

Comparative fracture behavior of monolithic and veneered zirconia posterior fixed dental prostheses

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The purpose of this study was to evaluate and to compare the fracture load and the fracture pattern of monolithic and veneered zirconia posterior fixed dental prostheses (FDPs). Twenty standardized steel dies were prepared to receive posterior 3-unit FDPs. Specimens were randomly divided into 2 groups ($n=10$): (1) Lava Zirconia, and (2) Lava Plus. All FDPs were cemented using glass ionomer cement and subjected to thermal and mechanical cycling at 5–55°C with a 30-s dwell time for 120,000 masticatory cycles. All specimens were subjected to a three-point bending test until fracture. Data were statistically analyzed using Student's t test, paired t -test and Weibull statistics ($\alpha=0.05$). No differences were observed in fracture load between the groups. Veneering ceramic fractured before than framework in veneered zirconia group. The fracture pattern was different. The tested groups demonstrated clinically acceptable fracture load values. Monolithic zirconia solves the chipping problem.

Keywords: Zirconia, Monolithic, CAD/CAM, Fracture load, Fixed dental prostheses

INTRODUCTION

Since the introduction of the first ceramic crowns at the beginning of the 20th century, a constant progression occurred in materials and technologies in an attempt to look for an optimal solution to esthetic demand, as well as to avoid the disadvantage of the traditional manufacturing method. But since 1990s and mostly 2000s it was a great development in the field of dental ceramics, due to the high esthetic demand on the patients and in an attempt to improve the mechanical properties of the ceramics, specially to fabricate posterior fixed dental prostheses (FDPs). Therefore, research focused interest on computer aided design-computer aided manufacturing (CAD/CAM) zirconia ceramic¹⁻³.

Zirconia ceramic has excellent mechanical properties^{4,5}, however is highly opaque due to its completely crystalline microstructure, thus the framework must be covered with veneering porcelain for more acceptable esthetic outcome⁶.

But regardless of the high strength of the zirconia ceramic, one of the most important clinical problems is the chipping of the veneering ceramic according to the different clinic studies^{3,7-9}. This complication creates an uncertainty as regards the long-term clinical behavior of the zirconia bi-layered restorations¹⁰. Several efforts have been made to reinforce or to improve the fracture strength of the veneering ceramic such as high strength CAD/CAM ceramic¹¹, press ceramic^{12,13} or "double veneering"¹⁴. Monolithic zirconia has been recently introduced to avoid the bi-layered systems' disadvantages^{15,16}, however its behavior and chemical

stability have not yet been fully clarified¹⁶.

Consequently, in this study we prepared CAD/CAM zirconia 3-unit posterior FDPs with an intermediate pontic and investigated the fracture load of these FDPs. To this end, two types of commercial zirconia were selected. The objectives of the current study were to evaluate and to compare the fracture load and the fracture pattern of monolithic and veneered zirconia 3-unit posterior FDPs. The established null hypothesis was that no differences would be found in the fracture load values between the groups.

MATERIALS AND METHODS

Fabrication of the experimental model

Twenty standardized master dies, with two abutments and a base were prepared and machined in stainless steel (316L UNS S3 Alloy, Masteel, Birmingham, UK) in the Physical Science Faculty (University Complutense of Madrid, Spain) (Fig. 1). The abutments ($n=40$) were designed with 5 mm in height, a occlusal diameter of 5 mm, a 1-mm-wide chamfer circumferentially finish line, a 6° angle of convergence of the axial walls, and rounded angles, simulating clinical conditions. The abutments were randomly positioned and screwed in pairs on the metallic bases to receive posterior 3-unit FDPs, so that one of them simulated a first mandibular premolar and the other a first mandibular molar.

The master dies were randomly divided into two groups ($n=10$ each, according to the results of power analysis) categorized according to the zirconia system used to fabricate the FDPs: Group 1 (ZV): Lava Zirconia (3M ESPE, Seefeld, Germany) and Group 2 (ZM): Lava Plus (3M ESPE). The specimens were used

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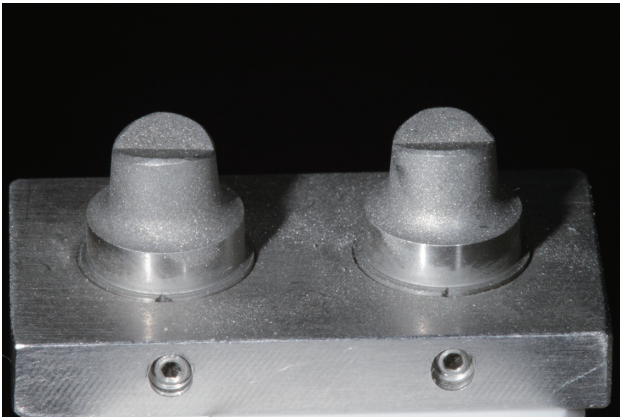


Fig. 1 Standardized steel specimen with two abutments and a base.

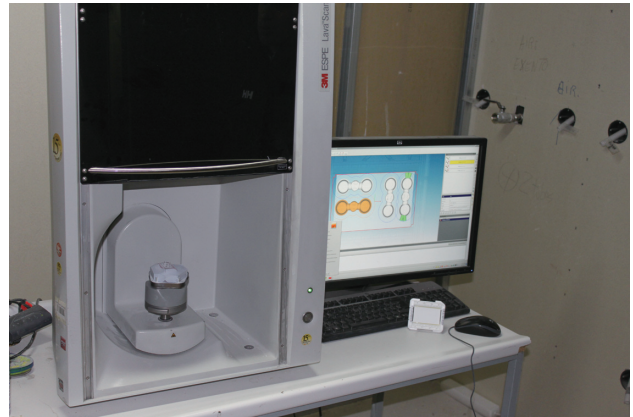


Fig. 2 Scanning and digitizing the steel dies with the Lava Scan.

as working dies.

Fabrication of the restorations

The restorations were prepared according to the manufacturer's specifications by the same experienced technician who was accustomed to work with the zirconia systems tested.

The fabrication of the veneered zirconia FDPs consisted of scanning and digitizing the steel dies with the Lava Scan (3M ESPE) (Fig. 2). All structures were prepared with a wall thickness of 0.5 mm, connector size of 9 mm² and an internal space of 50 μm for the luting agent. The restorations were milled from pre-sintered blocks in the milling unit (Lava Form, 3M ESPE), and the design was enlarged by 20% to offset post-sintering shrinkage. The sintering process was accomplished in the Lava Therm (3M ESPE) at 1,500°C. The frameworks were veneered, following the manufacturers' guidelines, with compatible hand-layered feldspathic ceramic (Lava Ceram, 3M ESPE) (0.5 mm thickness at the axial walls and 2 mm at the occlusal surface). To ensure that all the specimens had the same shape, one of the FDP framework was waxed and the shape was duplicated using a silicone putty-soft and light bodied material (Express Penta Putty and Express Penta Ultra-Light Body, 3M ESPE). The layering of the frameworks was then created from the impression.

The fabrication of the monolithic zirconia FDPs was similar to the veneered zirconia. The differences were that a total thickness of 1 mm at the axial walls and 2.5 mm at the occlusal surface was programmed in the software, and that the FDPs were milled with their final shape and were not veneered. All FDPs had the same final dimensions verified by measuring the FDPs at different locations using a digital micrometer (Mitutoyo, Tokyo, Japan) accurate to 0.01 mm.

The FDPs were luted onto their respective stainless-steel master dies using conventional glass ionomer cement (Ketac-Cem EasyMix, 3M-ESPE) by the same operator at room temperature (18–24°C) and relative

humidity (50±5%). The axial surfaces of the abutments were varnished with a thin layer of cement before inserting each FDP. A customized clamp was designed to maintain a constant seating load of 10 N for 10 min, determined with a dynamometric key (USAG 820/70, SWK Utensilerie, Milan, Italy).

Thermal and mechanical cycling

The experimental groups were subjected to thermal and mechanical cycling at the Faculty of Medicine and Dentistry of the Valencia University (Valencia, Spain). The specimens were thermocycled (Thermocycling TC-3, SD Mechatronik, Feldkirchen-Westerham, Germany) in distilled water for 43 cycles/h during 24 h (1,032 thermal cycles) at 5 and 55 degrees with a 30-s dwell time. A masticatory simulator (Chewing Simulator CS-4.2 economy line, SD Mechatronik) was used for mechanical cycling inducing 50 N load for 120,000 masticatory cycles. Loading was applied axially on the centre of the pontic of the FDPs with a vertical displacement of 2.5 mm¹⁷. After thermo-mechanical cycling all specimens were inspected under an stereo microscope (Nikon SMZ-10, Nikon, Tokyo, Japan).

Fracture load test

After fatigue simulation, all FDPs were subjected, according to the ISO 6872:2008, to a three-point bending test until fracture^{4,18} using a universal testing machine (UTM) at a crosshead speed of 1 mm/min (ME 405/10, SERVOSIS, Madrid, Spain) and at a room temperature of 23±1°C. This test was performed at the National Centre of Metallurgical Research (CENIM, CSIC, Madrid, Spain). Axial compressive loads were exerted by sliding a coneshaped stainless-steel bar (length: 12 mm) finished in a rounded tip (diameter: 1 mm) adapted to the UTM. This customized load piston was perpendicularly applied at the central fossa of each pontic until the fracture of the veneering ceramic in the Lava Zirconia group and the total fracture of the restorations in both groups, defined as a sharp decrease in the stress plot⁶.

The results were recorded using inbuilt software for the testing machine (PCD2K, SERVOSIS), and force (N)-displacement (mm) curves were automatically created.

The fracture patterns of the restorations were visually inspected and evaluated under a stereomicroscope (Nikon SMZ-10, Nikon) at 15 \times magnifications¹⁹. The fracture location was also assessed.

Statistical analysis

The mean values and standard deviations (SD) per group for the fracture load parameter were calculated. The data were analyzed using Students’s *t*-test and paired *t*-test. In addition Weibull characteristic strength (σ_0), and Weibull modulus (m), were calculated. The statistical significance level of significance was set at $\alpha=0.05$. All the statistical analyses were made with SPSS

22 (SPSS, Chicago, IL, USA) statistical software.

RESULTS

The specimens survived thermo-mechanical fatigue application. Neither cracks nor fracture failures were observed within the restorations.

The means and SD values for fracture load of the ceramic veneer and total fracture load of the ZV group are displayed in Table 1. The paired *t*-test revealed significant differences between ceramic veneer fracture and total fracture ($p<0.0001$).

The total fracture load values were higher than 1,000 N for both groups. Although ZM group showed the highest values (2,181.67 \pm 303.99 N) comparing with ZV (1,966.27 \pm 397.86 N), however no differences were shown between them (Fig. 3). Regarding Weibull

Table 1 Fracture load values of veneered zirconia group (Lava Zirconia)

Fracture	n	Mean	Maximum	Minimum
Veneering ceramic	10	927.96 (\pm 330.29)	1,548.40	487.06
Total fracture	10	1,966.27 (\pm 397.86)	2,473.52	1,255.38

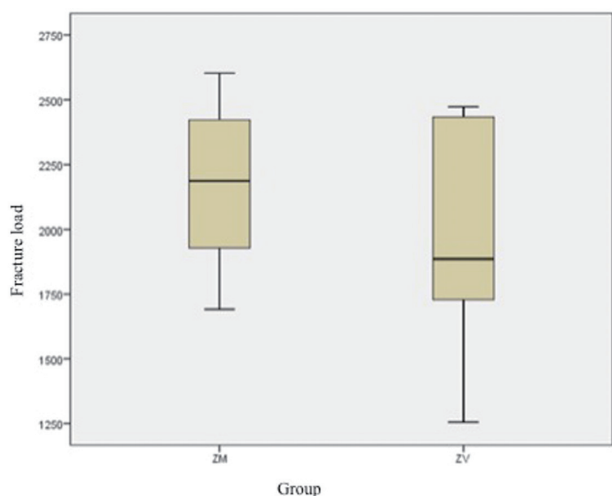


Fig. 3 Box plots of fracture load values of the FDPs. Horizontal line in each box represents median value (*ZM: monolithic zirconia. ZV: veneered zirconia).

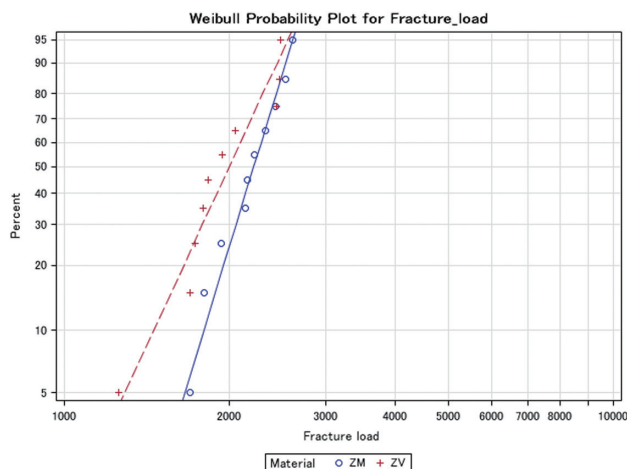


Fig. 4 Weibull probability plot of the fracture load (*ZM: average fracture load of the monolithic zirconia FDPs, ZV: average fracture load of the zirconia veneered FDPs).

Table 2 Weibull statistics of fracture load

	m=Weibull shape				σ_0 =Weibull scale			
	Estimate	St Error	Lower	Upper	Estimate	St Error	Lower	Upper
ZM	8.9585	2.2669	5.4557	14.7104	2,306.8193	85.8842	2,144.4843	2,481.4429
ZV	5.9567	1.4892	3.6493	9.7232	2,122.0645	118.9806	1,901.2233	2,368.5581

ZM: Monolithic zirconia; ZV: Veneered zirconia

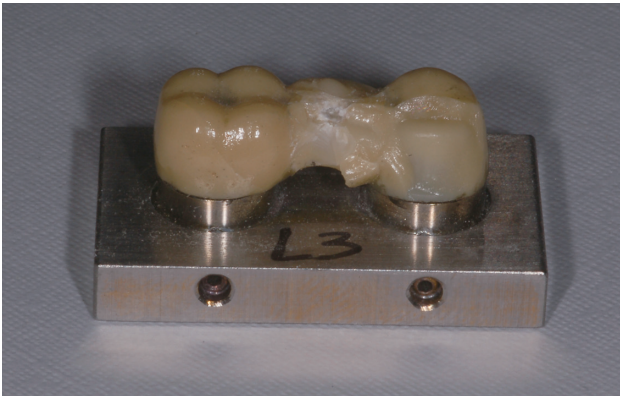


Fig. 5 Delamination of the veneering ceramic in a Lava zirconia specimen.

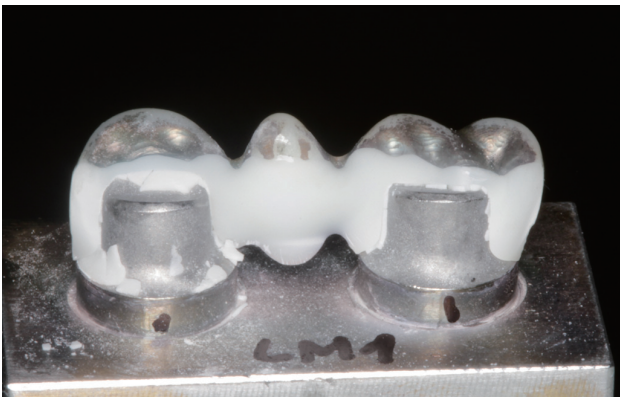


Fig. 6 Fracture pattern of a monolithic zirconia specimen.

statistics, upper and lower confidence bounds were applied on the curves to look for overlap in order to investigate the existence of significant differences among the Weibull distribution parameters. Likewise, no significant differences were found between ZM and ZV groups (Table 2, Fig. 4).

In the ZV group the veneering porcelain always failed before the total fracture of the specimens, resulting in delamination of the ceramic coating (Fig. 5). The fracture mainly (90%) started at the cervical area of the connectors and was diagonally propagated toward the occlusal surface of the pontic through the loading point. All (100%) of the monolithic restorations exhibited vertical fracture in a catastrophic manner, started at the occlusal surface of the FDPs (Fig. 6).

DISCUSSION

This research attempts to evaluate and to compare the fracture load of veneered and monolithic CAD/CAM zirconia on posterior FDPs. The data obtained in the study support the acceptance of the null hypothesis because no differences in fracture load were shown between the groups.

Monolithic zirconia obtained the highest fracture load values although no differences were shown with bi-layered zirconia group. Although a previous study²⁰ showed higher fracture strength of monolithic zirconia crowns in comparison to the bi-layer configuration, no studies were found with FDPs of monolithic zirconia, therefore comparison of the results was not possible. Lava Zirconia is the most studied zirconia system. The results of the study are similar to previous studies in crowns^{21,22}, but higher than the most studies in FDPs, with values below of 2,000 N^{23,24}. Nevertheless, it is important to consider that fracture load presented by the groups tested, higher than 1,000 N, was higher than maximum chewing forces reported in the literature, which is expected to be around 700 N for healthy young adults^{21,25}. Therefore, the results indicated that the fracture load presented by the zirconia groups tested may tolerate the clinical applications without restrictions.

Several factors that can affect the fracture resistance of zirconia restoration have been described previously in *in vitro* studies: microstructure, manufacture technique, veneering procedure, surface treatment, or cementation of the restorations⁴, and also the conditions of the experiment: storage conditions, fatigue test employed, or the direction and location of the load applied²⁶. Therefore, it is very difficult to compare the results of the studies²⁷.

In the present study, the design and dimensions of the specimens were identical, therefore both groups are comparable. Likewise, an anatomic design of the core was made, since previous studies reported the importance of the anatomic design to ensure a uniform thickness of the veneer ceramic and to avoid chipping^{4,28}.

Although thermal and mechanical cycling combined are unusual on zirconia studies¹⁷, in the present study both tests were applied before the fracture test to simulate the effect of the oral environment. This reproduction of the *in vivo* condition was designed to observe changes representative of the expected clinical *in vivo* changes, which might result in the undesired phenomenon of low temperature degradation (LTD)²⁰. In the study, a load application in the range of physiologic occlusal forces of 50 N was selected according to previous studies^{17,29}. All FDPs survived the artificial aging in the chewing simulator, indicating this result a stable performance of the zirconia ceramics analyzed in the presence of mechanical and thermal stress like in the oral environment, as previously reported^{17,20,29}. In the study 3-point flexure test until fracture was used as previously reported^{4,18}.

The veneering ceramic fractured before than the core in 100% of the Lava zirconia FDPs, similar to previous study in crowns²¹, but different to other findings²². Chipping of porcelain veneer could be due to a higher mechanical properties of zirconia core²⁸. The fracture load values in the ceramic veneer observed in the study were similar to those obtained for and Ludwig³⁰ in Lava FDPs, but are lower than reported by Agustin *et al.*²¹ for Lava crowns. It is well known the role of thermal behavior between bonded materials in bilayered ceramic

restorations³¹). Coefficient of thermal expansion (CTE) mismatch of the materials leads to decrease in bond strength³². The CTE of the veneering ceramic in the Lava Zirconia group was lower than the core material, therefore this could produce compression loads on veneering ceramic and compensatory tension loads on the core surface as previously reported³¹).

The failure mainly occurred at the cervical area of the connector on veneered zirconia restorations according with previous studies^{10,18,19,33,34}). The fracture was initiated at the gingival embrasure of the connector, and propagated toward the occlusal surface of the pontic diagonally through the loading point as previously described^{11,31-34}). Thus the results support that the connector design is an important factor for the fracture resistance and longevity of zirconia FDPs^{1,19,34-36}). In the study, the connector area was 9 mm² as previously recommended^{3,10,19,23,33,36}). However, monolithic restorations have demonstrated a different fracture pattern, with a catastrophic fracture initiated at the occlusal surface of the retainers and pontic. Further research are required to investigate this fracture pattern.

There were some limitations in the study. The sample numbers were small, although power analysis indicated that 10 samples per group were sufficient. Micro-structural variations of natural teeth preparations and other subsequent variables related to impression, pouring techniques and prescriptions^{37,38}) were avoided by using standardized metallic models^{2,6,12,19,39}), although this not reflects the clinical situation. The conditions of thermal cycles meet the requirements of the ISO TR 11450, however and although there is a lack of standardization, several studies recommend that more cycles are needed^{16,17,20,29,40}).

The results of the study indicate that monolithic zirconia restorations are an indication for clinical application and will solve the chipping problem⁴¹). However, futures *in vitro* research concerning the behavior of monolithic zirconia and clinical studies should be performed to evaluate the clinical performance of monolithic zirconia restorations before being considered generally applicable.

CONCLUSION

Within the limitations of this *in vitro* study, the tested groups demonstrated clinically acceptable fracture load values. The results indicate that monolithic zirconia may be recommended for solving the chipping problem, as it recorded comparable fracture resistance than did the analyzed veneered zirconia FDPs.

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