Original Article

In vitro evaluation of fracture resistance and cyclic fatigue resistance of computer-aided design-on and hand-layered zirconia crowns following cementation on epoxy dies

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Abstract

Aim: This *in vitro* study was to compare the fracture resistance and cyclic fatigue resistance of hand-layered zirconia crowns and computer-aided design (CAD)-on crowns (lithium disilicate with zirconium oxide).

Settings and Design: Comparative -*Invitro* study design.

Materials and Methods: All ceramic crown preparation was done on a mandibular molar ivorine tooth, impression made, and duplicated. Twenty hand-layered zirconia crowns and twenty CAD-on crowns were fabricated using CAD/computer-aided manufacturing (CAD/CAM) technique. All crowns were cemented to their respective dies using resin cement for evaluating fracture resistance and cyclic fatigue resistance using universal testing machine.

Statistical Analysis Used: Independent samples *t*-test, Mann–Whitney U-test, and Shapiro–Wilk test were used.

Results: The mean fracture resistance of CAD-on crowns (2660.50 ± 501.303 N) was significantly more than that of hand-layered zirconia crowns (1963.60 ± 452.895 N) (independent samples *t*-test, $P < 0.023$). Cyclic fatigue resistance test results showed that the mean number of cycles before failure for hand-layered zirconia crowns was 175,297 and for CAD-on crowns was 212,097 (Mann–Whitney U-test, $P < 0.012$).

Conclusion: CAD-on crowns were found to have significantly higher fracture resistance and cyclic fatigue resistance properties than hand-layered zirconia crowns.

Keywords: Cyclic fatigue, fracture resistance, lithium disilicate, zirconia

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INTRODUCTION

The porcelain fused-to-metal crowns (PFMs) were the most widely used fixed dental prosthesis until the advent of computer-aided design/computer-aided manufacturing (CAD/CAM) technology.[1,2] Although PFM crowns have given satisfactory esthetic results,[3-5] they had certain inherent limitations such as crown discoloration,[6,7] metal visibility at areas having minimal porcelain thickness,

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metal margin visibility when gingival recession occurs,[6] and metal hypersensitivity.[6] In addition to this, the fabrication of PFM crowns is highly technique sensitive[3] and requires a skilled and trained operator apart from being time-consuming.[3,8] In case of PFM crowns, the operator has to take safety precautions to prevent physical damage from heat generated during trimming of metal, metal particles from injuring the eye, skin allergy, and inhalation of metal particles.[6]

All ceramic prostheses have an inherent weakness in their compressive strength[3] and hence were not a popular choice for use as fixed dental prostheses in the posterior teeth.[3] However, the introduction of zirconia for fabricating fixed dental prostheses has brought about drastic advancement in obtaining high strength[3,7,9] and biocompatible properties of all ceramic restorations.[9,10] The versatility of CAD/CAM has made the fabrication of ceramic-based fixed prostheses less cumbersome and improved esthetics to a greater extent.[9-13]

Over the last 10 years, zirconia has garnered attention due to its favorable optical and mechanical properties. Although some research has been performed that revealed certain important properties of zirconia, many parameters are unknown for which further testing and evaluation is necessary.[14]

CAD-on is a novel and an innovative technique which employs fabricating veneer and coping structures separately through CAD/CAM and fusing them to obtain a single-crown structure. The objective of this study was to compare the fracture resistance and cyclic fatigue resistance of hand-layered zirconia crowns with CAD-on crowns (lithium disilicate with zirconium oxide) in *in vitro*. The null hypothesis of the study is that there is no difference in fracture resistance and cyclic fatigue resistance between hand-layered zirconia crowns and CAD-on crowns.

MATERIALS AND METHODS

The study was approved by the Institutional Review Board (IRB Approval No: SRB/SDMDS12ORT43). All ceramic crown preparation was done on a mandibular molar ivorine tooth, polyvinyl siloxane impression made, and duplicated. A master cast was scanned using an optical scanner. Forty replication dies were made using epoxy resin. Twenty hand-layered zirconia crowns and twenty CAD-on crowns were fabricated using CAD/CAM technique (CEREC 3 system). The crowns were cemented to their respective dies by resin cement for evaluating fracture resistance and cyclic fatigue resistance using a universal testing machine (Instron).

Procedure

Tooth preparation

The ceramic crown preparation was done on a mandibular molar ivorine tooth replica [Figure 1] to receive an CAD/CAM crown that followed the measurements suggested for the CEREC 3 system (ver. 4.2) (Dentsply Sirona, Long Island City, New York, United States).[15]

Master cast preparation and optical scanning

The impressions of the prepared mandibular molar ivorine tooth along with the lower and upper teeth were made using polyvinyl siloxane impression material (Betasil putty and light body, Müller-Omicron GmbH®, Lindlar, Germany). The master cast was poured using CEREC stone (Dentsply Sirona, Long Island City, New York, United States). Optic spray (Sirona Dental Systems GmbH®, Bensheim, Germany) was sprayed over the master cast in areas of the prepared tooth along with the adjacent teeth as well as their opposing teeth in the upper arch and subsequently scanned using an CEREC Omnicam (Dentsply Sirona, Long Island City, New York, United States).

Epoxy die preparation

The prepared mandibular molar ivorine tooth was used as a master die, and its impression was recorded forty times using a silicone putty material (Zhermack®, Italy). These putty indexes were used to fabricate 40 replicas of the prepared molar ivorine tooth by the application of epoxy resin (Alfa Aesar®, England) ISO specification 9001:2015, which is close to the human dentin Young's modulus (12.9 Grade Point Average [GPA]).[8,15,16] The epoxy resin was manipulated by mixing it with a hardener (BASF®, USA) in a ratio of 1:1. Immediately after mixing the resin with the hardener, it was poured into the 40 putty indices and

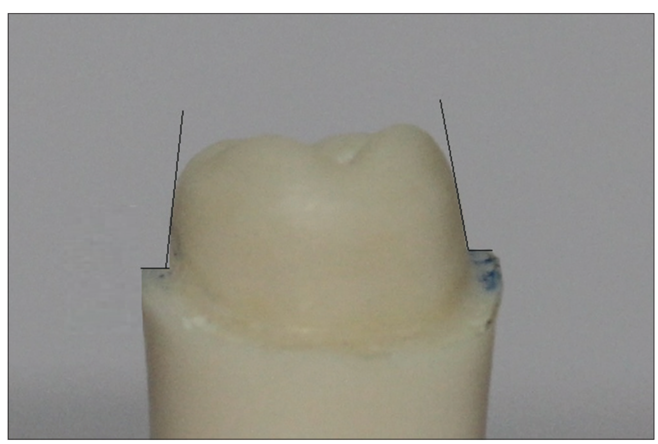

Figure 1: Dimensions of the prepared molar ivorine tooth – 6° ±2° (total angle of convergence) and 1 mm wide (circumferential shoulder)

then cured at room temperature for 24 h; once set, they were separated from their molds. The dimensional accuracy of these replicas was measured using a caliper (Ivoclar Vivadent®, Schaan, Liechtenstein) both faciolingually and mesiodistally at predetermined locations.

Preparation of hand-layered zirconia crowns

Twenty copings were fabricated from partially sintered zirconia block shade A2 LT (low translucency) with dimensions of 65 mm × 25 mm (length × breadth) employing CEREC 3 version 4.2 milling unit (Dentsply Sirona, Long Island City, New York, United States), and CAD/CAM system is a subtraction method in which material is removed to create the precise shape of ceramic crown. Two types of burs were used for milling: cylinder-pointed bur and step bur with size 12 S and 20 (Dentsply Sirona, Long Island City, New York, United States), respectively. Preparing diamond burs was changed after milling ten copings. The zirconia copings had a 0.5 mm occlusal wall thickness with 40 μm cement space thickness, and the copings were sintered using Sirona InLab (Dentsply Sirona, Long Island City, New York, United States) based on the manufacturer's instructions: sintering temperature was maintained at 1540°C for the duration of 3 h. Ceramic layering was performed using Cercon Ceram Kiss (Dentsply®, USA) powder as per the manufacturer's instructions. The ceramic veneering material (Cercon Ceram kiss) which is distinctly made for the veneering purpose in crowns and bridges was fabricated using zirconia.[17] Initially, Power Chroma 2 (for A2 shade) was layered upon the coping followed by layering with dentin/body (DA2) and finally by layering at the shoulder (SM2) and incisal (S2) and fired at 850°C. The furnace Programat P300 (Ivoclar Vivadent®, Schaan, Liechtenstein) was used to firing the veneering porcelain. To reduce the disparity in the crowns, the skills of an experienced dental technician were used. To attain uniform thickness of 1.5 ± 0.1 mm in the region of central fossae, mesiodistal and buccolingual measurements at the height of contour, were measured and verified using a stainless steel caliper (Buffalo Dental Manufacturing Co®. Syosset, NY).

Preparation of computer-aided design-on crowns

Twenty veneers were fabricated from IPS e.max CAD (lithium disilicate) block A2 shade LT (low translucency) 14 mm (length) (Ivoclar Vivadent®, Schaan, Liechtenstein). Twenty zirconia (zirconium oxide) copings were fabricated as previously mentioned for hand-layered zirconia crowns. The IPS e.max CAD-lithium disilicate (veneer) and zirconia (coping) had an occlusal wall thickness of 1 mm and 0.5 mm, respectively [Figure 2], with 40 μm cement space thickness. IPS e.max CAD Crystal/Connect (Ivoclar Vivadent®, Schaan, Liechtenstein) contains powder (SiO_2, Al_2O_3, Na_2O, K_2O, ZnO, and other oxides) and liquid (water, butanediol, and zinc chloride). It was used to create a homogenous bond to fuse the glass ceramic between veneer structure (lithium disilicate) and coping (zirconium oxide).[17,18] The IPS e.max CAD Crystal/Connect material was applied over the coping (zirconium oxide) as well as inside the veneer structure (lithium disilicate). Gentle finger pressure was applied and the veneer along with the coping was placed over the Ivomix vibrator (Ivoclar Vivadent®, Schaan, Liechtenstein) for 20 s. A soft brush was used to remove excess material. IPS Object Fix Flow material (Ivoclar Vivadent®, Schaan, Liechtenstein) is easy to apply and remove after the firing procedure, contains oxides, water and thickening agent which is used for stabilization of crowns on crystallization tray and attach the restorations on the silicon nitride pins.[19,20] The firing is done at 840°C and then glazing at 810°C. Crown dimensions were similar to hand-layered zirconia crowns.

Cementation

The marginal fit of the crowns was placed on the respective epoxy die models and tested using a stereomicroscope (Celestron Labs S20®, USA). 9.6% hydrofluoric acid etching gel is used to etch the internal surfaces of IPS e.max CAD-on and hand-layered zirconia crowns (Pulpdent® Corporation, Watertown, MA, USA) for 2 mins[21] and cleaned under water spray followed by ultrasonic cleansing using digital ultrasonic cleanser (Henan Baistra®, Zhengzhou, China) in distilled water for 1 min.[22] To enhance bonding properties, a micro-rough surface is created using 37% phosphoric acid (Ivoclar Vivadent®, Schaan, Liechtenstein) for 30 s to etch the prepared surfaces of molar tooth model and they were rinsed with water spray

Figure 2: Fusing the coping and veneer using IPS e.max Crystal/Connect material

and dried. The internal surfaces of both the types of crowns were coated using a silane coupling agent (Monobond® N) following the recommended guidelines.[15] Each crown was luted using dual-cure resin cement (Variolink® N Intro Pack, Ivoclar Vivadent, Schaan, Liechtenstein) based on the manufacturer's guidelines. All the crowns were placed using finger pressure on their respective replicas and cured for 20 s after removing excess cement on each surface.[13] We performed a pilot study and analyzed the hand pressure exerted during the cementation of crowns (4/group), and the mean force of 43.6 N (standard deviation 2.1) was not important within and between the groups. This procedure helped us standardize the finger pressure exerted on each sample approximately.[23] Subsequently, a static load of 22 N was applied on the crowns for 5 mins.[24] The seating of the crown was verified before and after cementation using a caliper (Ivoclar Vivadent®, Schaan, Liechtenstein) by measuring from the occlusal surface of crown to the base of the replica.

Mechanical fracture resistance tests

Each crown was luted with their respective die and mounted in resin material (DPI®, Mumbai) which was fabricated with definitive dimensions used for positioning in the loading jig. For fracture tests, ten hand-layered zirconia crowns and ten CAD-on crowns were chosen. Crowns were kept under the head of the jig in the universal testing machine at the central fossa of the crown. The specimens were uniaxially loaded in the universal testing machine with a crosshead speed of 1 mm/min,[15] and the load at fracture was recorded. Crowns were classified as fractured and cracked.[15] This enables to measure, compare the variables, and to evaluate the outcome of the study. It gives an insight into the different types or patterns in which ceramic crowns were classified. The data were recorded in Microsoft Excel as load-displacement curves, and the resultant load (N) was considered as a failure at the first drop along the load-displacement curve.

Cyclic fatigue resistance tests

In the cyclic fatigue resistance test, ten hand-layered zirconia crowns and ten CAD-on crowns were chosen. Each crown in a group was tested for fatigue resistance by inducing mechanical cyclic loading (Instron 8874) at loads ranging between 50 and 250 N for 250,000 cycles at a frequency of 20 Hz. The tested crown specimens were examined under light microscope and classified as fractured and cracked.[15] The data were recorded in Microsoft Excel as load-displacement curves, and the resultant load (N) was considered as a failure at the first drop along the load-displacement curve.

Statistical analysis

The collected data were analyzed to check for normality using Shapiro–Wilk test and hence independent samples *t*-test was used to compare the fracture resistance, and Mann–Whitney U–test was used to evaluate the cyclic fatigue resistance of the crowns made from the two materials with 95% confidence level. The significance level was set at 5% using SPSS software v21.0 (IBM SPSS statistics for windows, Version 21.0. New York, USA). For descriptive analysis, we used central tendency (mean) and variance. The fracture resistance data followed normal distribution and the cyclic fatigue followed nonparametric distribution based on the Shapiro–Wilk test.

RESULTS

Fracture resistance test

In hand-layered zirconia crowns, seven samples showed visible cracks occurring within the veneering porcelain whereas three samples showed fracture involving the entire crown thickness. On the other hand, all the ten CAD-on crowns that were tested showed cracks in the veneering porcelain only. The mean fracture resistance for CAD-on crowns was 2660.50 ± 501.303 N ($P < 0.023$) and for hand-layered zirconia crowns was 1963.60 ± 452.895 N ($P < 0.023$), which was statistically significant [Table 1 and Figure 3].

Cyclic fatigue resistance test

In hand-layered zirconia crowns, eight samples showed fracture on the veneering porcelain whereas two samples showed cracks on the veneering porcelain at around 180,000 cycles. In contrast, eight samples showed no evidence of cracks and/or fractures on the veneering porcelain whereas only two samples of the CAD-on groups showed cracks on the veneering porcelain after about 220,000 cycles. The mean number of cycles before failure for hand-layered zirconia crowns was 175,297 cycles ($P < 0.012$) and for CAD-on crowns was 212,097 cycles ($P < 0.012$) [Table 2 and Figure 4].

DISCUSSION

In the present study, tooth preparation and epoxy die fabrication was standardized and did not affect the outcome

Table 1: Statistical analysis of fracture resistance tests

Groups	*n*	Mean±SD	95% CI		*P*
			Lower	Upper	
Hand-layered zirconia crowns	10	1963.60±452.895	133.13	1026.73	0.023
CAD-on Crowns	10	2660.50±501.303	142.11	1035.71	

*Independent samples *t*-test. SD: Standard deviation, CI: Confidence interval, CAD: Computer-aided design of this study, as reports state that the Young's modulus of dies made from these materials is around 12.9 GPA,[9,15,16] which is close to that of human dentin.

The most important factor affecting the outcome of the study was the thickness of coping and veneer. In this study, the thickness of coping (0.5 mm) and veneer (1 mm) in the case of CAD-on crowns was uniformly maintained. However, in the case of hand-layering technique, even though the thickness of coping was maintained at 0.5 mm (because it was machined), uniform thickness of veneer portion cannot be ensured because it was subject to operator error. In addition, hand-layering technique has the potential for incorporating structural defects either during layering or sintering/firing process.[25] The mechanical property of the ceramic employed also determines the fracture strength of the all ceramic crowns.[26] Additionally, the physical and mechanical properties such as coefficient of thermal expansion and the internal stresses can have an influence on the fracture resistance of all ceramic crowns.[27]

Crowns in both the groups were luted using the same dual-cured resin cement, namely Variolink N. Hence, the influence of the luting agent was also negated. In this study, two factors, namely the type of ceramic employed and crown fabrication techniques, were the only variables that affected the outcome of the study.

The fracture propagation in all ceramic crowns has been studied by few investigators.[28,29] Previous studies state that in zirconia samples, the crack expansion under low force will initiate the fracture, and with the increase in power, this crack propagates and approached the core with an acute angle.[29]

Table 2: Statistical analysis of cyclic fatigue resistance tests

Groups	*n*	Mean±SD	95% CI		*P*
			Lower	Upper	
Hand-layered zirconia crowns	10	175317.5±24394.862	4585.16	69015.43	0.012
CAD-on Crowns	10	212117.8±41925.962	4010.76	69589.83	

*Mann-Whitney U-test. SD: Standard deviation, CI: Confidence interval, CAD: Computer-aided design

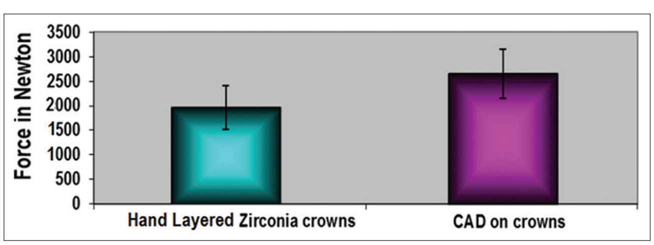

Figure 3: Bar chart representing the fracture resistance tests of both the groups. Computer-aided design-on crowns were significantly better than hand-layered zirconia crowns

The hand layered zirconia crowns were liable to develop internal stresses at the veneer interface due to discrepancy in coefficient of thermal expansion. These internal stresses were more prone to failure of the hand-layered zirconia crowns.[30,31] These factors may contribute to the low fracture resistance of the hand-layered zirconia crowns. On the other hand, CAD-on crowns are completely automated, with the only intervention being the application of fusing material between the zirconia coping and lithium disilicate veneer and subsequent firing. IPS e.max Crystal/Connect material was applied over the coping (zirconium oxide) as well as inside the veneer structure (lithium disilicate) and the veneer was fused to the coping. It was observed that none of the CAD-on crowns exhibited separation of veneer from coping, indicating improved bulk properties of CAD-on crowns.

The CAD-on crowns were fabricated in stress-free conditions where the ceramic material is veneered on the zirconia copings. Therefore, internal stresses were relieved during the fabrication process.[32,33] Although the compressive potency of lithium disilicate is lesser than the zirconia,[34,35] the CAD-on crowns (comprising of lithium disilicate veneer over zirconia coping) performed better in withstanding compressive forces than hand-layered zirconia crowns. This could be because the force exerted upon the lithium disilicate veneer was transmitted to the underlying zirconia coping. Due to the reasons discussed above, fracture in the CAD-on group, in contrast to the hand-layered zirconia group, was limited to the veneer layer only.

In this study, the samples were subjected to cyclic fatigue resistance using a range of forces for 250,000 cycles, which is equivalent to 5 years of normal intraoral condition.[36] A high frequency of 20 Hz was used to simulate the chewing cycles during cyclic loading instead of low frequency (1–2 Hz). In addition, fatigue studies have been reported using a frequency of 20 Hz.[37] Hence, performing this study at similar frequency would enable the comparison

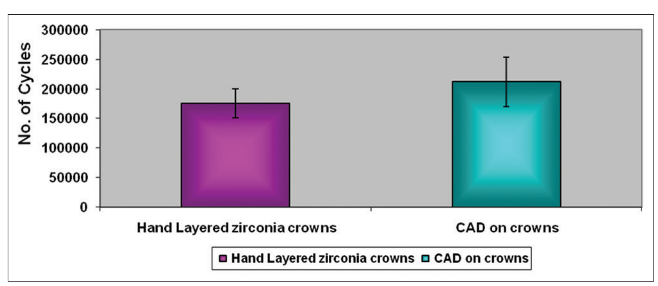

Figure 4: Bar chart representing the cyclic fatigue resistance tests of both the groups. Computer-aided design-on crowns were significantly better than hand-layered zirconia crowns

of the results with those of other investigators. In the present study, the force used was between 50 and 250 N by staircase approach at a frequency of 20 HZ.

Previous studies with similar methodology compared different types of all ceramic crowns[9,15,16] and a similar study found that CAD-on crowns was superior than hand-layered zirconia crowns.[38] The present study compared CAD-on crowns and hand-layered zirconia crowns, CAD-on crowns were found to have significantly higher fracture resistance and cyclic fatigue resistance than hand-layered zirconia crowns which may translate to improved resistance to the masticatory forces clinically.

The limitations of this study include the small sample size of the groups. Although the results of this study suggest that CAD-on crowns have superior fracture resistance and cyclic fatigue resistance over hand-layered zirconia crowns, other parameters such as tensile strength, wear properties, and coefficient of thermal expansion need to be evaluated. In fatigue resistance tests, the use of high-frequency loading was prone to more heat generation as compared to 1–2 Hz.[15] This could probably act as an impediment for stress relaxation in the study samples. Apart from this, properties such as adhesive strength between the veneer and coping must also be evaluated. Future studies need to be carried out using larger sample sizes to ensure more reliable results.

CONCLUSION

In this study, CAD-on crowns were found to have significantly higher fracture resistance and cyclic fatigue resistance than hand-layered zirconia crowns.

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Conflicts of interest

There are no conflicts of interest.

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