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A Comparative Evaluation of Different Zirconia CAD/CAM Milled Three-Unit FPDS with Two Variable Connector Design -An In Vitro Study

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Abstract

Background: This study was done to compare and evaluate the effect of different connector designs in 3- unit FPD fabricated from different zirconia materials using CAD/CAM on the fracture resistance. Total forty 3-unit zirconia frameworks with two different connector designs were designed and milled using two commercially available zirconia blanks and were divided into four groups. **Material & Methods:** Each group consisted of 10 samples. The FPD frameworks were cemented on metal dies using dual cure resin cement. The specimens were loaded axially at the centre of the pontic at a speed of 1.0 mm/min in a universal testing machine. Loading was continued to the point of fracture and failure loads. **Results:** The propagation of crack pathways was oblique from gingival embrasure to occlusal direction through the connector and pontic in some of the samples. Post-hoc Bonferroni test was used for multiple comparisons after the application of the ANOVA test for comparison within the group. For group 1 (3616.79 ± 78.71), Group 2 (3545.83 ±74.16), group 3 (5812.70± 72.34), Group 4 (5655.84± 83.51) N. Fracture resistance was found to be highest in group 3 followed by group 4, group 1 and lowest in group 2. **Conclusion:** By increasing the dimension of connector from 9mm2 to 12mm2 the fracture resistance of zirconia increased by 62.22% for group 1 and 3, 62.69% for group 2 and group 4. The fracture resistance was highest for AIDITE zirconia with 12mm2 connector design.

Keywords:- Connector Design, CAD/CAM, Zirconia, 3D- Printing, Fixed dental prosthesis.

INTRODUCTION

The most frequently provided treatment for single to multiple missing teeth is Fixed partial denture, as it gives a sense of confidence to the patient due to its superior aesthetic appearance and at the same time being cost effective.[1] Materials used till date range from Alloys, Ceramics, Zirconia and lithium disilicate but nowadays, Zirconia is the most promising material for the restoration of partial edentulism because of its high fracture resistance and ability to withstand the loads of occlusal loads. Along with choice of material, the design of the connector site should be aesthetically acceptable while maintaining its strength, so as to prevent the fracture of the FPD at the connector site.[2] In the posterior region because of reduced height of the posterior teeth, height of the connector also reduces leading to decreased strength of the connector and consequently fracture of the FPD, thus compromising the success of the prosthesis.[3,4]

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The FPDs fabricated with CAD-CAM workflows showed less discrepancy than the frameworks obtained with the traditional workflow as poorly fitting margins may lead to caries through increased plaque accumulation and micro leakage. Also, in terms of accuracy in the region of the shoulder, digitally fabricated zirconia frameworks presented similar or better fit than the conventionally fabricated metal frameworks. Therefore, this study was done to compare and evaluate the effect of different connector designs in 3- unit FPD fabricated from different zirconia materials using CAD/CAM on the fracture resistance.

MATERIAL AND METHODS

This In-Vitro comparative study was carried in the Department of Prosthodontics and Crown and Bridges at Institute of Dental Studies and Technologies, Modinagar, Ghaziabad, Uttar Pradesh from November 2019 to November 2021.

Two ideally prepared teeth models were selected this study which were used to make die model simulating a sectional edentulous region with missing 36, 34 and 37 as abutments. These two prepared teeth models were cleaned properly and sprayed with opaque powder i.e. spot check SKD-S2, contrast spray. Then these two teeth models were scanned with SolutionNIX c500 lab scanner. The scanned STL format was edited in EZscan 2017 software to make a die model with accurate dimensions as shown in [Figure 1]. The STL format of the model was manipulated in NEXTDENT 3D printing software to attach pillars/sprues for 3D printing the model as shown in [Figure 2]. FORMALABS, photopolymer resin liquid was used in the 3D printing machine to make the die. After the 3D printing is completed, the model is cleaned with sprit to remove the excess resin material form the surface and was kept under UV post curing unit LC-3Dprint box for curing the 3D printed model completely and the pillars were removed from the base of the die, see [Figure 3].

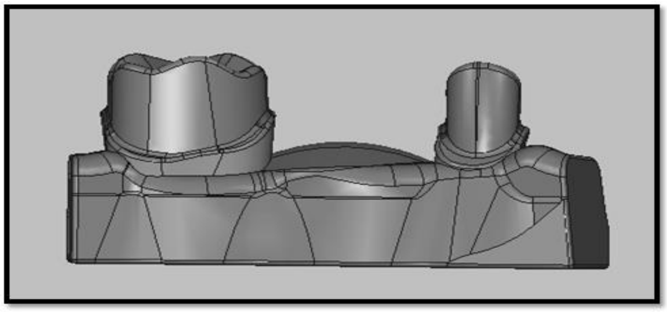

Figure 1: 3D model for the metal die

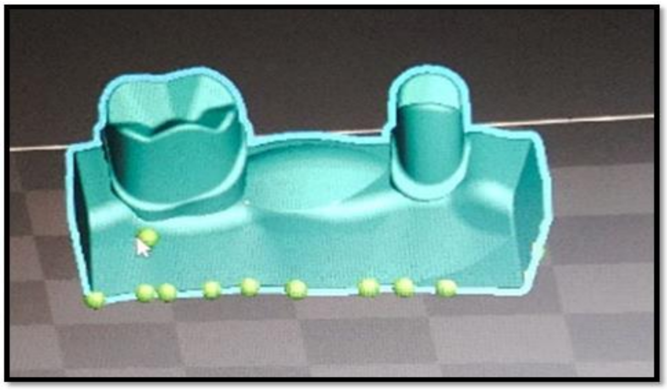

Figure 2: 3D model for 3d printing

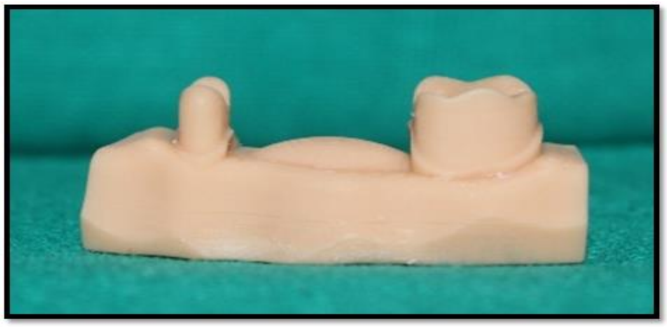

Figure 3: 3D printed model

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Figure 4: Mould for duplication of the 3D model

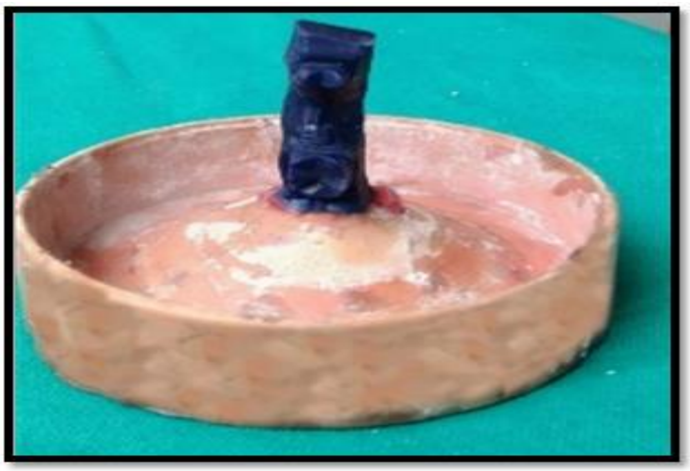

Figure 5: wax pattern of 3D model

Figure 6: wax pattern attached to crusible former

Figure 7: Finished and Polished metal dies with the 3D- printed model

Figure 8: Scanning of the metal die with intra oral scanner

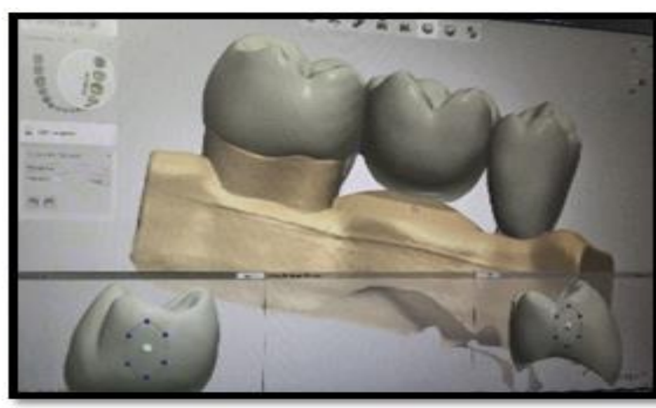

Figure 9: Designing of the framework

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To make metal die, the 3D printed model was duplicated and, three wax patterns were made and invested and casted as shown in [Figure 4, 5 and 6]. The dies were removed from the casting ring and they were finished and polished properly with metal finishing and polishing burs, see [Figure 7].

The metal die was scanned with 3 Shape Global intra-oral scanners followed by scanning of the opposite cast and bite, [Figure 8]. Type of pontic design and framework was selected on the 3 Shape intra-oral scanner software and sent to Delhi dental labs. Two designing's for 3-unit zirconia CAD/CAM milled prosthesis were done on the 3 Shape CAD software in Delhi dental lab with two different connector designs i.e., elliptical 3 x 3 mm and 4 x 4 mm with circular cross section and height/width ratio of 1:1 was used as shown in [Figure 9]. The cement gap was 0.030 mm, extra cement gap of 0.070 mm, distance to the margin line was 0.80 mm. the thickness of zirconia retainer was minimum 1.5 mm at all the surfaces. Two commercially available (Aidite and Jyodent) zirconia blanks were selected. the zirconia blank was placed inside VHF S1 milling unit, [Figure 10]. After milling the sprues were removed with disc bur. The milled frameworks were dipped into Shade liquid A3 Aidite. After dipping in the shade liquid, the frameworks were placed in the ceramic beads and kept inside sintering furnace TABEO-1/M/ZIRKON/100, at a temperature of 15000c for 12 hours, [Figure 11]. After sintering glaze was applied in the surfaces of the sintered frameworks and they were kept inside the VITA ZAHNFABRIK VACUMAR 20T glazing furnace and was heated at 5000c for 4 minutes, followed by 9400c for 1 minute and 6000c for 1 minute. Total forty 3-unit zirconia frameworks were milled and divided into four groups. Each group consisted of 10 samples.

Figure 10: Completely milled frameworks

Figure 11: Before and after sintering

After the FPD frameworks were fabricated, they were seated on the metal dies to check for the fit. The frameworks were then cemented to three metal dies using FUSION ULTRA D/C dual cure resin cement which was manipulated according to the manufacturer's recommendation. The excess flash was removed with sharp explorer. The cement was cured with LED curing unit for 60 seconds under a finger pressure for 3 min and was allowed to set for 24 hours, [Figure 12]. The bridge specimens were loaded axially to fracture in a universal testing machine, [Figure 13]. The load was applied at the centre of the pontic at a speed of 1.0 mm/min with a stainless-steel rod. Loading was continued to

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the point of fracture and failure loads were recorded with computer software. The propagation of crack pathways was oblique from gingival embrasure to occlusal direction through the connector and pontic in some of the samples, [Figure 14]

Figure 12: curing resin cement under LED light

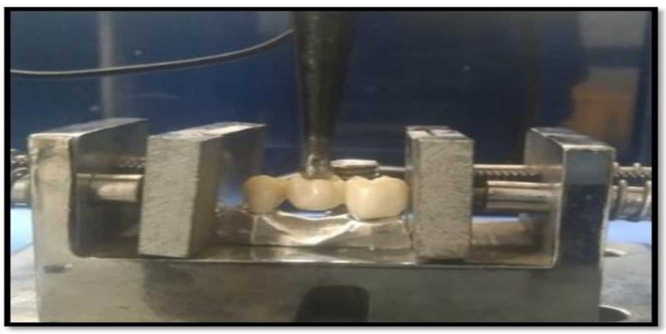

Figure 13: Testing under UTM machine

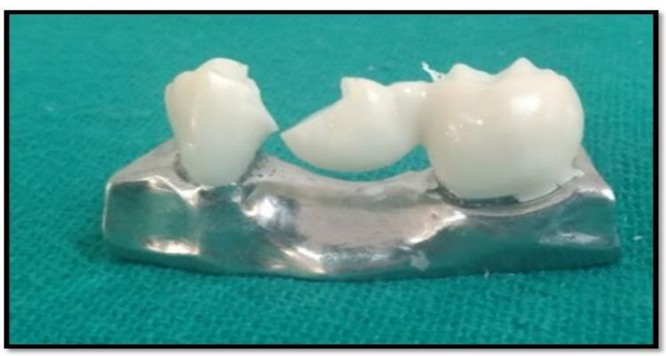

Figure 14: Fractured prosthesis after UTM testing.

RESULTS

The results obtained were statistically analysed. Fracture resistance was found to be highest in group 3 followed by group 4, group 1 and lowest in group 2, hence Aidite with 12mm2 connector had highest fracture resistance followed by Jyodent 12mm2 connect or followed by Aidite 9mm2 connector, whereas Jyodent 9mm2 connector had lowest fracture resistance. Difference in fracture resistance between groups was found to be very highly significant. On multiple comparison, Difference in fracture resistance was found to be statistically not significant between groups 1 and 2. Difference in fracture resistance was found to be statistically very significant between groups 1 and 3, 1 and 4, 2 and 3, 2 and 4, 3 and 4 [Table 3]

Sample no.	Fracture resistance
1996	3531.15 N
1997	3582.36 N
1998	3688.36 N
1999	3514.89 N
2000	3762.17 N
2011	3573.63 N
2012	3573.30 N
2013	3597.99 N
2014	3685.82 N
2015	3658.26 N

Sample no.	Fracture resistance
2003	3487.72 N
2001	3429.55 N
2001	3621.26 N
2004	3572.23 N
2005	3597.23 N
2006	3639.22 N
2007	3591.38 N
2008	3578.72 N
2009	3483.65 N
2010	3457.36 N

Sample no.	Fracture resistance
2016	5891.21 N
2017	5739.37 N
2018	5720.38 N
2019	5883.12 N
2020	5892.36 N
2021	5797.28 N
2022	5729.92 N
2023	5848.25 N
2024	5873.28 N
2025	5751.80 N

Sample no.	Fracture resistance
2026	5703.32 N
2027	5525.12 N
2028	5671.98 N
2029	5638.55 N
2030	5562.86 N
2031	5721.72 N
2032	5597.26 N
2033	5784.38 N
2034	5743.89 N
2035	5609.27 N

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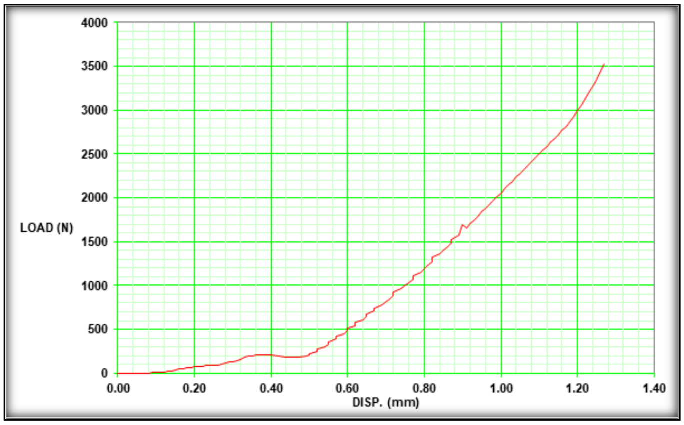
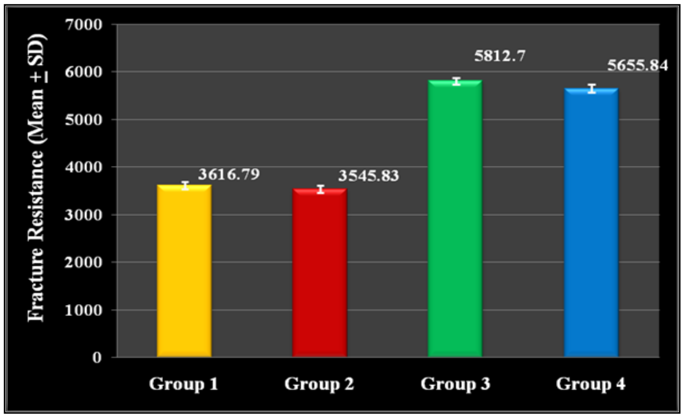


Graph 1: Graphic representation of Compressive strength individual sample



Graph 2: Peak Fracture Resistance of Each Group

Table 1: Compressive strength of individual samples

Group	**Fracture Resistance**	
	Mean	**SD**
Group 1 (AIDITE 9mm)	3616.79	78.71
Group 2 (JYODENT 9mm)	3545.83	74.16
Group 3 (AIDITE 12 mm)	5812.70	72.34
Group 4 (JYODENT 12 mm)	5655.84	83.51
ANOVA	2593.970	
p-Value	< 0.001 (VHS)	

Table 2: Fracture Resistance

Groups	**(p – Value)**
Group 1 vs Group 2	0.285 (NS)
Group 1 vs Group 3	< 0.001 (VHS)
Group 1 vs Group 4	< 0.001 (VHS)
Group 2 vs Group 3	< 0.001 (VHS)
Group 2 vs Group 4	< 0.001 (VHS)
Group 3 vs Group 4	< 0.001 (VHS)

P value was not significant (i.e,0.285) for between group 1 and group 2 and the remaining values were highly significant (p value: $p < 0.001$) [Table 2]. In the present study, there was a statistically significant difference between the Groups 1 and 2 and Groups 3 and 4. The fracture resistance increased by 62.22% between group 1 and group 3, when connector dimension was increased from 9mm2 to 12mm2 milled with same commercially available zirconia blanks. and 62.22% between Groups 2 and 4 when connector dimension was increased from 9mm2 to 12mm2 milled with same commercially available zirconia blank.

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DISCUSSION

The most oftenly provided treatment for partial edentulous state is Fixed partial denture, as it is economically acceptable, conservative and easy to fabricate and less invasive as compared to other treatment modalities like implant retained prosthesis. But for an acceptable success rate the materials used for FPD fabrication should have excellent strength, durability and biocompatibility.[3] Nowadays, Zirconia is the most promising material for the restoration of partial edentulism mainly in posterior edentulous regions because of its high fracture resistance and ability to withstand the loads of occlusal loads. Also, its biocompatible and have superior aesthetics with less plaque accumulation, low thermal conductivity and resistance to corrosion.[4,5,6,7,8]

Yttria stabilised tetragonal zirconia polycrystals (Y-TZP) was introduced in 2002. The high strength of the Y-TZP compared to the other forms of zirconia and this property was attributed to a phase transformation toughening mechanism. Other than material, the fracture resistance of the FPD also depends upon the size, shape and position of the connectors and most the fracture of the prosthesis is noticed near or at the site of connector and that too mostly on or near the distal connector.[9,10,11,12,13,14,15] Plengsombut K et al (2009) studied the effect of two connector designs on the fracture resistance of all-ceramic core materials for fixed dental prostheses. Two connector designs, round and sharp with a 3.00 ±0.05-mm cross-section for each connector, were studied. They concluded that fracture resistance of ceramic core materials is affected by fabrication technique and connector design. Connector design affected fracture resistance of the milled ceramic.[16,17,18,19,20]

A connector is that portion of a fixed partial denture (FPD) that unites the retainer(s) and pontic(s). During mastication occlusal forces are applied directly through the long axis of a three-unit bridge, due to which compressive stresses develop at the occlusal aspect of the connector at the marginal ridge and tensile stresses develop at the gingival surface of the connector.[6] As zirconia is weak under tensile stresses, this contributes to the propagation of microcracks located at the gingival surface of the connector through the core material in an occlusal direction leading to fracture. As connector is the smallest component in a Fixed partial denture all the forces are concentrated at it and leads to fracture.[8] Therefore, the dimensions of FPD connectors must be large enough to counteract the concentrations of stress that develop in the framework but also small enough to allow for better hygiene maintenance and aesthetic.

In order to improve the survival rate of FPD restoration, it is desirable to make the cross-sectional area of the framework connector as large as possible, regardless of the material. The two types of connector designs chosen for this study was elliptical 3 x 3 mm and 4 x 4 mm with circular cross section and height/width ratio of 1:1 was used.[21,22,23,24]

P value was not significant (i.e,0.285) for between group 1 and group 2 and the remaining values were highly significant (p value: $p < 0.001$) (Table No. 3). In the present study, there was a statistically significant difference between the Groups 1 and 2 and Groups 3 and 4. The fracture resistance increased by 62.22% between group 1 and group 3, when connector dimension was increased from 9mm2 to 12mm2

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milled with same commercially available zirconia blanks. and 62.22% between Groups 2 and 4 when connector dimension was increased from 9mm2 to 12mm2 milled with same commercially available zirconia blanks. Rezaei SMM et al, (2011)34 conducted a study to determine the effect of buccolingual increase of the connector width on the stress distribution in posterior fixed partial dentures made of IPS Empress 2. The buccolingual connector width varied from 3.0 to 5.0 mm. They found that during vertical or angled load application, increasing the connector width decreases the failure.

Onodera K et al, (2011) conducted a study to determine the relationship between cross sectional design and fracture load using a static load bearing test in yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramic frameworks on a molar fixed partial denture. The cross-sectional area of the connector was 9.0, 7.0, or 5.0 mm2. In terms of shape, the cross-section was either circular or oval, with a height/width ratio of 1:1, 3:4, or 2:3. They deduced that clinical possible to apply a connector with a cross- sectional area of 7.0 mm2. Fracture often occurred at the distal connector between the pontic and the abutment, corresponding to the second molar.

Hence, the null hypothesis stating that there is no difference between the fracture resistance of Type I and Type II connector designs and there is no difference between the fracture resistance of Group I and Group II zirconia was rejected.

CONCLUSIONS

The rising interest in esthetic dentistry over the past decade has led to new materials and techniques to be developed in the quest for ultimate esthetic material. Because of their esthetics and biocompatibility, many patients prefer All-ceramic crowns to metal-ceramic crowns. The traditional methods were time consuming, and technique sensitive. CAD/CAM may be a good alternative as it reduces the fabrication time of high strength ceramics by up to 90%. The purpose of this in-vitro study was to compare and evaluate the effect of different connector designs in 3- unit FPD fabricated from different zirconia materials using CAD/CAM on the fracture resistance.

Within the limitations of this invitro study, the following conclusions were drawn:

1. By increasing the dimension of connector from 9mm2 to 12mm2 the fracture resistance of zirconia increased by 62.22% for group 1 and 3, 62.69% for group 2 and group 4.
2. The results suggest that even 9mm2 connector dimension can give acceptable results for a 3-unit CAD/CAM milled FPD
3. The fracture resistance was highest for AIDITE zirconia with 12mm2 connector design.
4. Group 2 (Jyodent 9mm2) had the lowest fracture resistance among all the four groups.
5. There was very highly significant difference between connector design I and II
6. Difference in fracture resistance was found to be statistically very significant between groups 1 and 3, 1 and 4, 2 and 3, 2 and 4, 3 and 4.
7. There was a significant difference between the fracture resistance of Aidite and Jyodent (Aidite had better resistance)

However, further studies should be conducted to evaluate the fracture resistance of these materials with larger sample size.

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