EGYPTIAN
DENTAL JOURNAL

VOL. 63, 2835:2846, JULY, 2017

I.S.S.N 0070-9484

FIXED PROSTHODONTICS, DENTAL MATERIALS, CONSERVATIVE DENTISTRY AND ENDODONTICS

www.eda-egypt.org • Codex : 139/1707

# EFFECT OF CONNECTOR SURFACE AREA AND TYPE OF CEMENT ON FRACTURE RESISTANCE OF FULL CONTOURED MONOLITHIC CAD CAM ZIRCONIA FIXED PARTIAL DENTURES

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## *ABSTRACT*

**The aim of this study:** was to investigate the influence of different connector surface areas on the fracture resistance of three and four units full contoured monolithic zirconia FPDs manufactured by CERCON machine and cemented by either zinc phosphate or resin cements.

**Materials and methods**: Sixty full contoured monolithic zirconia FPDs cementd on resin casts were divided into two main groups (30 FPDs each) according to the number of units (three and four units FPDs), each group was subdivided into three subgroups according to connector surface area dimensions (10FPDs each). Subgroup A1: Surface area of each connector didn't exceed 24 $mm^2$. , Subgroup A2: Surface area of each connector was greater than 24 $mm^2$ and less than 35 $mm^2$ and Subgroup A3: Surface area of each connector was more than 35 $mm^2$. Each subgroup was further randomly divided into two (5FPDs each). division C1 : FPDs were cemented using zinc phosphate cement and division C2 : FPDs were cemented using dual cured resin cement (Variolink N). the specimens were stored in deionized water in an incubator (QWJ500; Queue Systems Inc. USA) maintained at oral temperature (37°C) for and removed 24 hours before mechanical testing. Specimens were loaded in universal testing machine until failures were observed. The obtained data of fracture resistances were statistically analyzed.

**Results**: showed that for all subgroups, by increasing the connector surface area a statistically significant increase in the fracture resistance was observed, whether using resin cement or zinc phosphate cements. For three units FPDs, using adhesive resin cement produced higher fracture resistance values than using zinc phosphate cements, that were statistically non-significant for subgroupsA1,A2 while it was statistically significant for subgroup A3. (at $p\text{-value} < 0.05$). For four units FPDs, using adhesive resin cement produced higher fracture resistance values than using zinc phosphate cements that were statistically non-significant for subgroup A1, while they were statistically significant for subgroups A2and A3. (at $p\text{-value} < 0.05$). using Zinc phosphate cements with three units FPDs produced statistically significant higher values than with four units FPDs

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Using resin cements with three units FPDs produced statistically significant higher values than with four units FPDsfor only subgroup A3. While the difference was not statistically significant for subgroup A1 and A2. **conclusions:** it was found that the fracture resistance of the full contoured three and four units FPDs made using monolithic zirconia is affected by the connector dimension , span length and the used cement. By increasing the connector surface area, the fracture resistance values increased significantly with both cements. Generally, For all tested subgroups, three units monolithic zirconia FPDs have higher fracture resistance values than four units FPDs. Using resin cement produced higher values of fracture resistance than using zinc phosphate cement.

**KEYWORDS**: Full contoured zirconia; monolithic zirconia;Resin and zinc phosphate cements; CERCON; connector surface area; fracture resistance.

## INTRODUCTION

Advances in technology and manufacturing of dental materials resulted in increased number of ceramic materials available for esthetic restorations(1). Zirconia is the only ceramic material which can be used to construct four or more all ceramic FPDS units and fulfill the flexural strength requirements recommended by the International Organization for Standardization (ISO)(2-4). The fracture strength of zirconia restorations was reported to be twice that of alumina restorations(5). Recently, Cercon CAD/CAM machine can be used to fabricate full contoured zirconia restorations that eliminate the use of veneer improving fracture strength of fixed partial dentures. Different in vitro(6-11) and in vivo(12-16) studies proved that restorations fabricated with CAD/CAM techniques have adequate marginal fit and have sufficient fracture strength, however fractures of posterior all-ceramic FPDs occurs and it is the main type of failures for zirconia based restorations, and the connector area dimensions are the most influential in failure(17). Failure rate is relatively high in three unit all-ceramic FPDs around the sharp connector area(18,19), and when connectors dimensions decreased for biological and esthetic reasons, The minimal recommended connector cross section area is 12–16 $mm^2$(20-22). Despite zirconia restorations have sufficient fracture resistance, the importance of the cement type should not be underestimated(23-24). The supporting materials, such as abutment material and cement type will influence the fracture resistance of all-ceramic crowns(25-26).Several studies have analyzed the stress distributions in FPDs, Johanson et al (27) analyzed 115 metal ceramic FPDs, it was found that the vertical dimensions of the connectors were much longer in the anterior region (with average mean: 4.4 mm.) than in the posterior region (mean 3.6 mm). Argereau et al. (28) used 3D FEA to study the effect of connector size on the magnitude of strain, they applied axial force of 500 Newton to the pontic central region, they found that the maximum strain was always initiated practically in the center of the connector's cervical area. Tamer et al (29) studied the effect of different connector designs on the flexural strength of simulated 3-unit FPDs made of yttria-stabilized tetragonal zirconia using CAD/CAM, it was concluded that the round connector design was more able to withstand occlusal forces than the sharp design, and The connector design with a minimum cross section of 6 $mm^2$ is recommended for anterior fixed dental prostheses, provided it has a round curvature. In the case of zirconia-based restorations, conventional cementation using glass ionomer or zinc phosphate cement is acceptable, although resin cement might be the first choice (30), clinical studies in which conventional cements were used for cementation of zirconia-based single crowns reported no increased incidence rate of fracture related to the cementation(31,32).The purpose of this in vitro study was to evaluate the effect of different connector surface area and type of cement on Fracture resistance of full contoured CAD/CAM monolithic zirconia fixed partial dentures.

## MATERIALS AND METHODS

Two standardized models were used in this study ;the first had prepared upper second premolar and upper second molars as abutments, they were made from stainless steel and screwed onto a platform (30 mm in length, 17 mm in width, and 4.5 mm in thickness) to receive posterior 3-units FPDs with an intermediate pontic space (representing missed maxillary first molar tooth). The abutments were prepared using engineering lathe (Automatic feedback lathe- BV20B-L Bengu Dome Siticmaxhime tool, China) to be 5 mm. in height with a 1 mm. wide shoulder finish line, and a 12 degrees angle of convergence of the axial walls (Figure 1). The second model is similar to first one but the abutments were upper first premolar and second molars with pontic space of missing upper second premolar and first molar teeth to receive posterior 4-units FPDs. Sixty impressions (thirty for each model) were made with polyether impression material (Impregum Penta; 3M ESPE,USA), impressions were poured using self -cure acrylic resin (Table Top Epoxy Resin-clear crystal-USA) using the manufacturer's recommended liquid/ powder ratio to produce resin models, these resin models were subsequently used during mechanical testing. Resin models were duplicated to stone models (Figure 2) which were sawed to dies to allow easy scanning by Cercon scanner (Cercon EYE).

### Manufacturing of 3 and 4 unit FPDs

FPDs were divided into two equal groups (table 1), thirty samples for each group, Group I: Models were restored with three units FPDs. Group II: Models were restored with four units FPDs. Each group was divided into three subgroups according to connector surface area. Subgroup A1: Surface area of each connector didn't exceed 24 mm$^2$. , Subgroup A2: Surface area of each connector was greater than 24 mm$^2$ and less than 35 mm$^2$ and Subgroup A3: Surface area of each connector was more than 35mm$^2$. Each subgroup was further randomly divided into two divisions according to type of cement used division C1 : FPDs were cemented using zinc phosphate cement and division C2 : FPDs were cemented using dual cured resin cement (variolink N).

Stone model was placed in Cercon scanner (Cercon EYE , Degudent GmbH, Hanau, Germany) to scan the model, design of full contoured zirconia restoration was made using a CAD software (Cercon ART, Degudent GmbH, Hanau, Germany)). The virtual cement thickness was set as 30 $\mu$m, Spacer coverage was 90% spacer coverage corresponding to approximately 0.5 mm off the finish line as suggested by the manufacturer, type of restoration was set to be full anatomical. Every time of designating, the previous parameters were standard for 3 or 4 units FPDs but the connector surface areas were changed according to experimental design

TABLE (1): Experimental design of the study:

| Group I<br>Three units FPDs<br>(30 samples) | | | | | | Group II<br>Four units FPDS<br>(30 samples) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1<br>(10samples) | | A2<br>(10samples) | | A3<br>(10samples) | | A1<br>(10samples) | | A2<br>(10samples) | | A3<br>(10samples) | |
| C1<br>(5) | C2<br>(5) | C1<br>(5) | C2<br>(5) | C1<br>(5) | C2<br>(5) | C1<br>(5) | C2<br>(5) | C1<br>(5) | C2<br>(5) | C1<br>(5) | C2<br>(5) |
| Total No. of samples : 60 | | | | | | | | | | | |

of the study. Designed restorations were sent to Cercon Brain using flash memory card, then Cercon zirconia discs (Cercon smart ceramics, base colored disk 30, Degudent GmbH, Hanau, Germany)) were milled using a CAM system (Cercon Brain expert, Degudent GmbH, Hanau, Germany). Cercon brain gives partially sintered ceramic bridges with an enlargement factor (approximately 18% linear enlargement) to compensate for sintering shrinkage . Crowns were further sintered in a special furnace (Cercon Heat, Degudent GmbH, Hanau, Germany) at 1350°C for 6 hours(33).

## Cementation of FPDs to resin models

FPDs were cemented to their resin models using either dual-cure resin cement (Variolink N, Ivoclar-Vivadent Co., Liechtenstein) or Zinc phosphate cement (Adhesor fine, Spofa Dental, Czech Republic ) according to manufacturers' instructions (Figure 4). A load of 3Kgm. Was applied to the occlusal surface of each FPD during setting to ensure complete seating(34,35), the load was removed after 3 minutes. Excess zinc phosphate cement was removed by carver after setting while resin cement was removed before light curing, the end surfaces of each specimen were polished using Silicon Carbide paper disc (400 grit) to remove excess cement. After cementation, the specimens were stored in deionized water in an incubator (QWJ500; Queue Systems Inc. USA) maintained at oral temperature(37°C) for and removed 24 hours before mechanical testing.

## Mechanical testing

Each FPD was positioned under a stainless steel ball of 6 mm. in diameter, fixed to the upper crosshead of a universal testing machine (Instron 5565, Norwood, USA) (Fig. 1). A compressive load was applied at a crosshead speed of 1 mm./min. to the central fossa of the occlusal surface of the pontic, and failure was recorded at a sudden reduction to 40% of the applied load (Figure 5).All data were collected, tabulated and statistically analyzed using SPSS 22( IBM Corporation,New York, USA)

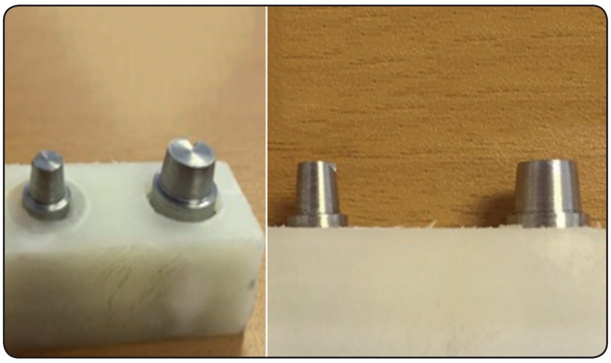

Fig. (1) Stainless steel standardized models

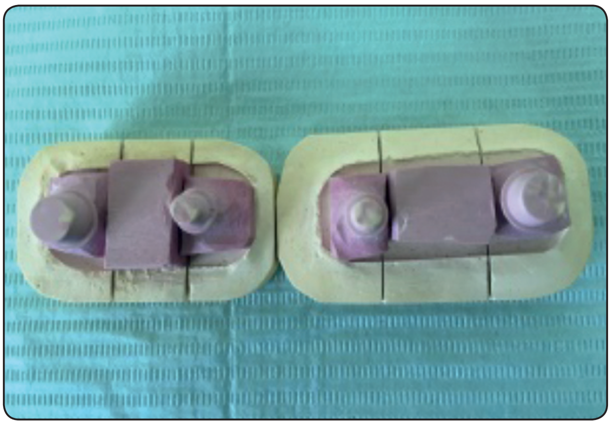

Fig. (2) Duplicated stone models

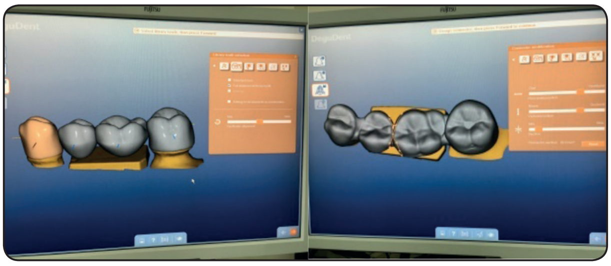

Fig. (3) Design of FPDs by Cercon ART

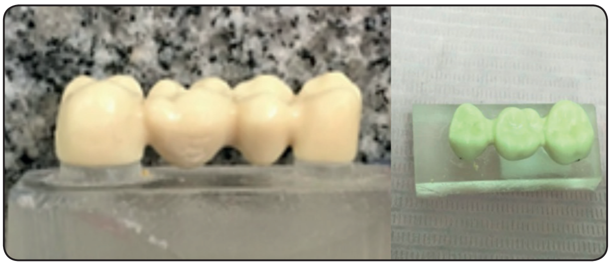

Fig. (4) Finished and cemented three and four units FPD on resin models.

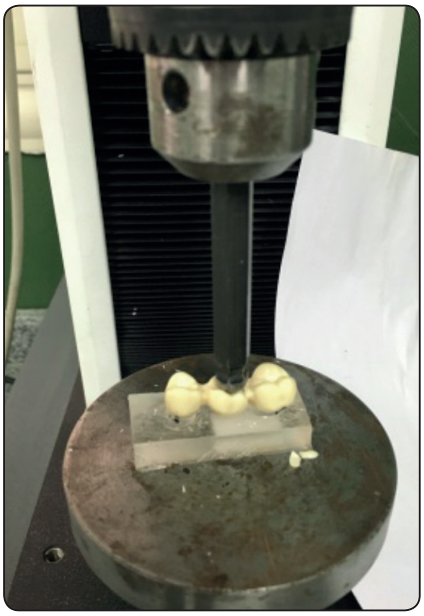

Fig. (5) Mechanical testing of FPD.

## RESULTS

Mean fracture resistance values were statistically analyzed according to factorial experiment in a completely randomized design to study the effect of the individual factors as well as the effect of their interactions using Wilcoxon rank sum test and Kruskal-Wallis rank test (Figure 6). For three units FPDs cemented either by zinc phosphate cement or resin cement, mean fracture resistance were significantly increased by increasing connector surface area (P-value <0.05) (Tables2,3) Also for four units FPDs, increasing connector surface area dimensions will statistically significant increase fracture resistance of bridges cemented by zinc phosphate (table 4) or resin cement (table 5) (P-value <0.05).

Considering the effect of cements on the fracture resistance of Three units FPDs, the use of adhesive resin cement resulted in higher non-statistically significant mean fracture load values than zinc phosphate for subgroup A1 and subgroup A2 but higher statistically significant fracture resistance for subgroup A3 (Table 6).

In case of four units FPDs ,Also resin cement showed higher values than zinc phosphate but it wasn't statistically significant in subgroup A1 but significant in subgroups A2 and A3 (Table7). Using zinc phosphate cement with either subgroup A1 or A2 or A3, three units FPDs showed statistically higher fracture resistance load than four units FPDs. (P-value <0.05) (Table 8).When using Resin cement, three units FPDs gave higher statistically significant fracture load values than four units FPDs with subgroups A1, A2 and higher statistically non-significant in group A3 (P-value <0.05) (Table 9).

TABLE (2) Mean fracture resistance among three units bridges and zinc phosphate cement with different connectors:

| Unit bridges | Connector surface area | Cement | Mean ± SD | p- value |
|---|---|---|---|---|
| Three unit bridges | Subgroup A1 | zinc phosphate cement | 1805 ± 33.7 $^{a}$ | 0.03* |
| | Subgroup A2 | zinc phosphate cement | 2270.33 ± 49.52 $^{b}$ | |
| | Subgroup A3 | zinc phosphate cement | 3503.67 ± 187.46 $^{c}$ | |

***Statistically significant difference a, b, c: indicate significant difference in-between each pairs of connector surface area p-value for Kruskal-Wallis rank test***

TABLE (3) Mean fracture resistance among three units bridges and resin cement with different connectors:

| Unit bridges | Connector surface area | Mean ± SD | p- value |
|---|---|---|---|
| Three unit bridges | Subgroup A1 | 1830 ± 13.23 [a] | 0.03* |
| | Subgroup A2 | 2369.67 ± 62.17 [b] | |
| | Subgroup A3 | 4490.67 ± 574.49 [c] | |

***Statistically significant difference a, b, c: indicate significant difference in-between each pairs of connector surface area p-value for Kruskal-Wallis rank test***

TABLE (4) Mean fracture resistance among four units bridges and zinc phosphate cement with different connectors:

| Unit bridges | Connector surface area | Cement | Mean ± SD | p- value |
|---|---|---|---|---|
| Four unit bridges | Subgroup A1 | zinc phosphate cement | 1385.33 ± 248.36 | 0.03* |
| | Subgroup A2 | zinc phosphate cement | 1933.33 ± 69.34 | |
| | Subgroup A3 | zinc phosphate cement | 3164.67 ± 53.54 | |

***Statistically significant difference***

TABLE (5) Mean fracture resistance among four units bridges and resin cement with different connectors:

| Unit bridges | Connector surface area | Cement | Mean ± SD | p- value |
|---|---|---|---|---|
| Four unit bridges | Subgroup A1 | Resin cement | 1475.67 ± 229.65 | 0.02* |
| | Subgroup A2 | Resin cement | 2213.67 ± 85.73 | |
| | Subgroup A3 | Resin cement | 4038 ± 592.09 | |

***Statistically significant difference***

TABLE (6) Mean fracture resistance among three units bridges with different connector surface area and different cements:

| Unit bridges | Connector surface area | Cement | Mean ± SD | p- value |
|---|---|---|---|---|
| Three unit bridges | Subgroup A1 | zinc phosphate cement | 1805 ± 33.7 | 0.1 (NS) |
| | | Resin cement | 1830 ± 13.23 | |
| | Subgroup A2 | zinc phosphate cement | 2270.33 ± 49.52 | 0.1 (NS) |
| | | Resin cement | 2369.67 ± 62.17 | |
| | Subgroup A3 | zinc phosphate cement | 3503.67 ± 187.46 | 0.04* |
| | | Resin cement | 4490.67 ± 574.49 | |

***NS: no statistically significant difference *Statistically significant difference p-value for Wilcoxon rank sum test***

TABLE (6) Mean fracture resistance among three units bridges with different connector surface area and different cements:

| Unit bridges | Connector surface area | Cement | Mean ± SD | p- value |
|---|---|---|---|---|
| Three unit bridges | Subgroup A1 | zinc phosphate cement | 1805 ± 33.7 | 0.1 (NS) |
| | | Resin cement | 1830 ± 13.23 | |
| | Subgroup A2 | zinc phosphate cement | 2270.33 ± 49.52 | 0.1 (NS) |
| | | Resin cement | 2369.67 ± 62.17 | |
| | Subgroup A3 | zinc phosphate cement | 3503.67 ± 187.46 | 0.04* |
| | | Resin cement | 4490.67 ± 574.49 | |

***NS: no statistically significant difference*** ****Statistically significant difference*** ***p-value for Wilcoxon rank sum test***

TABLE (7) Mean fracture resistance among four units bridges with different connector surface area and different cements:

| Unit bridges | Connector surface area | Cement | Mean ± SD | p- value |
|---|---|---|---|---|
| Four unit bridges | Subgroup A1 | zinc phosphate cement | 1385.33 ± 248.36 | 0.5 (NS) |
| | | Resin cement | 1475.67 ± 229.65 | |
| | Subgroup A2 | zinc phosphate cement | 1933.33 ± 69.34 | 0.04* |
| | | Resin cement | 2213.67 ± 85.73 | |
| | Subgroup A3 | zinc phosphate cement | 3164.67 ± 53.54 | 0.04* |
| | | Resin cement | 4038 ± 592.09 | |

***NS: no statistically significant difference*** ****Statistically significant difference*** ***p-value for Wilcoxon rank sum test***

TABLE (8) Mean fracture resistance among three versus four units bridges with different connector surface area subgroups and cemented by zinc phosphate cement:

| Connector surface area | Cement | Unit bridges | Mean ± SD | p- value |
|---|---|---|---|---|
| Subgroup A1 | zinc phosphate cement | Three unit bridges | 1805 ± 33.7 | 0.04* |
| | | Four unit bridges | 1385.33 ± 248.36 | |
| Subgroup A2 | zinc phosphate cement | Three unit bridges | 2270.33 ± 49.52 | 0.04* |
| | | Four unit bridges | 1933.33 ± 69.34 | |
| Subgroup A3 | zinc phosphate cement | Three unit bridges | 3503.67 ± 187.46 | 0.04* |
| | | Four unit bridges | 3164.67 ± 53.54 | |

****Statistically significant difference*** ***p-value for Wilcoxon rank sum test***

TABLE (9) Mean fracture resistance among three versus four units bridges with different connector surface area subgroups and Resin cement:

| Connector surface area | Cement | Unit bridges | Mean ± SD | p- value |
|---|---|---|---|---|
| Subgroup A1 | Resin cement | Three unit bridges | 1830 ± 13.23 | 0.04* |
| | | Four unit bridges | 1475.67 ± 229.65 | |
| Subgroup A2 | Resin cement | Three unit bridges | 2369.67 ± 62.17 | 0.04* |
| | | Four unit bridges | 2213.67 ± 85.73 | |
| Subgroup A3 | Resin cement | Three unit bridges | 4490.67 ± 574.49 | 0.3 (NS) |
| | | Four unit bridges | 4038 ± 592.09 | |

***Statistically significant difference*** ***NS: no statistically significant difference***

***p-value for Wilcoxon rank sum test***

Fig. (6) Mean fracture resistance among three and four units bridges with different connector surface area and different cements:

## DISCUSSION

All-Ceramic FPDs exhibit better esthetics and excellent biocompatibility compared to other materials. However, they have limited loading capability. Long span bridges may be subjected to higher bending especially in the posterior region of the oral cavity. Posterior areas experience higher load values, and the connector height may be limited by the short clinical molar crowns height(36), Moreover, connector areas are usually narrowed for biological or esthetic reasons, which typically add more stresses relative to the average stress levels in other areas of the prosthesis(37). In the present study, standardized models were used to eliminate the bias in the evaluation of the effect of cement and connector dimensions on the fracture resistance of the monolithic zirconia FPDs. Anatomic FPDs were fabricated to imitating clinical situations, Monolithic Y-TZP-based framework was used without adding a porcelain veneer because the veneer layer may affect standardization and to exclude chipping failure that is common happen with zirconia-based ceramic-layered restorations.In order to exclude other variables rather than the design of all-ceramic restoration,Cercon CAD/CAM machine was used to generate identical FPDs both in external and internal dimensions-except connector dimensions-and in marginal contours to precisely fit all the resin models replacing missing maxillary tooth or teeth. Resin models were used due to their closer flexural strength, elastic modulus and Poisson's ratio values to that of human dentine(38-40). Fracture resistance test was performed without any thermal cycling, cyclic loading,thermo-mechanical cycling or autoclave-induced low temperature degradation (LTD), however it was shown that flexural strength of zirconia decreases when subjected to different aging treatments (41,42). Kohorst et al. (43) concluded that fracture resistance of zirconia-basedFDPs. was decreased after cyclic loading with 1x$10^6$ cycles at 100 N. together with 1x $10^4$ thermal cycles between 5–55°C.

### Connector surface areas

it is generally preferable to make the surface area of the connector as large as possible. Lüthyet al (44) recommended that minimum cross-sectional area for clinical application is 7.3 mm$^2$, however higher values were obtained in CERCON screen during designing FPDs. Thus, in the present study, we tested larger surface areas (less than 24 mm$^2$, from 24 to 35 mm$^2$ and more than 35 mm$^2$). It was well known in the past that fracture resistance was directly proportion with ceramic thickness, however it is believed nowadays that amount of flaws in regions of reduced thickness are generally more important than thickness which plays a secondary role in fracture initiation(45). Our results showed that in either three or four units FPD increasing connector dimensions will lead to higher fracture resistance values. When occlusal forces are applied directly to the long axis of a ceramic FPDs connector, compressive stresses develop on the occlusal aspect, while tensile stress develop on the gingival aspect; such stresses contribute to the propagation of microcracks located at the gingival surface, leading to fracture. Increasing the dimensions of the connector may decrease this effect. These results are in agreement with other studies, which found the possibility of fracture of zirconia FPDs increased with small sized connectors. This was in agreement with the findings of Studart et al(46) who compared 3-, 4-, and 5-unit zirconia FDPs, suggesting that the minimal connecting surface must be not less than 2.7 mm$^2$, 4.0 mm$^2$, and 4.9 mm$^2$, respectively with a failure probability of 5%.After 20 years of function. In this study,fracture occurred in central or distal connectors rather than mesial connector where no fracture was Observed, because distance from the center of the abutment to loading region was smaller for the mesial than for the central or distal connectors, as pointed out by Tsumita et al (47).

### Three units FPDs versus four units

According to the findings of this study, a significant difference in fracture resistance was found between three and four FPDs group with either zinc phosphate or resin cement (Table 8) (P-values 0.04), The average masticatory forces in literature are varying from 11 to 150 N., whereas force peaks are 200 N. in the anterior, 350 N. in the posterior and 1000 N. with bruxism. Adding a 30% safety loading buffer results in requirements of 300 N for anterior application and 500–580 N total for an average person(48).Thus all results are within acceptable values for clinical use.

### Cements

Both resin cements and zinc phosphate are recommended as luting agent for zirconia restorations, there is an interest in comparing both cements as zinc phosphate exhibit simplicity of use, easiness of removing excess from marginal regions after cementation and easiness of removing a previously cemented crown if so needed.In this study, three or four units FPDs cemented with zinc phosphate cements showed significantly lower compressive strengths than those cemented with resin cement, the same results were obtained by Bindle et al(49) however they fabricated single restorations. Our results were also in accordance to

Habekost et al (50) who explained this that cements with higher flexural modulus exhibits higher values of fracture resistance.

But Zesewitz et al (51) compared fracture resistance of monolithic zirconia crowns cemented with resin cements with those cemented with glass ionomer and that there was no statistically significant differences in cements however,in their study they used metal dies. The results of the present study showed that there were no significant differences between three and four units in the fracture resistance when connector surface area exceed 35mm$^2$, (table 9). This may indicate that the compression strength of the resin cement alone will not suffice in showing how strong the crown-cement-tooth complex will be when surface areas of connectors were too large.

## CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were found:

1. The fracture resistance values of all tested subgroups showed that monolithic zirconia FPDs can withsthand the masticatory forces in the molar region, even with the minimal tested connector surface area of less than 24.
2. The fracture resistance of the full contoured monolithic zirconia is affected by the connector dimension , span length and the used cement.
3. Increasing the connector surface area, regardless of the used cement, for both three and four units bridge will increase the fracture resistance significantly.
4. Generally, For all tested subgroups, three units monolithic zirconia FPDs have higher fracture resistance values than four units FPDs.
5. For three units bridges, using resin cement produced higher values of fracture resistance than using zinc phosphate cement. The increase in the fracture resistance was statistically significant at connector surface area more than 35 mm$^2$.
6. For four units bridges, using resin cement produced higher values of fracture resistance than using zinc phosphate cement. The increase in the fracture resistance was statistically significant at connector surface area more than 24 mm$^2$.
7. Using zinc phosphate cementation a statistically significant higher values of fracture resistance were found, for three units FPDs than for four units FPDs for all subgroups.
8. Using adhesive resin cementation a statistically significant higher values of fracture resistance were found, for three units FPDs than for four units FPDs for subgroup A3 only (connector surface area more than 35 mm$^2$.
9. Using either zinc phosphate or resin cement for cementation of zirconia restorations is considered clinically acceptable.

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