Original Article

A Comparative Analysis on Fracture Resistance of Three All-Ceramic Systems – An *In Vitro* Study

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Abstract

Background: All-ceramic dental materials, like any other ceramics, are inherently fragile in tension, and may be affected by microcracking, flaws, and defects that may be introduced during thermal treatment or fabrication procedures. The objective of the study was to evaluate and compare the fracture resistance of three all-ceramic materials, zirconia, lithium disilicate, and conventional feldspathic porcelain under standardized laboratory condition. **Methods:** Sixty identical monolithic disk-shaped samples of approximately 10 mm diameter and 2 mm even thickness were fabricated using zirconia, lithium disilicate, and feldspathic porcelain with 20 samples in each group. All the sample specimen were stored in artificial saliva (prepared according to Macknight – Hane and Whitford formula 1992) at temperature of 37 ± 1°C for 3 months until they underwent compressive loading in a Universal Testing Machine. The values so obtained were evaluated and compared. **Results:** The results on fracture resistance showed that zirconia had the highest fracture resistance (3542.98 ± 176.00589 N) exhibiting highest strength followed by lithium disilicate (2504.03 ± 264.35990 N) and feldspathic porcelain ceramics (732.09 ± 15.28330 N). **Conclusion:** Within the limitations, the present study supports the finding that monolithic zirconia crowns were found to have higher fracture resistance than monolithic heat pressed lithium disilicate crowns. The fracture resistance of conventional monolithic feldspathic porcelain crown was significantly lower compared to the other two groups.

Keywords: All-ceramic systems, Fracture resistance, Lithium disilicate, Monolithic, Zirconia.

Introduction

In dentistry, ceramics represent one of the major classes of materials used for the reconstruction of decayed, damaged or missing teeth, as well as associated supporting structures. The American Ceramic Society had defined ceramics as inorganic, non-metallic materials, which are typically crystalline in nature, and are compounds formed between metallic and non-metallic elements such as aluminum and oxygen, calcium and oxygen, and silicon and nitrogen. All-ceramic materials mimic the life-like esthetics of natural teeth, but they too have some drawbacks.[1] All-ceramic dental materials, like any other ceramics, are inherently fragile in tension, and may be affected by micro cracking, flaws, and defects that may be introduced during thermal treatment or fabrication procedures. All-ceramic restorations are subjected to intermittent forces during fabrication and mastication. The optimum strength of any ceramic is dependent on the fabrication procedure and the minimization of flaws extensive research into the mechanical properties and clinical performance of various all-ceramic materials have been carried out over the past two decades. In spite of this, there still exist a dilemma as of which material is best in its performance.[2]

Before being adopted as a routine clinical or laboratory procedure, it is important that the procedure be substantiated by *in vitro* and *in vivo* studies. With the plethora of new ceramic systems and materials on the market, the selection and decisions about their suitability in different clinical stress situations can be difficult. Therefore, it is advantageous to assess the fracture and durability of ceramic materials using relevant *in vitro* tests. This study investigates the fracture

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resistance of three monolithic all-ceramic materials and compares their fracture resistance with each other.[3]

Materials and Methods

In this study, monolithic disk-shaped samples of feldspathic porcelain, lithium disilicate, and zirconia were used to compare the fracture resistance. Samples were prepared with dimensions of 10 mm diameter which approximately simulated the mesiodistal and buccolingual dimensions of mandibular molar and 2 mm thickness which was considered as ideal thickness for all-ceramic crowns. To obtain these disk-shaped samples, 60 wax patterns were fabricated. The wax patterns were fabricated using pressing wax (Delta Labs) with the help of PKT instruments. Metal mold with slots of 10 mm diameter and 2 mm depth was fabricated to standardize the wax pattern. Wax gauge and scale were used to measure the dimension and necessary arrangements were done (Figure 1).

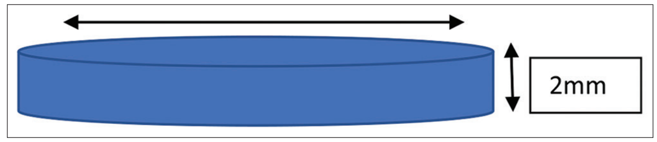

Figure 1: Schematic diagram of disk-shaped wax pattern

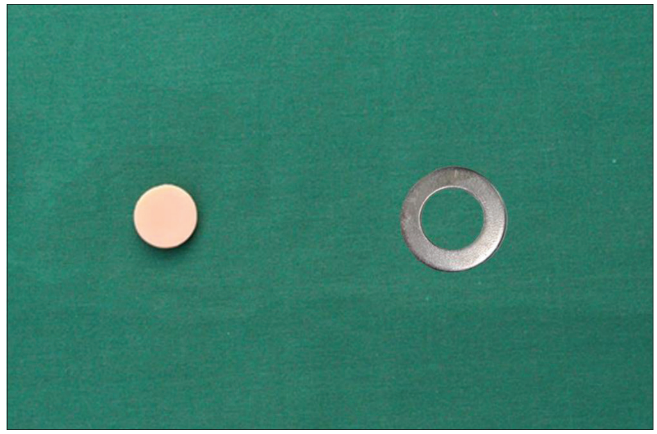

Figure 2: Metal mold used to standardize the size

The first group of samples was fabricated with monolithic conventional feldspathic porcelain.

Twenty disk-shaped wax patterns were invested using phosphate bonded investment (IPS PressVest) in the IPS investment ring system. After the investment was completely set, it was placed in a burnout furnace up to 1562°F (850°C) with a holding period of 60 min for wax elimination. The mold so obtained was applied with a separating agent (unisep no.15511000) and was allowed to dry.

The dentin powder was mixed to a creamy consistency with VITA modeling fluid on a glass slab. The mix was painted on to the prepared mold. Gentle tapping with a brush and light tapping on the mold produced adequate vibration during the preliminary stage of condensation. Excess surface moisture was removed with the help of a tissue paper. The ceramic build up was done to mold size and mold was introduced into the furnace for firing. The firing was done in the ceramic furnace (IvoclarVivadent, E Programmat 3000). Once the firing was over, the investment was allowed to cool before the ceramic disk was retrieved. Once the core was retrieved using diamond disks, the core was then sandblasted using 50 µm glass beads to remove any further residue for 15 s at 60 psi. Then, the core was trimmed and polished to get the required dimensions. The dimensions of the cores were confirmed using digital calipers. The size of the samples was also confirmed using the metal mold (Figure 2).

The second group of samples was fabricated using fresh ingots of lithium disilicate. Twenty disk-shaped wax patterns were fabricated in the standardized dimension as mentioned above.

These disk-shaped wax patterns were then invested using phosphate bonded investment (IPS PressVest) in IPS investment ring system. After the investment was completely set, it was placed in a burnout furnace up to 1562°F (850°C) with a holding period of 60 min for wax elimination. In each investment ring one ingot of E-max Press 3.2 gram, ingot was placed followed by Alox plunger for pressing at 920°C. The firing furnace was programmed according to manufacturer's recommendations. Once the firing was over, the investment was allowed to cool before the pressed cylindrical core was retrieved.

Once the core was retrieved using diamond disks, the cylindrical core was placed in IPS E.max press Invex liquid for removal of all the residue and investment material. The core was, then, sandblasted using 50 µmeter glass beads to remove any further residue for 15 s at 60 psi. Then, the core was trimmed and polished to get the required dimensions. The dimensions of the cylindrical cores were confirmed using digital calipers as well as metal mold.

The third group was fabricated with monolithic zirconia. Twenty disk-shaped samples of monolithic zirconia were milled from zirconia disks using cad cam technology. To obtain the disk-shaped samples, 20 wax patterns were prepared. The image of the wax patterns was acquired with digital impression system. The samples were milled from zirconia disks by the milling machine with the help of digital data obtained.

Testing of Compressive Strength

The specimens were ground flat on both sides using 400 and 5600 grit silicon carbide paper and were measured with a digital caliper for parallelism to ±0.05 mm, and the thickness of each specimen was recorded.

The 60 samples each of Group A, Group B, and Group C were stored in artificial saliva (prepared according to Macknight – Hane and Whitford formula 1992) at temperature of 37 ± 1°C for a period of 3 months until they underwent compressive loading. The saliva preparation was changed with fresh formula for 3 months.

A standard test method was used for testing the compressive strength of the disks.

The instrument used for measuring the compressive load at which the disks fractured was INSTRON Universal Testing Machine (INSTRON 3365). The loading and supporting rings were designed to utilize miniature disk specimens in accordance with ASTM C1499-05 (Standard Test Method for Monotonic Equibiaxial Flexural Strength of Advanced Ceramics at Ambient Temperature).

The universal testing machine used for the test was connected to a computer for operating the machine and for analysis and printing of data obtained by this machine. A total of 60 specimens were tested, that is, 20 specimens each, from three groups were tested. The support ring of 5 mm diameter was placed on the loading platform of the testing device. The disk-shaped sample was placed on the support ring. The loading ring, which had a diameter of 2.5mm, was then placed on top of the specimen disk. A force was applied with the universal testing machine at a rate of 0.75 mm/min in compressive mode until the material failed. The machine stopped when the sample failure occurred.

A 10-kN load cell was used with a load range of 50%. The load at which the disk fractured was recorded for each disk. The obtained results were statistically studied and results were analyzed.

Results

The ring on ring test was used to measure the fracture resistance of the specimens. The fracture resistance values obtained is tabulated in Table 1.

Table 1: Fracture resistance of ceramics obtained from ring on ring test

	Fracture resistance (N)		
S. No.	Feldspathic porcelain	Lithium disilicate	Zirconia
1	702.54	1650.85	2894.98
2	715.23	1984.03	3056.85
3	694.25	2013.86	2988.03
4	732.09	2487.55	3200.96
5	685.71	2384.95	3475.85
6	714.63	2504.03	3275.65
7	731.85	2115.92	3276.05
8	697.05	1873.98	2996.94
9	675.67	1739.05	3420.05
10	711.02	1994.89	3297.54
11	679.86	2067.43	3542.98
12	703.99	2367.04	3014.98
13	711.63	1989.97	3156.76
14	693.56	2265.92	3253.76
15	687.64	2438.85	3283.07
16	703.54	2046.84	3096.54
17	718.09	2401.54	3256.85
18	696.96	2473.05	3116.94
19	705.99	2311.76	3285.58
20	710.02	1854.96	3438.93

The statistical analysis of fracture resistance of lithium disilicate, feldspathic ceramic, and zirconia is shown in Table 2.

The fracture resistance values obtained in Table 2 were analyzed for significance by subjecting to analysis of variance test (ANOVA). It was observed that there is statistically significant difference in values among the three commonly used ceramics as $P = 0$ ($P < 0.05$). Hence, intergroup comparisons were done using *post hoc* analysis.

It was, therefore, inferred that the fracture resistance of Zirconia > Lithium Disilicate > conventional porcelain which is statistically significant (Figure 3).

Discussion

The use of ceramics in dentistry dates as far back as 1889 when Charles H. Land patented the all-porcelain "jacket" crown (PJC). The restoration was extensively used after improvements were made by E.B. Spaulding and publicized by W.A. Capon. While not known for its strength due to internal micro-cracking, the PJC was used extensively until the 1950s. To reduce the risk of internal microcracking during the cooling phase of fabrication, the porcelain-fused-to-metal crown was developed in the late 1950s by Abraham Weinstein. A resurgence of an all-ceramic restoration came in 1965 when W. McLean and T.H. Hughes developed a new version of the porcelain jacket crown that had an inner core of aluminous porcelain containing 40–50% alumina crystals. Although it had twice the strength of the traditional PJC, it still could be used in the anterior region only (due to its lower strength). Its higher opacity was also major drawback. Another development in the 1950s by Corning Glass Works led to the creation of the castable Dicor® crown.[4]

The fracture resistance of monolithic zirconia has been explored by different authors, since it has been recommended to use full-contour zirconia especially in load-bearing areas.[5,6]

Preis *et al.* evaluated the failure and fracture resistance of three-unit zirconia-based FPDs under the influence of different surface treatments (veneering and glazing) and adjustment (polishing and grinding) procedures. All the groups were subjected to thermal cycling (TC) and mechanical loading (ML). Except for one group, all the groups were anatomically designed. Sintering, sandblasting, and glazing procedures were performed on the specimens of the control group without TC and ML. The authors observed no failure of fixed-dental-prostheses (FDPs) during TC and ML conducted in a chewing simulator, but wear occurred at contact points. The median fracture force ranged between 1173.5 and 1316.0 N without significant differences either between the groups, or in comparison to the control. Full-contour polished or glazed zirconia FDPs might be an alternative to veneered restorations due to their high resistance to failure and fracture.[7]

Zesewitz *et al.* used single monolithic zirconia crown (MZC), monolithic lithium disilicate, and monolithic feldspar ceramic

Table 2: Statistical analysis of fracture resistance among ceramics

Sample units	N	Mean	Standard deviation	Standard error	95% confidence interval for mean
					Lower bound
Feldspathic porcelain	20	703.5660	15.28330	3.41745	696.4132
Lithium disilicate	20	2148.3235	264.35990	59.11267	2024.5993
Zirconia	20	3216.4645	176.00589	39.35611	3134.0912
Total	60	2022.7847	1053.96947	136.06687	1750.5155

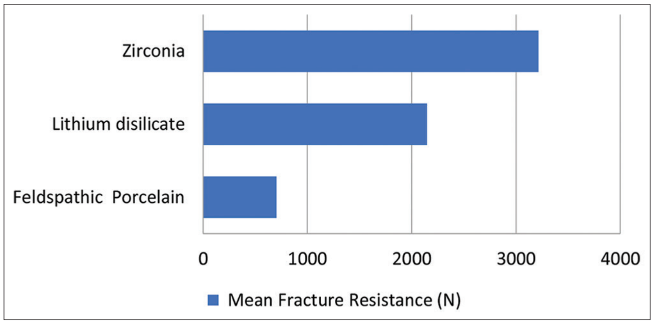

Figure 3: Comparison of fracture resistance of feldspathic porcelain, lithium disilicate and zirconia samples

in their study. Monolithic zirconia showed the highest fracture resistance of all the samples studied under axial loading. The highest mean fracture force was reported as 5.620 N for zirconia crowns.[8]

Beuer *et al.* tested the load-bearing capacity of full-contour zirconia with different surface treatments. Polished, sintered, and glazed zirconia showed a significantly higher load-bearing capacity than conventional veneering. The authors found no significant difference in the fracture load between polished and glazed zirconia, while sintered zirconia had a significantly lower load-bearing capacity than polished zirconia and glazed zirconia. The mean fracture load for both polished and glazed zirconia was above 10,000 N, which is higher than most values reported in the literature.[9] The authors ascribed this result to the abutment material, which was metal, and the diameter of the loading piston (tungsten ball with a 10.0 mm diameter).[10,11]

Sun *et al.* performed a load-to-fracture test to evaluate the load-bearing capacity of monolithic zirconia with different thicknesses. The fracture load for MZCs (1.5 mm), calculated as 4109.93 ± 610.18 N, was found to be significantly higher than that of monolithic lithium disilicate (1863.16 ± 116.81 N), metal ceramic (2284.77 ± 355.60 N), and layered zirconia (2308.0 ± 510.94 N). The value of the fracture load of monolithic zirconia decreased with reduced material thickness (3068.31 ± 233.88 N for MZC (1.2 mm), 2429.88 ± 315.03 N for MZC (1.0 mm), 1814.60 ± 68.21 N for MZC (0.8 mm), and 1308.38 ± 111.38 N for MZC (0.6 mm). The fracture mode was catastrophic failure for MZCs, which indicates better resistance to fracture load than veneered crowns.[12]

In a study by Nakamura *et al*., the effect of the axial and occlusal thickness of MZCs on the fracture load was tested. The fracture resistance of MZCs with reduced thickness was compared with that of monolithic lithium disilicate crowns with regular thickness.[13] The load-to-failure test revealed that the fracture load of the zirconia crowns with occlusal thickness of 0.5 mm (5558 ± 522 N) was significantly higher than that of lithium disilicate crowns with occlusal thickness of 1.5 mm (3147 ± 409 N).[14]

The clinical performance of all-ceramic crown is known to be associated with a complex combination of factors including the material selected, damage introduced during shaping and placement procedures, adhesive or luting system, the tooth substrate (natural dentin or foundation restoration), and the response to cyclic loading in response to complex loading of occlusal function.[15-17]

In the present study, three groups of monolithic all-ceramic crowns were tested for their fracture resistance and their values were compared. To simulate a clinically relevant condition, the sample specimen were fabricated in disk shape with a thickness of 2 mm which is considered as ideal thickness for all-ceramic crowns and diameter of 10 mm which approximately simulates the mesiodistal and buccolingual dimension of mandibular molars.[18,19] These samples were then soaked in artificial saliva and were placed in an incubator at 37°C for 3 months to simulate oral environment.[20,17]

The samples were then subjected to compressive loading in a Universal Testing Machine. A 10-kN load cell was used with a load range of 50%. The load at which the disk fractured was recorded for each disk. Twenty values were obtained from each group. The fracture resistance values were compared among the three groups and were statistically analyzed.

Within the limitations of this study, the present study support the finding that MZCs were found to have higher fracture resistance than monolithic heat pressed lithium disilicate crowns. The fracture resistance of conventional monolithic feldspathic porcelain crowns was significantly lower compared to the other two groups and is considered to be not suitable for all-ceramic restorations in load-bearing areas.

Conclusion

Within the limitations of this study:

- The fracture resistance of feldspathic porcelain samples varies from 675.67 N to 732.09 N with mean and standard deviation of 703.5660 N and 15.28330 N, respectively.
- The fracture resistance of lithium disilicate samples varies from 1650.85 N to 2504.03N with mean and

standard deviation of 2148.3235 N and 264.35990 N, respectively.

- The fracture resistance of zirconia samples varies from 2894.98 N to 3542.98 N with mean and standard deviation of 3216.4645 N and 176.00589 N.

On subjecting to ANOVA test, it was observed that there was statistically significant difference in values among the three commonly used ceramics as $P = 0$ ($P < 0.05$).

Therefore, the present study supports the finding that MZCs were found to have higher fracture resistance than monolithic heat pressed lithium disilicate crowns. The fracture resistance of conventional monolithic feldspathic porcelain crown was significantly lower compared to other two groups. Thus, monolithic zirconia and monolithic lithium disilicate materials are considered to be suitable for all-ceramic restorations in load-bearing area.

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