Original Article

Evaluation of flexural strength of Zirconia using three different connector designs: An *in vitro* study

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Abstract

Aim: The aim of this study is to evaluate the flexural strength of zirconia using three different connector designs under vertical and oblique loads.

Setting and Design: Invitro - analytical study.

Materials and Methods: For simulating zirconia fixed partial prosthesis, a specimen with three octagonal cylinders connected with each other was designed. Each face of the octagon was 3.75 mm ± 0.1 mm, and the total width was 9 mm ± 0.1 mm with a standard connector area of 10 mm^2 at cross-section. Three different connector designs, i.e., round, oval, and triangular were milled. Universal testing machine was used to test flexural strength with vertical and oblique forces.

Statistical Analysis Used: Intergroup comparison of flexural strength was made using Descriptive statistics (1) one-way ANOVA, Bonferroni's *post hoc* test (2) Kruskal–Wallis test. The confidence interval was set at 95%, $P < 0.05$ was considered statistically significant for both the tests.

Results: The highest flexural strength was observed in the triangle connector with vertical forces and lowest with oblique forces.

Conclusions: Triangle connector design proved to be better than round and oval connectors on the application of vertical loads. Round connector design proved to be better than triangle and oval connector on application of oblique loads.

Keywords: Connector, fixed partial denture, fixed prosthesis, zirconia

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INTRODUCTION

The zirconia-based fixed prosthetic restorations demand esthetically pleasing restorations with high strength. For achieving such results technicians design smaller connector size which allows them to give separation of units and naturally appearing embrasures. However, it compromises its overall strength and becomes more prone to fractures.[1] Thus, determining the ideal shape of the connector can be clinically useful.

During mastication, the average force on the posteriors was reported to range between 300 and 880 N. Under horizontal and oblique load, it was found to be 275N. It has been

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reported that the connector design has an influence on the strength of zirconia prosthetic restorations.[2] Providing a proper cross-sectional dimension and shape of the rigid connectors could become challenging due to the specific, natural shape of the abutment teeth.[3] For Zirconia-based restorations, studies have evaluated the different sizes of the connectors. They recommended that the minimum size of the connector to fabricate a clinically acceptable zirconia restoration is 9 mm^2at cross-section.[4] The shape of the connector design needs further studies.

MATERIALS AND METHODS

The study was approved by Institutional review board Ref No. 616/SSCDS/IRB -E/2017.

Designing of specimens in CAD software

For simulating zirconia 3-unit fixed partial prosthesis, an octagonal specimen with three cylinders connected using different connector configuration were designed at RR Dental Labs Pvt Ltd by Mr Ramana Reddy(CDT), Telangana, India. The octagonal shape facilitates to apply oblique loads at 45°. Each octagonal face was 3.75 mm ± 0.1 mm, and the width of each cylinder was set at 9 mm ± 0.1 mm. The length of the cylinder was 26 mm ± 0.1 mm. Each connector designed had a standard area of 10 mm^2. The separation between each cylinder was 2 mm due to milling limitations. Three different connector designs that were used in clinical scenarios were chosen, i.e., round, oval, and triangular [Figures 1-3] and prepared for milling. Ten samples were tested for vertical loads and 10 for 45° oblique loads for each of the connector designs totaling 60. The total number of samples has been thus divided into the following groups:

- Group 1: Round connector for vertical force evaluation-(RV)
- Group 2: Oval connector for vertical force evaluation–(OV)
- Group 3: Triangular connector for vertical force evaluation-(TV)
- Group 4: Round connector for oblique force evaluation-(RO)
- Group 5: Oval connector for oblique force evaluation-(OO)
- Group 6: Triangular connector for oblique force evaluation-(TO).

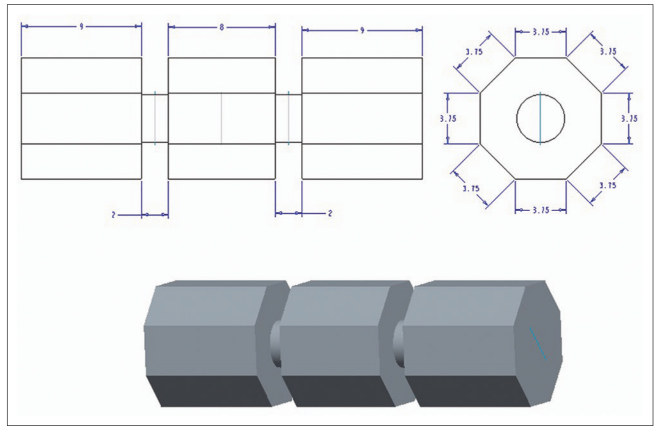

Figure 1: Schematic diagram of the round connector specimen

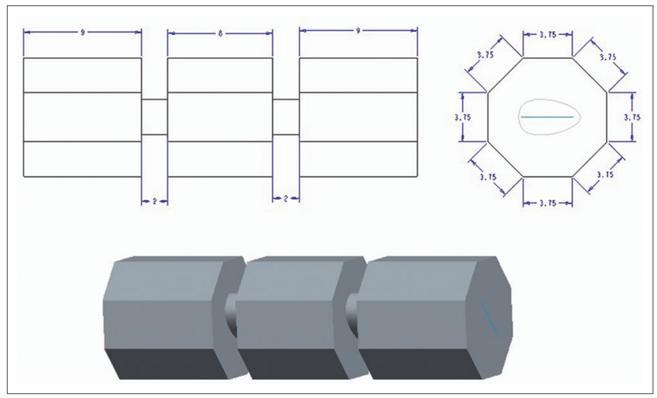

Figure 2: Schematic diagram of the oval connector specimen

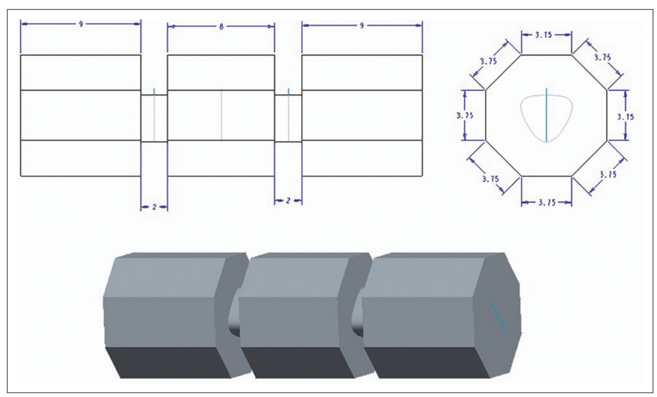

Figure 3: Schematic diagram of the triangle connector specimen

Milling of zirconia specimens

The connector designs were milled out of Zirconia blanks (Shine T) of dimensions 98 mm diameter and 14-mm thickness using 5-axis CAD/CAM milling machine (IMES icore 250i). After milling, the specimens were detached from the mounting frame. The supports were grinded off carefully with a low-speed hand-piece using fine grit diamond bur. All the specimens were sintered according to the manufacturer's instructions (1500°C for 6 h) in a furnace (MIHM-VOGT). The specimens were verified for dimensional accuracy with an electronic caliper to an accuracy limit of 0.1 mm.

Testing on universal testing machine

Specimens were subjected to 3-point bend test using universal testing machine. In triangle shape connector, the base of the triangle was oriented upward for vertical load and turned clock-wise to test 45° oblique load. For oval shape connector, it was oriented such that longer dimension of oval was placed vertically for vertical loads and turned clock-wise to test 45° oblique load. No such orientation was required for testing round connector. The specimens were loaded by means of a mandrel of 6 mm width at a crosshead speed of 1 mm/min placed at the center of the octagonal cylinder.

RESULTS

Statistical analysis was performed using IBM SPSS version 25.0. Mean flexural strength between groups were analyzed using one-way ANOVA Bonferroni's *post hoc* test [Tables 1 and 2] and Kruskal–Wallis ANOVA with *post-hoc* analysis using Mann–Whitney tests [Tables 3 and 4]. The confidence interval was set at 95%. P <0.05 was considered statistically significant. All the groups were found to be statistically significant. The highest strength was found in the triangle connector with vertical loads.

DISCUSSION

We designed octagonal cylinders connected by three different designs of connectors to simulate a 3 unit fixed partial denture (FPD). If we would have designed only connector shaped specimen of triangle, oval and round shape, it would have just represented forces on the connector directly and not forces directed toward the connector through a pontic. Although the use of an anatomic FPD shape would be more clinically relevant, a standardized geometrical shape was needed to calculate the flexural strength. Thus, an octagonal-shape was designed, incorporating two connectors in-between. While designing the specimens, we kept width between each octagonal cylinder as 2 mm due to milling limitations [Figures 4 and 5]. This 2 mm width definitely decreases the strength of the connector, but it is kept standard for all the samples for standardizing. Furthermore, our study is designed to compare different connector designs and not measuring the obsolute connector strength [Figure 6].

The connector is definitely the weak point of the entire restorations and its size should be adjusted in height and width in order to allow long-term survival of the restoration without the danger of unexpected failure. In fact, in several studies it was shown that the failure of the restoration is almost always due to a fracture that begins at the connector area.[5]

The size, shape, and position of connectors all influence the success of the prosthesis.[6]

Schmitter *et al*. stated that 9 mm^2 area at cross-section was the ideal connector dimension for zirconia fixed partial prosthesis frameworks. The connector they studied was of 9 mm^2 and was found to be optimum for the strength of the prosthesis and soft tissue around the abutment teeth, which could improve both esthetics and periodontal health.[4] We

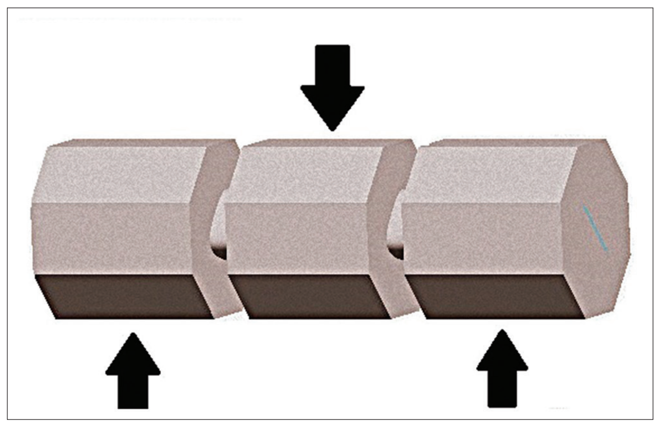

Figure 4: Diagramatic representation of the octagonal cylinder

Table 1: Statistical analysis of vertical loads, one-way ANOVA, Bonferroni's *post hoc* test

	n	Mean	SD	SE	95% CI for mean		Minimum-maximum	*P*	*Post hoc* analysis
					Lower bound	Upper bound			
Round vertical	10	1438.00	235.94	74.61	1269.22	1606.78	1180-1960	<0.01	1, 2>3
Triangle veritcal	10	1478.80	215.26	68.07	1324.81	1632.79	1053-1800		
Oval vertical	10	1095.60	133.44	42.20	1000.15	1191.05	928-1320		
Total	30	1337.47	260.24	47.51	1240.29	1434.64	928-1960		

SD: Standard deviation, SE: Standard error, CI: Confidence interval

Table 2: Statistical analysis of oblique loads, one-way ANOVA, Bonferroni's *post hoc* test

	n	Mean	SD	SE	95% CI for mean		Minimum-maximum	Significant	*Post hoc* analysis
					Lower bound	Upper bound			
Round oblique	10	1393.20	265.744	84.036	1203.10	1583.30	1018-1858	<0.01	1>2, 3
Triangle oblique	10	931.00	158.089	49.992	817.91	1044.09	705-1138		
Oval oblique	10	1119.10	243.325	76.946	945.04	1293.16	828-1468		
Total	30	1147.77	292.070	53.324	1038.71	1256.83	705-1858		

SD: Standard deviation, SE: Standard error, CI: Confidence interval

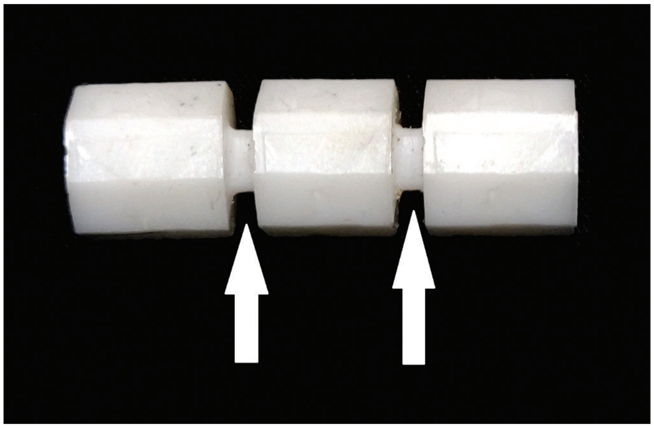

Figure 5: Arrows showing the connector in milled zirconia specimen

Table 3: Kruskal-Wallis ANOVA, Mann-Whitney *post hoc* tests for vertical loads

Vertical load	*n*	Minimum	Maximum	Mean	SD	*P*	*Post hoc* analysis
Round	10	1180	1960	1438	235.94	0.008	1, 2>3
Triangle (2)	10	1053	1800	1478	215.26		
Oval (3)	10	928	1320	1095	133.44		

SD: Standard deviation

Table 4: Kruskal-Wallis ANOVA, Mann-Whitney *post hoc* tests for oblique loads

Oblique load	*n*	Minimum	Maximum	Mean	SD	*P*	*Post hoc* analysis
Round	10	1018	1858	1348.10	265.74	0.033	1>2, 3
Triangle	10	705	1138	991.00	158.08		
Oval	10	828	1468	1119.10	243.32		

SD: Standard deviation

chose connector area of 10 mm^2 for our study as it depicts an average connector size in the premolar region.

Pantea *et al*. who compared oval and round shaped zirconia connectors and stated that the behavior of the zirconia-based fixed prosthetic restoration is influenced to a large extent by achieving an optimal connector dimension and crown length. They compared connector of 5 mm^2 and 9 mm^2 and tested for flexural strength and found 9 mm^2 connector of elliptical shape to be significantly stronger. They suggested that the elliptical connector might be stronger due to the wider area of stress distribution.[7]

According to Clausen *et al*.[8] zirconia prosthesis can be used for posterior restorations. They stated that the ceramic had enough fracture strength to withstand mean masticatory force. In the posteriors, the mean maximum posterior masticatory forces varied from 300 to 880N.

The resultant force exerted due to vertical load on the cuspal inclines of natural teeth were calculated using the formula ($N = mg.\cos \theta$). The average cuspal inclination of 37° was taken. In addition, we also calculated resultant force

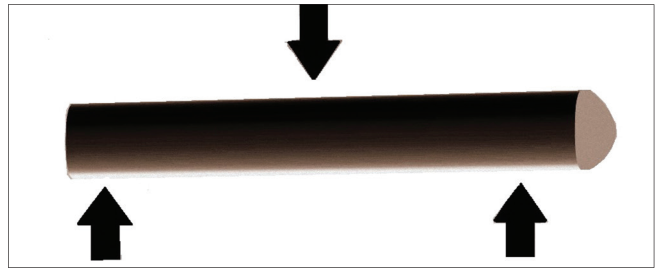

Figure 6: Diagramatic representation of triangle shaped cylinder

acting on the patient with bruxism habits. For posteriors, it was 276N and for bruxism habituates, it was 963N.

The results of our *in vitro* study highlight the fact that the strength of zirconia-based fixed prosthetic restorations is influenced by the proper selection of the rigid connector design for the studied samples and the triangle-shaped connector ensured the best strength. All the connector designs were found capable to withstand vertical and lateral forces exerted during mastication. We suggest that appropriate design should be selected depending on the clinical situation.

From the above, it is evident that the round-shaped connector subjected to oblique forces and the triangular-shaped connector subjected to vertical forces withstood the force better. Round connector withstood oblique forces better due to equal area of force distribution. Triangle connector withstood vertical forces better due to the flat base, which provided better distribution of forces.

An important aspect to be taken into consideration when comparing all these results is the fact that most of the available scientific literature[9-20] on zirconia strength uses geometric plane samples that do not reflect the actual configuration of a fixed prosthesis, which has curved lines or uneven material thickness, thus leading to an approach different from the ones applicable in clinical situations.

CONCLUSIONS

Within the limitations of the study, we conclude that:

- The highest flexural strength was observed in specimens with triangle connectors when force was applied vertically
- Round connector design was proved to be better than triangle and oval connector on application on oblique loads
- All the connector designs withstood both vertical and horizontal forces generated during normal mastication.
- Design of the connector is to be decided by the clinician/technician depending upon the clinical

scenario. "One size fits all" cannot be applied in designing the shape and size of the connector.

Limitations

- Milling of standardized samples in zirconia is challenging due to the difference in properties of different zirconia blanks
- Milling calibration changes due to wearing of bur will cause inaccuracies, which might give us false results.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: A laboratory study. Int J Prosthodont 2001;14:231-8.
2. Oh WS, Götzen N, Anusavice KJ. Influence of connector design on fracture probability of ceramic fixed-partial dentures. J Dent Res 2002;81:623-7.
3. Inan O, Secilmis A, Eraslan O. Effect of pontic framework design on the fracture resistance of implant-supported all-ceramic fixed partial dentures. J Appl Oral Sci 2009;17:533-8.
4. Schmitter M, Mussotter K, Rammelsberg P, Stober T, Ohlmann B, Gabbert O. Clinical performance of extended zirconia frameworks for fixed dental prostheses: Two-year results. J Oral Rehabil 2009;36:610-5.
5. Gargari M, Gloria F, Cappello A, Ottria L. Strength of zirconia fixed partial dentures: Review of the literature. Oral Implantol (Rome) 2010;3:15-24.
6. Mathews MF, Breeding LC, Dixon DL, Aquilino SA. The effect of connector design on cement retention in an implant and natural tooth-supported fixed partial denture. J Prosthet Dent 1991;65:822-7.
7. Pantea M, Antoniac I, Trante O, Ciocoiu R, Fischer CA, Traistaru T. Correlations between connector geometry and strength and zirconia-based fixed partial dentures. Materials Chem Physics 2019;222:96-109.
8. Clausen JO, Abou Tara M, Kern M. Dynamic fatigue and fracture resistance of non-retentive all-ceramic full-coverage molar restorations. Influence of ceramic material and preparation design. Dent Mater 2010;26:533-8.
9. Onodera K, Sato T, Nomoto S, Miho O, Yotsuya M. Effect of connector design on fracture resistance of zirconia all-ceramic fixed partial dentures. Bull Tokyo Dent Coll 2011;52:61-7.
10. Kenneth J, Anusavice KJ. Effect of connector design on the fracture resistance of all-ceramic fixed partial dentures. J Prosthet Dent 2002;87:536-42.
11. Guazzato M, Proos K, Quach L, Swain MV. Strength, reliability and mode of fracture of bilayered porcelain/zirconia (Y-TZP) dental ceramics. Biomaterials 2004;25:5045-52.
12. Studart AR, Filser F, Kocher P, Gauckler LJ. *In vitro* lifetime of dental ceramics under cyclic loading in water. J Biomaterials 2007;28:2695-705.
13. Von Steyern PV, Carlson P, Nilner K. All-ceramic fixed partial dentures designed according to the DC-Zirkon® technique. A 2-year clinical study. J Oral Rehabil 2005;32:180-7.
14. White SN, Miklus VG, McLaren EA, Lang LA, Caputo AA. Flexural strength of a layered zirconia and porcelain dental all-ceramic system. J Prosthet Dent 2005;94:125-31.
15. Tsumita M, Kokubo Y, Von Steyern PV, Fukushima S. Effect of framework shape on the fracture strength of all-ceramic fixed partial dentures in the molar region. J Prosthodont 2008;17:274-85.
16. Larsson C, Holm L, Lövgren N, Kokubo Y, Vult von Steyern P. Fracture strength of four-unit Y-TZP FPD cores designed with varying connector diameter. An *in vitro* study. J Oral Rehabil 2007;34:702-9.
17. Yilmaz H, Aydin C, Gul BE. Flexural strength and fracture toughness of dental core ceramics. J Prosthet Dent 2007;98:120-8.
18. Gurram R, Krishna CH, Reddy KM, Reddy GV, Shastry YM. Evaluating the fracture toughness and flexural strength of pressable dental ceramics: An *in vitro* study. J Indian Prosthodont Soc 2014;14:358-62.
19. Correia AR, Fernandes JC, Campos JC, Vaz MA, Ramos NV, da Silva JP. Effect of connector design on the stress distribution of a cantilever fixed partial denture. J Indian Prosthodont Soc 2009;9:13.
20. Badwaik PV, Pakhan AJ. Non-rigid connectors in fixed prosthodontics: Current concepts with a case report. J Indian Prosthodont Soc 2005;5:99-102.