimensions have a substantial influence on the Fracture resistance of monolithic zirconia FDPs. A 3×3 mm connector design provides superior mechanical performance for both conventional and highly translucent zirconia materials and may improve long-term clinical success.

Ethics Statement

This was an in vitro laboratory study involving fabricated specimens. Ethical approval was not required according to institutional guidelines.

Conflict of Interest

The authors declare no conflict of interest.

Funding

3Y-TZP and 5Y-PSZ zirconia blanks were received for this study b.

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