COMPARATVE EVALUATION OF FAILURE LOAD OF TWO DESIGNS CAD/CAM ZIRCONIA FIXED PARTIAL DENTURES USING LASER SCANNING CONFOCAL MICROSCOPY

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ABSTRACT

INTRODUCTION: Chipping of the porcelain veneer was a common failure of zirconia based restorations, especially in the presence of high occlusal loads. The development of full-contour monolithic zirconia (MZ) restorations promises an end to the heartbreak of fractured esthetic porcelain on posterior restorations. The clinical recommended thickness of zirconia monolithic restorations has not been reported. It is essential to find out a proper thickness guarantee not only the load bearing capacity but also conservation of dental hard tissues.

OBJECTIVES: was to evaluate the failure load of two different preparation designs – (classical and conservative) – in three units monolithic zirconia fixed partial dentures.

MATERIALS AND METHODS: 2 parallel groups (n = 5/group) examined in this study. Group I: Classical tooth preparation design with occlusal reduction of 1.5 mm and rounded 1 mm finish line. Group II: Conservative tooth preparation design with occlusal reduction 0.5 mm and rounded 0.2 mm finish line. All fixed partial dentures (FPDs) adhesively luted on epoxy resin dies and subjected to thermal cycling and cyclic loading corresponding to 6 months of clinical service. Specimens then loaded till failure in a universal testing machine. The load of failure recorded in Newton. Fractographic analysis was done using stereomicroscope, scanning electron microscope (SEM) and confocal laser scanning microscope (CLSM). Data statistically analyzed using Student t-test.

RESULTS: None of the FPDs failed during the aging process. Mean of failure load of Group I was 1317.36 ± 186.11 N and for Group II was 1215.92 ± 217.03 N without significant difference between the groups (P =0.450).

CONCLUSIONS: The conservative tooth preparation design of the posterior three units FPDs was a very good alternative to the classical one. Aging behavior, translucency testing, color reproduction and long-term clinical performance need to be further assessed before recommending this conservative FPDs design for daily practice.

KEYWORDS: Fixed Partial Denture, Zirconia, Monolithic, Preparation Design.

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INTRODUCTION

Esthetic is the main goal for the optimum dental work nowadays. Both patients and dentists looking for metal free restorations that provides maximum esthetic and minimum toxicity and tissue allergy. Dental ceramics fulfill those requirements unless improvement in their tensile strength and brittleness is very important to suit all types of restorations in the patient mouth especially posterior FPDs where maximum force of mastication is located Esthetic is the main goal for the optimum dental work nowadays. Both patients and dentists looking for metal free restorations that provides maximum esthetic and minimum toxicity and tissue allergy. Dental ceramics fulfill those requirements unless improvement in their tensile strength and brittleness is very important to suit all types of restorations in the patient mouth especially posterior FPDs where maximum force of mastication is located (1).

Interest in using high-strength yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) ceramics for oral rehabilitation has grown in recent years as it has the most favorable mechanical properties with a flexural strength of 900 MPa to 1200 MPa, a fracture resistance of >2000 N, and a fracture toughness of 9 to 10 MPa (2).

Due to its relative opacity and high strength, zirconia is used as core material, on which veneering porcelain is applied to get a tooth colored restoration. However, layered zirconia restorations fail due to low strength of the veneering porcelain compared to the high strength zirconia substructure material (3).

An innovative possibility for further improvement of the mechanical stability of fixed dental prosthesis might be the fabrication of full-contour zirconia restorations without veneering. New CAD/CAM technologies allow for the creation of anatomically designed monolithic restorations, which may be indicated especially in posterior regions, where aesthetics do not rank first (4).

The development of full-contour monolithic translucent zirconia (MZ) restorations promises an end to the fractured veneering porcelain on posterior and anterior restorations (5).

The recommended preparation thickness for abutment teeth of all ceramic restorations is based on the mechanical properties of the ceramic material. Layered zirconia restoration needs about 1.5 mm to 2 mm at occlusal surface and 1mm cervical, leading to loss of up to 75 % of coronal tooth substance (6).

Reduction of the minimum required wall thickness of monolithic zirconia ceramic restorations will help to reduce preparation trauma and associated risks. The clinical recommended thickness of zirconia monolithic restorations has not been reported. It is essential to find out a proper thickness guarantee not only the load bearing capacity but also conservation of dental hard tissues (7).

Fractographic analysis is very important to understand the mechanical behavior of the brittle materials in laboratorial studies and allows estimating the material's fracture toughness value, fracture origin and stress state at failure. Despite the evident limitations of in vitro tests, they still generate most of the data related to the mechanical behavior of Y-TZP used in dental restorations (8).

This study was designed to compare and evaluate the failure load of two different teeth preparation designs in three unit monolithic zirconia FPDs.

MATERIALS AND METHODS

Two acrylic models with interchangeable hard resin teeth used in the study to make the preparation on them. Preparations were done on Lower right second premolar and second molar according to the study preparation design criteria. A space of 11mm was kept free corresponding to a missing lower right first molar (9).

I - Classical tooth preparation design criteria

1- An occlusal reduction of 1.5 mm.
2- Axial reduction with 8° occlusal conversion.
3- A circumferential deep chamfer margin, 1mm in width and 0.5 mm coronal to the cervical line.

II - Conservative tooth preparation design criteria

1- An occlusal reduction of 0.5 mm.
2- Axial reduction with 8° occlusal conversion.
3- A circumferential light chamfer margin, 0.2 mm in width and 0.5 mm coronal to the cervical line.

All preparations were done on high speed hand piece and guided with silicon index. Confirmation of all preparations criteria, parallelity and path of insertion were checked virtually after scanning in a 3D optical scanner using zirconzhan Archiv CAD/CAM software.

Negative replica from the prepared models were made using Duosil addition silicon duplicating material (Duosil™ SHERA, Lemförde, Germany). The negative replicas were filled with epoxy resin material (klybeckstrasse200, BASEL, Switzerland) having the same elastic modulus of dentin, following manufacturer's instructions, to get ten positive replicas (working models) (10).

One model from each group scanned in 3D activity 880 scanner (Activity 880 © smart optics Sensortechnik GmbH | Lise-Meitner Allee 10 | D-44801 Bochum). Designing of the full contour FPDs was done on the software according to the study criteria with connector diameter of 9 mm^2 according to manufacturer instructions. Zirconia blank used (Zenostar translucent© 2015 Ivoclar Vivadent Inc. USA) and milling was done followed by sintering, finishing and final staining and glazing according to manufacturer instructions.

Adhesive resin cement (Multilink® N ivoclar Vivadent Schaan/Liechtenstein) was used for cementation of the FPDs on the corresponding epoxy resin models. All specimens were subjected to 600 cycles of thermocycling and 120,000 cycle of mechanical loading (TCML) to simulate 6 months of clinical service (11). Then, all specimens loaded till failure in a universal testing machine (Maxitorq, Com-Ten industries, FL, USA) using a 12 mm diameter metal sphere loading on the centre of the occlusal surface of the pontic with cross head speed of 1mm/min (10, 12).

Load was raised gradually, until sudden sharp decrease of the force, which was also accompanied by failure of the specimens. The maximum load before the sharp decrease of force was recognized as "failure load", and was determined for each specimen in Newton.

Mode of failure and fractographic analysis was determined using stereomicroscope. Further qualitative evaluation was done using scanning electron microscope (SEM) and confocal laser scanning microscope (CLSM).

Statistical Analysis (13)

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. Quantitative data were described using range (minimum and maximum), mean, standard deviation and median. Significance of the obtained results was judged at the 5% level (14).

Student t-test was used for normally quantitative variables, to compare between the two studied groups.

RESULTS

The means of failure loads in Newton for all groups and the descriptive statistical analysis were shown in (table 1). Group I showed higher mean of failure load 1317.36 ± 186.11 N. Group II showed lower mean of failure load 1215.92 ± 217.03 N. All these data are presented in (Fig. 1). Statistical test revealed no significance difference between the two groups (p=0.450).

Table (1): showing comparison between the two studied groups according to failure load in Newton.

	Group I (n=5)	Group II (n=5)	t	p
Newton			0.793	0.450
Min. – Max.	1228.0 – 1650.20	912.20 – 1519.0		
Mean ± SD.	1317.36 ± 186.11	1215.92 ± 217.03		
Median	1235.60	1224.10		

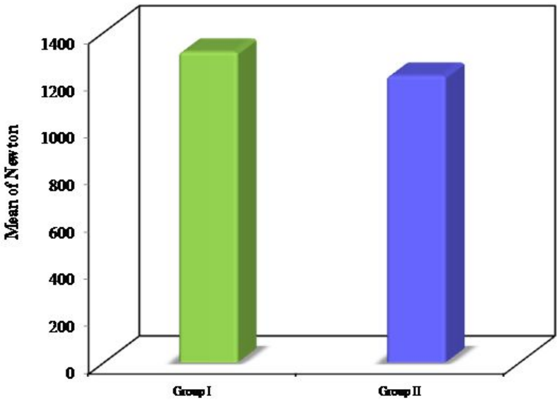

Fig. (1): showing comparison between the two studied groups according to the mean of fracture resistance in Newton

Mode of failure

1. Group I

Evaluation of the specimens visually revealed that all test specimens fractured at connector area. The fracture was oblique, located in the loading point and through the mesial connector.

2. Group II

Evaluation of the specimens visually revealed that four specimens fractured with crack extending from the middle of the buccal margin of the second molar obliquely to the loading point including the distal connector, and fracture from the middle of the buccal margin of the premolar obliquely ended at the mesial connector without including it.

The fifth specimen showed different mode of failure, there was a perpendicular crack in the distal connector and fracture from the middle of the buccal and lingual margins of the premolar obliquely ended at the mesial connector without including it.

Results of the stereo microscope, SEM and CLSM study

Fractographic analysis results from stereomicroscope, SEM and CLSM showed presence of multiple fractographic features like compression curl, hackles, twisted hackles and crack arresting lines. The fracture origin was difficult to be revealed in the specimens, but the analysis of the direction of each fractographic feature concluded that the direction in general was in occlusal direction with tensile fracture from the gingival surface of the connector. (Fig.2, 3, 4)

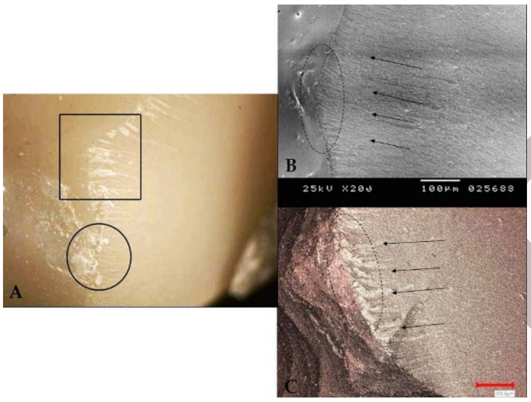

Fig. (2): showing Group I Stereo microscopic image (A) of the occlusal margin of the fracture. Both SEM (image B magnification of the square area) and CLSM (image C magnification of the circle area) scanning show presence of cohesive zirconia fracture. Arrows show hackles direction and oval dotted lines show multiple twisted hackles at the margin, that indicates fracture propagation from the gingival part of the connector directed occlusaly.

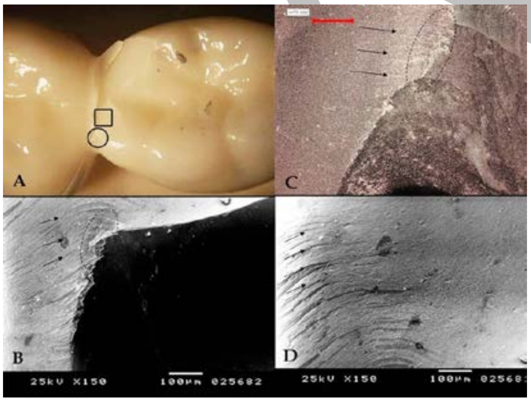

Fig. (3): showing Group II Stereo microscopic image (A) of the occlusal margin of the fracture. Both SEM (image B magnification of the circle and image D magnification of the square) and CLSM (image C magnification of the circle area) analysis show the same fractographic features of the Group I. Hackles and twisted hackles show the same direction of the crack from gingival part of the connector directed occlusaly.

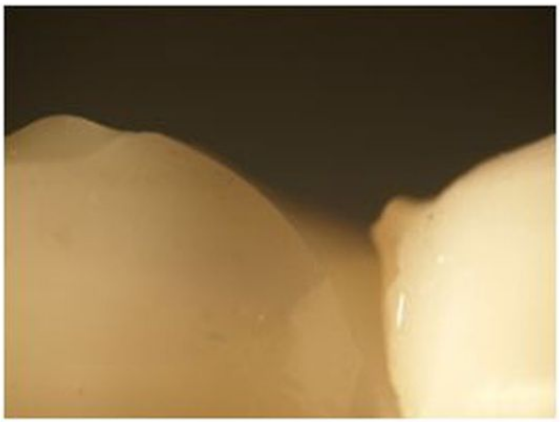

Fig. (4): stereomicroscope image here showing presence of compression curl which is an evidence of a tensile fracture that originate in an opposite direction from it. So the direction is from gingival to occlusal.

DISCUSSION

The aim of performing in-vitro experiments is to analyze indirect restoration failures, improving restorative procedures. And to get results comparable with in-vivo situations, it is important to design a test set-up producing a failure mode similar to that occurs clinically (10).

For standardizations in this study, natural teeth were not used for accurately control and duplicate preparation parameters, such as taper and finish line. Use of human teeth as abutment increases variability of fracture load results, possibly because the variability of extracted teeth dimensions usually leads to different preparation dimensions (15). The elastic modulus of the supporting structure is an important factor that controls stress distribution, so epoxy resin dies with same elastic modulus of dentin were used (16-18).

Confirmation of all preparations criteria, finish line thickness, parallelity and path of insertion checked virtually after scanning in a 3D optical scanner using zirconzhan Archiv CAD/CAM software.

According to Jalalian et al who stated that a deep chamfer margins improves the biomechanical performance of ceramic restorations due to the greater thickness and the rounded internal angles in deep chamfer margins which could resist the tensile forces created during cementation and loading of restorations a classical tooth preparation design with 1.5 mm occlusal reduction and 1mm chamfer finish line was done in Group I in this study (19).

Conservative tooth preparation design was used in Group II with 0.5 mm occlusal reduction and light chamfer 0.2 mm finish line comparing it with the first group according to manufacturer instructions.

In the present study, Group I fixed partial dentures showed a mean value of failure load of 1317.36 ± 186.11 N and Group II showed a mean of 1215.92 ± 217.03 with no significant difference between them ($P= 0.450$).

The absence of failure during cyclic loading as well as the high failure load of both groups investigated in this study may be explained by the mechanical properties of zirconia, especially high strength, hardness and resistance to crack propagation combined with a small range of strength variation. Increased fracture toughness is commonly attributed to a local tetragonal to monoclinic phase transformation of Y-TZP (yttria-stabilized tetragonal zirconia polycrystals) upon external application of stress (20), which is accompanied by a 3–5% increase in volume.

The associated development of local compressive stresses is known to prevent further crack extension (21).

This transformation-toughening may have taken place in the investigated FPDs and may have contributed to the high failure load results. Group II showed a mean of failure load a little bet lower than that of Group I that may be due to the thin margin thickness of the retainers (0.2mm) that designed in Group II.

These results were in agreement with results of Preis et al who compared the failure load of three unit monolithic zirconia FPDs with different surface treatment. The preparation design was conventional with 1 mm deep chamfer finish line. The results of fracture resistance were between 1173.5 N and 1316.0 N (22).

Bömicke et al. compared failure load of monolithic zirconia FPDs with different designs of preparation in 2016. Results showed that the mean of failure load exceeded 1000N and showed fracture through the retainer wall (23).

In 2017, Partiyan et al. compared the failure load of monolithic zirconia FPDs with different designs and techniques of fabrication. Results showed mean of failure load over 1000N and the monolithic design showed fracture at the facial surface of the retainer extended to the loading point (24).

Again in 2017 Amaral et al. studied the effect of the grinding on the gingival part of the connector and the fatigue limit on the failure load of three unit monolithic zirconia FPDs. The failure load mean was 1907.66 N and the grinding didn’t affect the failure load results (25).

Waltimo and Anderson measured the maximum biting force during mastication. They found that biting force varies with the region in the oral cavity. The greatest biting force was found in the first molar region, whereas at the incisors it decreased to only about one third to one fourth that in the molar region. They showed that maximum biting force at the molar region varies from 216 to 847 N (26-29).

Körber and Ludwig who found that posterior FPDs should be strong enough to withstand a mean load of 500 N. Additionally, cyclic fatigue loading and stress corrosion fatigue caused by the oral environment must be considered as they weaken the all-ceramic restorations (29-32).

The endurance limit for fatigue cycling that can be applied to dental ceramics is approximately 50% of the maximal fracture strength of the restoration. Therefore, it is reasonable to assume that a minimum failure load of 1000 N is required for a favorable clinical prognosis of any all-ceramic FPD (33).

In the present study all the failure load results of the two groups exceeded 1000 N. Also, the fractographic analysis revealed that specimens demonstrated a typical tensile or brittle fracture pattern.

In Group I: Fracture propagated obliquely from gingival part of the connector to the occlusal loading point on the pontic. That may be due to the axial loading on the pontic, the occlusal embrasure was subjected to initial compressive stress, and tensile stress developed at the gingival embrasure area resulting in the crack propagation and fracture. Fractographic analysis results from stereomicroscope, SEM and CLSM showed presence of multiple fractographic features like *compression curl* (failure caused by bending stress, and is also known as a cantilever curl. It is the curved lip just before the total fracture of a ceramic body that failed by bending), *hackles* (lines on the fracture surface that runs in the local direction of cracking. It separates the crack surface, *twisted hackles* (that separates portions of the crack surface, each of which has rotated from the original crack plane in response to a lateral rotation or twist in the axis of principal tension) and *crack arresting lines* (the crack front shape of an arrested or momentarily hesitated crack prior to continuation of crack propagation under a more or less altered stress configuration). The analysis of the direction of each fractographic feature concluded that the direction was in occlusal direction from the gingival surface of the connector.

This mode of failure was in agreement with Onodera et al., in which the load was applied on the pontic of three units FPDs and the failure occurred at the connector and fractographic analysis revealed that failure started at the gingival part of the connector (34).

Preis et al. study revealed that all FPDs fracture pattern was a typical fracture between crown and pontic, originating at the gingival surface of the connector. Fractographic features like hackles, wake hackles, arrest lines and compression curls were clearly visible as indicators of the origin and direction of the crack propagation (22). In the study conducted by Amaral et al., the fracture that caused the failure of the FPDs was at the connector extended from the gingival and buccal part of the connector and directed occlusaly (25).

In Group II

Distal failure started from the margin of the retainer passing obliquely through the gingival part of the connector and then to the occlusal loading point on the pontic. That was due to the very thin retainer’s designed margins (0.2 mm thick). Fractographic analysis using stereomicroscope SEM and CLSM results in the presence of hackles and twisted hackles directed from the gingival part of the connector to occlusal. Presence of compression curl indicates brittle fracture and bending of the FPD which lead to fracture from the gingival part of the connector and directed occlusaly.

This mode of failure was in agreement with results of Bömicke et al. in 2016 (23) and Partiyan et al. in 2017 (24). In their studies the axial wall margin thickness of the retainer was o.5mm. The fracture also propagated from the thin margin to the gingival part of the connector and then to the occlusal loading point.

Mesial failure started at the buccal margin of the mesial retainer and ended at the gingival part of the mesial connector without including it as showed by crack arresting lines and the convexity of these arresting lines opposite to the hackles direction.

In the present study, the connector area was 9mm^2 according to manufacturer instructions; this was in agreement of previous studies of Filser et al and Raigrodski and Saltzer who concluded that the connector area had a strong effect on the failure load of any FPD and The connector size for three-unit FPDs should range between 7mm^2 and 16mm^2 (35, 36).

CONCLUSION

Within the limitations of this in vitro study, the following conclusions could be drawn:

1- The conservative tooth preparation design of the posterior 3 units FPDs is a very good alternative to the classical one.
2- Aging behavior, translucency testing, color reproduction and long-term clinical performance need to be further

assessed before recommending this conservative FPDs design for daily practice.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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