EGYPTIAN
DENTAL JOURNAL

Vol. 64, 1571:1586, April, 2018

I.S.S.N 0070-9484

Fixed Prosthodontics, Dental materials, Conservative Dentistry and Endodontics

www.eda-egypt.org • Codex : 116/1804

EVALUATION OF FRACTURE RESISTANCE AND FIT ACCURACY OF THREE TYPES OF CAD/CAM FABRICATED CROWNS USING CONE BEAM COMPUTERIZED TOMOGRAPHY

Maha Adly Abd El Moaty* *and* Amir Shoukry Azer**

ABSTRACT

Aim: The aim of this study was to evaluate the internal and marginal fit accuracy using cone beam computerized tomography as an innovative nondestructive method and to assess the fracture resistance of the recently introduced zirconia reinforced lithium silicate glass ceramic in comparison to lithium disilicate and monolithic zirconia.

Materials and Methods: Three types of CAD/ CAM ceramic blocks were used; zirconia reinforced lithium silicate glass ceramics (Vita Suprinity), lithium disilicate glass ceramic (IPS e.max CAD) and partially sintered translucent zirconia (In-Coris TZI). A ceramic master die was fabricated and scanned using the Cerec Omnicam to produce a total number of 30 crowns, which were divided into 3 groups (n = 10) according to the ceramic material used . Group I: Vita Suprinity. Group II: IPS e.max CAD and Group III: In- Coris TZI. A highly computerized cone beam tomography (CBCT) was used to evaluate the fit accuracy of the crowns on the master die. For fracture resistance test, epoxy resin dies were optically scanned using Omnicam scanner and 30 crowns were fabricated using the CAD/ CAM ceramic materials (n = 10) for each tested material. The crowns were cemented using self-adhesive resin cement. A compressive load was applied at a cross head speed of 1mm/min and the fracture load in Newtons was recorded for each specimen. Fractured crowns were examined to determine the mode of fracture.

Results: Marginal and internal fit evaluation showed that group I (Vita Suprinity) recorded the least mean in respect to all measuring points (103.6±10.4μm), while group III (In Coris TZI) showed the highest mean in respect to all points (146.7±9.23μm). For fracture resistance, In Coris TZI zirconia showed the highest fracture load (4548.9±200.9 N), while the lowest mean value was recorded in Vita Suprinity (3484.8±22.17 N). There was no significant difference between Vita Suprinity and IPS e.max CAD.

Conclusion: Vita Suprinity crowns showed the best marginal and internal fit when compared to the other two materials. In- Coris TZI exhibited the highest fracture strength of all three groups. All values were within a clinically acceptable range for the three ceramic materials tested.

* Assistant Professor of Dental Biomaterials, Faculty of Dentistry, Alexandria University.
** Lecturer of Fixed Prosthodontics, Faculty of Dentistry, Alexandria University.

INTRODUCTION

In recent years, various CAD/CAM – machinable ceramic materials have been developed in order to enable the esthetic demands of prosthetic restorations to be accomplished.[1] The clinical selection of ceramic systems is based on the mechanical and optical properties of the materials.[2] Clinical evaluations have indicated an excellent clinical survival rate (over 95%) of zirconia-based FPDs and crown restorations. In terms of fracture resistance zirconia have the potential to withstand physiological occlusal forces in the posterior region and provides alterations to metal ceramic restorations.[3] However, chipping/ delamination of the veneering ceramic has been repeated as the most frequent complication of bilayered zirconia restorations.[4-6] In recent years monolithic glass-ceramics have been developed in order to provide exceptional esthetics, without requiring a veneering ceramic. It has been reported that greater structural integrity can be accomplished by elimination of the veneered ceramic and its bond interface.[7] Lithium disilicate ceramic restoration is one of the monolithic systems that have gained popularity for anterior and posterior single crowns and partial coverage restorations because of its superior physical properties. Due to enhanced translucency and different shades of lithium disilicate, anatomically continued monolithic restorations are feasible.[8,9] CAD/CAM lithium disilicate blocks are manufactured with an optimized pressure casting process to minimize microstructural defects. As the blocks are formed in an immediate phase due to partial crystallization, they are easier to machine and can obtain high strength.[1] Combined with esthetic concerns, they could be used for single crown restorations in the anterior and posterior regions.[2] Recently, a zirconia reinforced lithium silicate glass ceramic (Vita Suprinity)[10] for dental CAD/CAM applications has been introduced to the dental market. It is used for the fabrication of inlays, onlays, partial crowns, veneers, anterior and posterior single tooth restorations on implant abutments. The manufacturer has claimed that this newly developed generation of glass ceramic materials combine the positive characteristics of zirconia and glass ceramics. The zirconia particles are incorporated in order to reinforce the ceramic structure by crack interruption. It has been supposed that after crystallization, the ceramic material exhibited enhanced mechanical properties and highest esthetic requirements. It is anatomically contoured as monolithic ceramic restoration due to enhanced translucency and different shades.[10] Accuracy of fit is considered a very important factor in crown fabrication. Inadequate fit creates a potential space between the restoration and the prepared tooth. As space increases, more luting material is exposed to the oral environment. Bacterial plaque can easily accumulate in this defective areas, which causes gingival inflammation, caries and pulpal affection. In addition, variation in fit creates stress concentration which may reduce the strength of the restoration and consequently cause its fracture.[11] Computerized tomography (CBCT) allows accurate three dimensional imaging of hard tissue structures and is capable of providing sub-millimeter resolution images of high diagnostic quality with short scanning time and relatively low radiation exposure dose. In addition, CBCT is a non-destruction method that does not require sectioning which may distract the assembly of crown & die and allow three dimensional analysis of the fit accuracy at greater number of measuring points using the on screen software tools without affecting the original dimensions of the specimens.[12] However not much is known about the marginal fit and fracture resistance of these new materials. The aim of this study was to evaluate the internal and marginal fit accuracy (adaptation) using cone beam computerized tomography as an innovative non-destructive method, and to assess the fracture resistance of the recently introduced zirconia reinforced lithium silicate glass ceramic in comparison to lithium disilicate and monolithic zirconia.

The proposed hypothesis was that there is no difference between the three CAD/ CAM monolithic ceramic materials.

MATERIALS AND METHODS

Three types of CAD/CAM ceramic blocks were used in this study; zirconia reinforced lithium silicate glass ceramic (Vita Suprinity), lithium disilicate glass ceramic (IPS e.max CAD) and partially sintered translucent zirconia (In-Coris TZI). The materials used, their composition and manufacturers are presented in table (I).

Fabrication of the ceramic master die

An ivory upper first molar was seated in a typodont model and prepared to receive a full ceramic crown with the following criteria in the preparation: occlusal reduction 1.5- 2 mm, axial reduction 1-1.2 mm, axial taper 10-12 degrees, and 1mm supragingival circumferential chamfer finish line. All transitions from the axial to the occlusal surface were rounded, smooth, and free from sharp angles or undercuts.[13]

Before preparation of tooth, a silicone mold was made with normal-setting polyvinyl siloxane impression material for the coronal portion of the tooth. These pre-preparation silicone mold was used as reference guide to assist in checking for enough clearance during preparation.

The prepared ivory tooth was scanned using a laboratory optical scanner (ZirkonZahn S600 ARTI, Italy) and a wax pattern of the die was milled from a block of white wax (CopraPlex, WhitePeaks, Germany). The wax pattern was invested,

TABLE (I) Materials used and their composition.

Materials	Commercial name	Composition	Manufacturer
Zirconia reinforced Lithium silicate	Vita Suprinity	SiO_2 56-64 Li_2O 15-21 K_2O 1-4 P_2O_5 3-8 AL_2O_3 1-4 ZrO_2 8-12 Ce O_2 0-4 Pigments 0-6	Vita, Zahnfabrik Germany
Lithium disilicate	IPS EMAX CAD	wt% SiO_2 57°- 80.0 LiO 11.0-19.0 K_2O 0.0-13.0 P_2O_5 0.0-11.0 ZrO_2 0.0-8.0 ZnO 0.0- 8.0 Colouring oxide 0.0-12.0	Ivoclar Vivadent Liechtenstein
Trnaslucent Zirconia	In Coris TZI	$ZrO_2 + HFO_2 + Y_2O_3$ 99.0% Y_2O_3 5.6% $AL_2O_3 \leq 0.35\%$ Other Oxides except $Er_2 0_3 \leq 0.2\%$	Sirona Bensheim Germany

burnt out and a ceramic ingot was heat-pressed into the mold space to produce the ceramic master die from lithium disilicate ceramic (IPS e-max press, Ivoclar Vivadent, USA), figure (1).

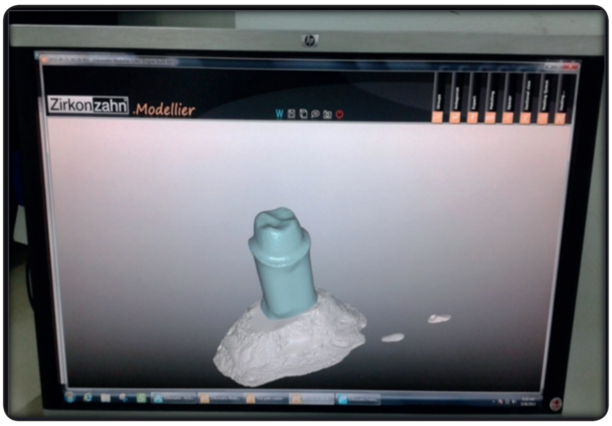

Fig. (1): Software designing for the master die.

Marginal and internal fit evaluation

The ceramic die in the typodont model was scanned without application of powder using white LED light of CEREC AC Omnicam (Sirona Dental Systems, Bensheim, Germany). The acquired optical data was transferred into an accurate three dimensional digital dies resembling the original preparation with fine details of all surfaces and margins. Five scans were performed to obtain five full-colored 3D models for the die and neighbouring teeth for milling crowns. In case of zirconia crowns, the software was designed to enlarge the milled crown by 30% as it will be milled in a partially sintered state.

A total of 30 crowns (specimens) were fabricated for this test.

Group I (Vita Suprinity): Ten crowns were designed using (CEREC 3D software, Version 4.2, Sirona Dental Systems, Bensheim, Germany) by making a copy of the anatomy of the contralateral tooth or 'Bioreference' mode with 80 μm die spacer. A Cerec inLab MC XL milling unit was used for CAM process of the designed crowns using zirconia reinforced lithium silicate blanks followed by crystallization firing at 850°C for 22 minutes in the Programat CS furnace. No internal adjustments, glazing, or polishing were made to the crowns before the marginal gap measurements to avoid any human interference.

Group II (IPS e.max CAD): Ten crowns were similarly designed using cerec 3D software to be milled, followed by crystallization firing at 840°C for 27 minutes in the Programat CS furnace. Also, no internal adjustments, glazing, or polishing were made to the crowns before the marginal gap measurements to avoid any human interference.

Group III (In Coris TZI): Ten crowns were also fabricated using the same software to be milled from InCoris TZI Zirconia. The crowns were inserted into the sintering furnace, and the sintering cycle began by gradual rise in temperature, till it reached 1540° C. At this temperature, the crowns spent holding time of 120 minutes, followed by gradual decrease in temperature to room temperature. The overall sintering time was about six hours.

Measurements of marginal and internal fit:

A highly accurate computerized cone beam tomography system was used (Morita R100 Veraview Wepocs, USA) to evaluate the fit accuracy of the crowns on the master die. The master die was fixed to an acrylic base to stabilize it during imaging process then each crown was seated on the master die with maximum finger pressure for 3 seconds then scanned with CBCT.

Three dimensional images were reconstructed on a computer monitor with special software (On Demand VeraView Wepocs). Five sectional images of the samples were made in sagittal plane (buccolingual) and other five slices in coronal plane (mesiodistal). A slice was made every 1mm so that 10 slices were made for each sample.

On each slice image the following points were measured so that a total of 70 measuring points were obtained for each sample:[14] Mid-occlusal gap (MO), Axio-occlusal gap (AO), Mid-axial gap (MA), Absolute marginal discrepancy (AMD) as shown in figures (2,3).

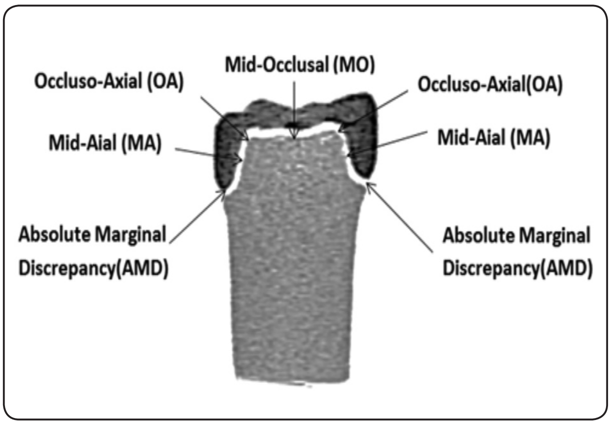

Fig. (2): Showing measuring points on a sectional CBCT image.

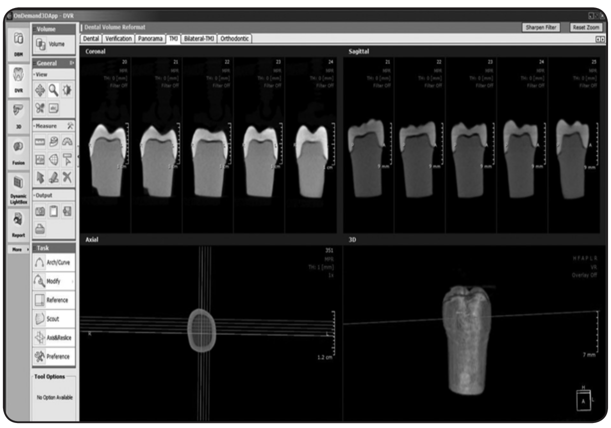

Fig. (3): CBCT software 3D, axial, sagittal and coronal images.

Fracture Resistance testing

Epoxy resin dies production

Addition silicon duplicating material was used to fabricate a negative replica for the ceramic master die. The negative replica was then filled with epoxy resin material following manufacturer's instructions, to get positive replicas (dies). The epoxy resin has the same elastic modulus of dentin.[15]

Thirty epoxy resin dies were obtained (n=10). Resin dies were randomly divided into three main groups of ten die specimens each, according to the material used for crowns fabrication: All epoxy dies were optically scanned using the omnicam intraoral scanner and 30 crowns were fabricated using the CAD/CAM as previously mentioned, for each tested material; Vita Suprinity, IPS e-max CAD and InCoris TZI zirconia respectively.

Surface treatment of the crown specimens

For Groups I and II (Vita Suprinity and IPS e.max CAD respectively), the internal surface of the ceramic crowns were etched using hydrofluoric acid etching gel (5%) for 20 seconds. The etched surface was thoroughly rinsed under running tap water, followed by air/water spray, then finally dried using oil-free compressed air. Silane primer (Monobond-S) was applied to the intaglio surface of each crown using a micro-brush for 60 seconds then air dried. Excite DSC dual curing bonding agent was then applied to each crown of the two groups and slightly air dried for 3 seconds. For group III (Incoris TZI zirconia), the crowns were pretreated according to manufacturers' instructions. The fitting surfaces were sandblasted with 50 μm Al2O3 at pressure of 2.5 bars, rinsed with water spray for 60 seconds, and then dried with oil-free air. The Metal/Zirconia primer was then applied in a thin layer using a micro-brush and left to react for 180 seconds and subsequently dried with oil-free air.

Cementation:

Before cementation, the prepared epoxy dies were cleaned with pumice slurry and brush, then rinsed with a water spray, and lightly air dried in only 2-3 intervals with oil-free air. Self-adhesive luting resin cement was used to cement the crowns on their corresponding dies (RelyX Unicem 2 Automix; 3M ESPE).After mixing, the cement was directly applied to the internal surfaces of each crown , which was immediately seated on its respective prepared die with finger pressure then the restoration was sustained under a static load of 5kg using custom-made static load device for 10 minutes.[16,17] Excess material was briefly cured (2-4 seconds) with the polymerization light which was subsequently, easily removed with a scaler. Finally, all margins were again light-cured for 20 seconds for each surface. Crown margins were covered with Vaseline to prevent oxygen inhibition in the surface layer of the cement. Finishing of the cement at the crown's edges was carried out; margins of each crown were cleaned and polished with pumice-free polishing paste (low-abrasion paste) using both silicone rubber and soflex discs.

Testing

Each specimen was fixed in a metal ring to hold the specimen during testing. The ring was fixed on the lower jaw of the universal testing machine (AGS-X 100KN, Shimadzu, Japan). A metal sphere indenter of 6 mm diameter was attached by means of a stylus to the upper compartment of the machine.[18,19] The indenter was approached to the specimen to touch the occlusal surface in three points; occlusal inclines of the mesiobuccal, distobuccal and mesiopalatal cusps of the crowns. A piece of rubber sheet was placed between the sphere and the specimen in order to distribute the load.[20] A compressive load was applied at a cross head speed of 1mm/min until fracture of specimen occurred.[21] The fracture load was viewed in Newtons on a reading monitor and recorded for each specimen.

Surfaces of the fractured crowns were inspected and visually examined to determine the fracture mode of each sample.

The mode of fracture of was determined; depending on the severity of crown damage according to the classification of Burke and Watts (1994)[22] as following:

- Mode **I:** Minimal fracture or crack in the crown.
- Mode **II:** Less than half of crown lost.
- Mode **III:** Half of crown lost (crown fracture through midline).
- Mode **IV:** More than half of crown lost.
- Mode **V:** Severe fracture of crown.

RESULTS

I- Marginal and internal fit evaluation

Descriptive analysis for measuring points for each of the three groups in microns was illustrated in tables (II, III and IV). For group I (Vita Suprinity), the greatest mean value was recorded at the mid-occlusal point (MO) (117.9±17.4 μm), while the absolute marginal discrepancy (AMD) recorded the lowest mean value (90.4±3.9μm). For group II (e-max CAD), the greatest mean value was recorded also at the MO (132.3±8.3μm), while the AMD showed the lowest mean value (109.4±5.9μm). Similarly, for group III (In- Coris TZI zirconia), AMD points recorded the greatest mean value (160.3±9.7μm), while, the MO points showed the lowest mean value (130.5±10.4μm).

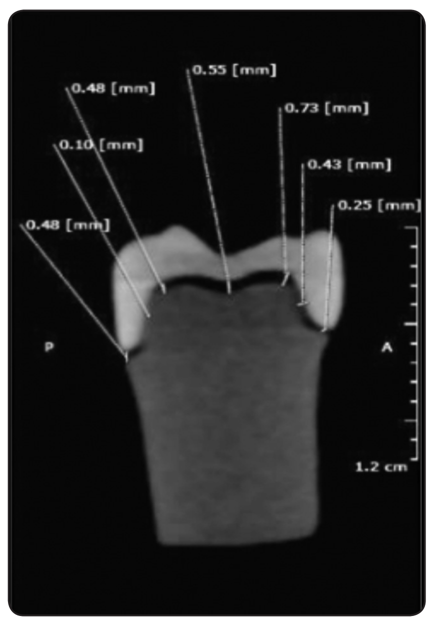

Fig. (4): Measurements on a coronal CBCT image for specimen.

TABLE (II) Statistical Analysis for measuring points for Vita Suprinity, Group I in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Mo	99.0	146.0	117.9	17.4	F= 891.7* P= 0.0001
AMD	84.5	96.0	90.4	3.9	
OA	96.5	130.0	112.0	14.4	
MA	90.5	120.0	101.3	10.4	

F= one way ANOVA ***P<0.05 = significant***

There is statistically significant difference between each group and the other two groups

Table (III) Statistical Analysis for measuring points for IPS e.max CAD, Group II in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Mo	118.0	147.0	132.3	8.3	F= 2664.5* P= 0.0001
AMD	99.0	117.5	109.4	5.9	
OA	111.0	144.5	129.5	8.8	
MA	104.5	132.0	120.9	8.5	

F = one way ANOVA ***P<0.05 = significant***

There is statistically significant difference between each group and the other two groups

TABLE (IV) Statistical Analysis for measuring points for In-Coris Zirconia, Group III in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Mo	139.0	175.0	160.3	9.7	F= 2596.09* P= 0.0001
AMD	107.0	114.5	130.5	10.4	
OA	135.0	167.5	156.3	10.2	
MA	133.0	157.0	146.6	8.2	

F= one way ANOVA ***P<0.05 = significant***

There is statistically significant difference between each group and the other two groups

The variability among the three groups was calculated using One Way ANOVA test at p<0.05, where there was a statistically significant difference between each group and the other two groups. This was illustrated in tables (V-VIII). The results in this aspect showed that group I recorded the least mean value in microns in respect to all measured points (AMD, MA, OA and MO), while group III showed the highest mean value in respect to all measured points.

TABLE (V) Comparison between mean values of AMD results for the three groups measured in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Vita Suprinity	84.5	96.0	90.4	3.97	F=75.6* P= 0.0001
IPS e.max CAD	99.5	117.5	109.4	5.9	
In Coris Zirconia	107.0	114.5	130.5	10.4	

F= one way ANOVA ***P<0.05 = significant***

There is statistically significant difference between each group and the two others

Table (VI) Comparison between mean values of MA results for the three groups measured in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Vita Suprinity	90.50	120.0	101.3	10.4	F=63.1* P= 0.0001
IPS e.max CAD	104.50	132.0	120.9	8.5	
In-Coris Zirconia	133.0	157.0	146.6	8.2	

****Significant at <0.05*** ***F = One way ANOVA***

There is statistically significant difference between each group and the 2 other groups

TABLE (VII) Comparison between mean value of OA results for the three groups measured in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Vita Suprinity	96.5	130.0	112.0	14.4	F=33.3* P= 0.0001
IPS e.max CAD	111.0	144.5	129.5	8.8	
In-Coris Zirconia	135.0	167.5	156.3	10.2	

F= one way ANOVA ***P<0.05 = significant***

There is statistically significant difference between each group and the other two groups

Table (VIII) Comparison between mean values of MO results for the three groups measured in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Vita Suprinity	99.0	146.0	117.9	17.4	F=29.89* P= 0.0001
IPS e.max CAD	118.0	147.0	132.3	8.3	
In-Coris Zirconia	139.0	175.0	160.3	9.7	

F= one way ANOVA ***P<0.05 = significant.***

There is statistically significant difference between each group and the other two groups.

Comparison between the mean values of the overall results of the three groups (I,II and III) was calculated also using One Way ANOVA test at $p<0.05$, as illustrated in table (IX) and figure (5). There was a statistically significant difference among the three groups tested, showing a mean of (103.6±10.4μm) for group (I), (121.6±7.5μm) for group (II) and (146.7±9.23μm) for group (III).

95% confidence intervals of the means of the overall results of the three groups were illustrated using scatter plot column figure (6).

II- Fracture resistance test

The means of fracture loads in Newtons for the three groups (I,II and III) and the descriptive statistical analysis for the fracture resistance testing were illustrated in table (X) and represented in figure (7). The higher mean value of fracture load in Newtons was recorded in group III (In-Coris TZI zirconia) (4548.9±200.9 N), while, the lower mean value was recorded in group I (Vita Suprinity) (3484.8±22.17N).

One Way ANOVA was used to compare between the three groups under investigation. It revealed a statistically significant difference ($p<0.05$) between group I and group III, and between group II and group III. While, there was no significant difference between group I and group II.

TABLE (IX) Comparison of the mean values of all measurements in the three groups measured in μm.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Vita Suprinity	91.7	117.7	103.6	10.4	F=56.5* P= 0.0001
IPS e.max CAD	106.7	133.1	121.6	7.5	
In-Coris Zirconia	127.0	157.0	146.7	9.23	

F= one way ANOVA ***P<0.05 = significant***

There is statistically significant difference between each group and the other two groups.

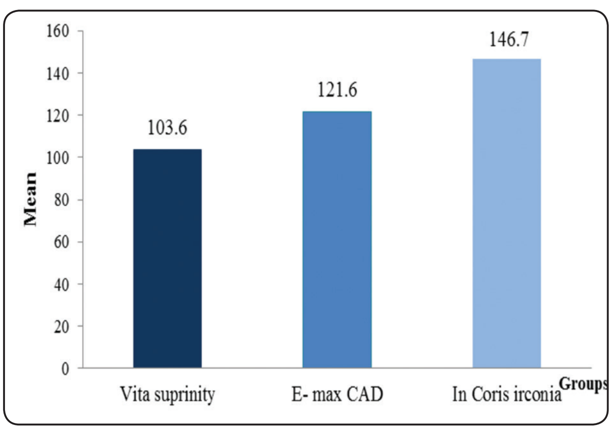

Fig. (5): Bar graph showing comparison between the mean values of the overall results of the three groups in μm.

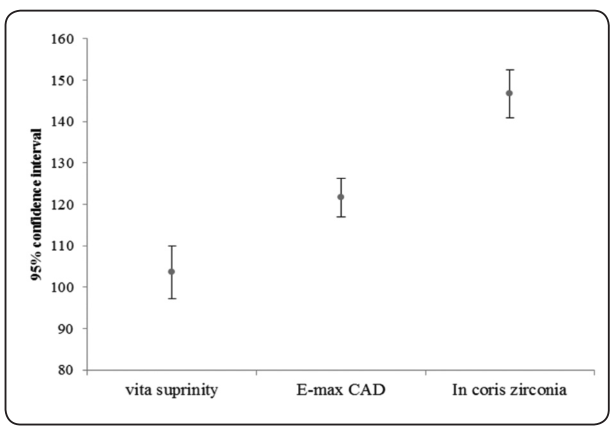

Fig. (6): 95% confidence interval of the means of the overall results of the 3 groups.

TABLE (X) Comparison between the fracture resistance of the 3 tested groups in Newtons.

Point	Minimum	Maximum	Mean	Std. Deviation	F , P
Vita Suprinity	3367	3620	3484.8*	22.17	F= 186.02 P= 0.0001*
IPS e.max CAD	3374	3651	3538.4Δ	95.4	
In-Coris Zirconia	4071	4787	4548.9*Δ	200.9	

F= one way ANOVA ****= significant at P<0.05***

**** Significant difference between group I and group III.***

Δ Significant difference between group II and group III.

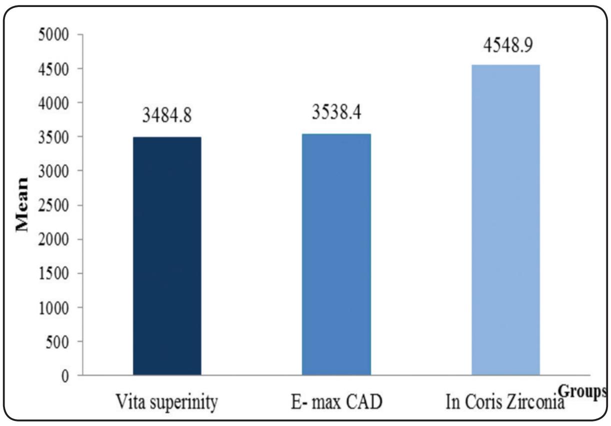

Fig. (7): Comparison between mean values of the fracture resistance of the three groups in Newtons.

Failure mode

Evaluation of the specimens was done by direct visual examination and through captured digital photographs. Fractured crowns were categorized according to their mode of fracture into one of five modes I-V In Group III, some specimens showed fracture of epoxy die itself denoting the higher fracture resistance of the In-Coris TZI zirconia compared to the other two groups as shown in figures (8-11) and table XI.

TABLE (XI) Fracture mode of the tested specimens.

Groups	Fracture mode and its percentage					Total
	I (%)	II (%)	III (%)	IV (%)	V (%)	
Group I **(Vita Suprinity)**	1 (10%)	2 (20%)	2 (20%)	2 (20%)	3 (30%)	10
Group II **(IPS e.max CAD)**	2 (20%)	3 (30%)	2 (20%)	2 (20%)	1 (10%)	10
Group III **(In-Coris zirconia)**	4 (40%)	3 (30%)	3(30%)	0 (0%)	0 (0%)	10
Total	7 (70%)	8 (80%)	7 (70%)	4 (40%)	4 (40%)	30

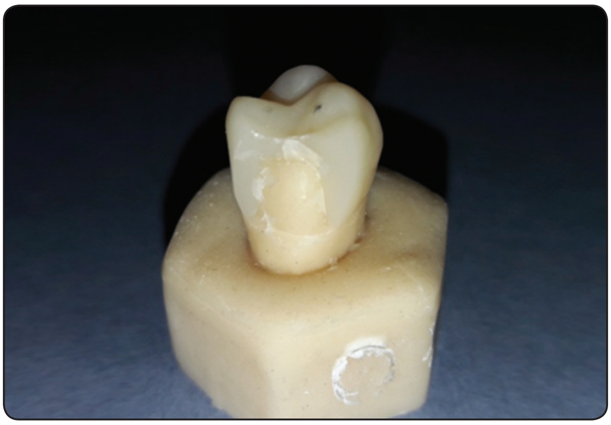

Fig. (8): Vita Suprinity.

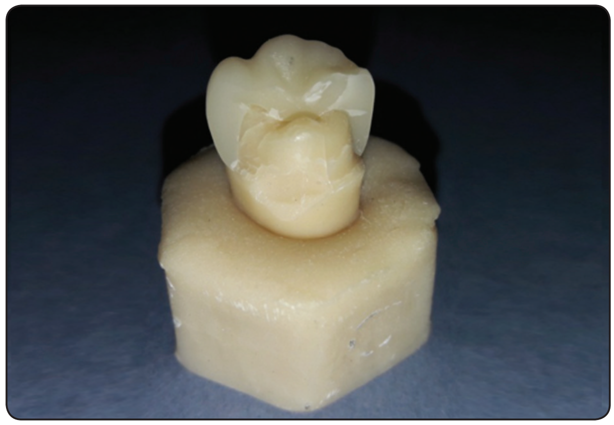

Fig. (9): IPS e.max CAD.

Fig. (10): In-Coris Zirconia.

Fig. (11): In-Coris Zirconia.

DISCUSSION

The present study evaluated the fracture resistance and fit accuracy of three crown restorations fabricated from zirconia reinforced lithium silicate (Vita Suprinity), lithium disilicate glass ceramic (IPS e.max CAD) and monolithic zirconia (In-Coris TZI).

Marginal and internal fit

The marginal fit of dental restorations is an important factor for the longevity of all-ceramic restorations, as failure to provide adequate marginal fit might increase the possibility of plaque accumulation, periodontal diseases and recurrent caries.[14] Marginal fit, accuracy or adaptation is synonymous for a key criterion used in the evaluation of fixed restorations and could be defined as the parameter that measures the proximity between the margins of the restoration and the finish line on the prepared tooth. Although the internal fit has not been found to be as clinically relevant as marginal fit, it is still of interest as it may affect the durability of the crown. Proper internal adaptation is also important as it facilitates the seating of the crown allowing for both retention and resistance.[11]

The methodology followed in this study was first applied by Pelekanos et al[23] using computerized tomography (CBCT) to measure internal and marginal gap as a radiographic method. The master die and the crowns were both fabricated from ceramic material as to distinguish the gap between similar materials using radiography, both should have the same coefficient of radiation absorption or similar radiodensity.

The limited field of view (FOV) setting was selected to allow accurate sub-millimeter resolution images with short scanning time and low radiation exposure dose, combined with greater image resolution.[24]

The sample size mentioned in the literature for measuring marginal fit was 10 per group. Fifty measurements per specimen were recommended by Groten et al[25] to attain clinically significant information about marginal gap size regardless of the systematic or random approaches of the measurement sites. Similar conclusions were made by Gonzalo et al[26] and Lee et al[27] who used a smaller sample size and compensated it with a large number of measurements per sample (60 and 50 measurements respectively) to achieve more consistent distribution of data with small standard deviations compared to the mean values and to avoid less relevant or invalid conclusions. In this research a sample size (n=10) was used and compensated by large number of measuring points of 70 per sample with standardized location through the aid of software tools of the CBCT. During measuring the marginal and internal gaps of In-Coris TZI zirconia using the CBCT, there was some difficulties due to the reflection and scattering of x-ray beam. This was not the case with the other two ceramic materials.

Clinically acceptable marginal gap of fixed restorations is difficult to be precisely identified through the literature. Till this data, there is no conclusive evidence of optimum fit of contemporary ceramic systems. Values reported are widely diverse ranging from 7.5 μm to 206.3 μm.[28,29] Furthermore, Bindle and Mormann[30] found that greater internal space resulted in less marginal gap, which can lead to less premature contact internally. Thus, the internal relief must accommodate the cement layer and any irregularities on the tooth and inner crown surface. In the present study, the cement thickness was adjusted at 80 μm as recommended by the resin cement manufacturer and the CAD software.

The results obtained in the current study showed that there was a statistically significant difference ($P<0.05$) in the overall internal gap width between group I, group II and group III, where Vita Suprinity crowns showed the lowest mean of overall internal gaps (103.6 μm); and better internal adaptation than either e-max CAD and In Coris zirconia crowns (121.6μm) and (146.7μm) respectively.

The present results were in agreement with those of Yildirim et al,[31] who concluded that the adaptation values of Vita Suprinity were significantly lower than those of the IPS e.max CAD crown restorations. Similarly they were in favour with those of Mously et al,[32] who compared and evaluated the marginal and internal adaptation of lithium disilicate with different spacer thickness settings (30μm, 60 μm and 100 μm).

The current results were also in accordance with those of Schriwer et al,[33] who compared the marginal quality and internal fit of several monolithic zirconia crowns. They concluded that production method and material composition affect internal fit and crown margin quality. They also stated that the digitally calculated shrinkage incorporated in the 3D models, may not compensate for the actual shrinkage occurring during sintering after machining.

This was in agreement with the results of Tinschert[34] and Reich et al[35] who found a significant influence of the fabrication techniques on the fit accuracy of zirconia restorations. The present results were also in agreement with those of Yildiz et al,[36] who reported that the significant difference in internal and marginal fit between the studied groups, could be attributed to differences in material properties and sintering shrinkage of zirconia when subjected to post machining sintering.

The present values of marginal and internal gaps were in disagreement to those reported by Lee et al (2018)[37], who evaluated the accuracy of fit of zirconia copings and reported much lower gap values. This may be due to the difference in cement spaces used in their study.

In the present study burs were changed every 5 millings regardless of the milled material to ensure maximum sharpness of the burs during milling, which might be a reason of the low marginal and internal discrepancies recorded in the present study for the three studied groups.

Fracture Resistance testing

Most of the recommendations for a clinically relevant in vitro load to fracture test for ceramic restorations described by Kelly[15] and Rekow et al[38] were followed in this study.

Epoxy resin dies rather than natural teeth were selected to accurately control and duplicate the preparation parameters, such as dimensions, taper and finish line. It was also selected because it has a modulus of elasticity (12.9 GPa) similar to that of human dentin (14.7 GPa).[38] The design of the preparation has an influence on the longevity of the restorations. Deep chamfer finish line was prepared since it was stated by Jalalian et al[39] that a deep chamfer margins improved the biomechanical performance of ceramic restorations due to greater thickness and rounded internal angles which resist tensile forces created during cementation and loading of ceramic crowns.

The selected cement was RelyX Unicem 2, a dual cure resin cement. Previous studies concluded that resin cements could increase the fracture resistance of all ceramic restorations. Zirconia crowns luted with resin cements were found to be more resistant to fracture than those luted with conventional cements.[40-42]

In case of zirconia, air-born particle abrasion with 50μm AlO_3 particles at pressure of 2.5 bar was performed on the fitting surface prior to cementation as recommended by Gargari et al.[43] Wang et al[42] also reported that sand blasting with 50 μm AlO_3 particles resulted in an increase in the strength of Y- TZP ceramics.

The results obtained in the current study showed a significant difference ($P \leq 0.001$) in the mean fracture resistance between the three studied groups, where In Coris TZI crowns (group III) showed higher mean of fracture resistance (4548.9 N) than either Vita Suprinity (group I) (3484.8 N) and IPS e.max CAD crowns (group II) (3538.4 N).

The present results were in agreement with that of Johansson et al (2014)[44] and Nakamura et al (2015),[45] who reported that the fracture load of monolithic zirconia crowns was significantly higher than that of lithium disilicate crowns. Similarly, the current results were in consistence with those of Zhang et al (2016),[46] who compared the fracture resistance of several materials, and found that monolithic zirconia crowns had the highest fracture loads. Also, they were in favor with those of Nordal et al (2015),[47] who reported that at equal thicknesses, the fracture resistance of monolithic zirconia crowns was significantly greater than that of lithium disilicate crowns. On the other hand, the results of the current study were in disagreement with those of El Saka and El Naghy,[48] who found that Vita Suprinity crowns had higher mechanical properties when compared to e.max CAD. This can be attributed to the difference in microstructure and composition between the three tested materials. The difference in grain size, nature, distribution and alignment of particles and orientation of crystalline phase, all these factors are known to affect their fracture behavior (Scherrer SS et al 1998).[49]

In case of e.max CAD, its partially crystallized micro-structure is composed of 40% elongated crystals embedded in a glassy matrix. These elongated crystals can inhibit crack propagation and thus increase the strength as mentioned by

Fasbinder et al (2010).[9] While, for Vita Suprinity, due to its partially crystallized microstructure and incorporation of zirconia filler which act as a nucleating agent, but remains in the solution of the glassy matrix forming a microstructure that consists of very fine lithium meta- silicate in the pre-crystalline stage (Kruger et al 2013).[50] In case of In Coris zirconia, the micro-structure is free from the glassy phase, thus exhibiting the most superior mechanical properties as compared to the other two materials.

The present results were in accordance with those of Choi et al[51], who concluded that the fracture resistance of Vita Suprinity and e.max CAD were comparable and had higher value than the maximum physiological masticatory force, thereby demonstrating their clinical applicability in posterior esthetic restorations. Similarly, Rosentritt et al[52] stated that CAD – CAM monolithic zirconia crowns showed sufficient fracture resistance to be used in molar regions, even in a thin configuration (0.5 mm). The enhanced performance of monolithic zirconia crowns may be caused by the elimination of the interface between the core and veneer which is believed to be the weak link in the bilayer system.

The fracture mode of the tested crowns was studied and evaluated through digital photographs and was found to augment the findings of the current study. In-Coris TZI zirconia showed only few crown fractures that involved more than half of the crown (modes III, IV without any mode V), those constituted about 30% of all tested crowns of this group. While, IPS e.max CAD exhibited about 50% of its group ranging from mode III, IV and V. In comparison, Vita Suprinity showed as much as 70% of its sample size that exhibited fractures involving more than one half of crowns (modes III, IV and V). The fracture load presented by all groups tested was still higher than the maximum chewing forces reported in the literature, which is expected to be around 700 N for healthy young adults.[53] So, all materials tested in this study may tolerate the clinical applications without restrictions.

CONCLUSIONS

Within the limitation of the present study, the following could be concluded:

1) Vita Suprinity crowns showed the best overall marginal and internal adaptation when compared to either IPS e.max CAD or In-Coris TZI zirconia crowns.
2) Monolithic zirconia exhibited the highest fracture strength of all three tested materials.
3) Production method and material composition of monolithic zirconia may affect the internal and marginal fit of crowns.
4) The marginal and internal adaptation values as well as the fracture resistance values were within a clinically acceptable range for all three materials tested.

REFERENCES

1. Coldea A, Swain MV, Theil N. Mechanical properties of polymer – infiltrated ceramic – network materials. Dent Mate 2013; 29: 419-26.
2. Kelly JR, Benetti P. Ceramic materials in dentistry, historical evaluation and current practice. Aust Dent J. 2011; 56(Suppl. 1) 84-96.
3. Komine F, Blatz MB, Matsumura H. Current status of zirconia-based fixed restoration. J Oral Sci – 2010 Dec; 52 (4): 531-9. Pub Med PMID 21206154.
4. Ferrari M. Vichi A, Zarone F. Zirconia abutments and restorations: from laboratory to clinical investigations. Dent Mater 2015; 31: 63-76.
5. Gherlone E, Mandelli F, Cappare P, Pantaleo G, Traini T, Ferrini F. A 3 years retrospective study of survival for zirconia – based single crowns fabricated from intraoral digital impressions. J Dent 2014; 42: 1151-5.
6. Hoff A, Lof H, Gunne J, Sjogren G. A retrospective evaluation of zirconia-fixed partial dentures in general practices: an up to 13- year study. Dent Mater 2015, 31: 162-70.

7. Tysowsky G. The science behind lithium disilicate today's surprisingly versatile esthetic and durable metal free alterative Oral Health J 2009; 3: 93-7.

8. Niu E, Agustin M, Douglas RD. Colour match of machinable lithium disilicate ceramics effects of foundation restorations. J Prosthetic Dent 2013; 110. 501-9.

9. Fasbinder DJ, Dennison JB, Heys D, Neiva G. A clinical evaluation of chairside lithium disilicate CAD/ CAM crowns a two year report. J Am Dent Assoc 2010; 141 (Suppl. 2) 105-45.

10. Vita Suprinity CAD/ CAM Restorative Vita Suprinity brochure. Available at: https://www.vita-zahnfabrik.com/en/vita-suprinity-14036.html.

11. Baig MR, Tan KB, Nicholls JI. Evaluation of the marginal fit of a zirconia ceramic computer-aided machined. J Prosthet Dent 2010; Oct, 104 (4): 216 -27.

12. Kumar M, Shanavas M, Sidappa A, Kiran M. Cone Beam computed tomography – know its secrets. J. Int Oral Health 2015; 7: 64-8.

13. IPS e.max CAD Labside instructions for use 2009, available from: http://www.ivoclarvivadent.us/en-us/.../IPS+e-max+CAD+Labside.

14. Holmes JR, Sulik WD, Holland GA, Bayne SC. Marginal fit of castable ceramic crowns. J Prosthet Dent 1992;67: 594-49.

15. Kelly JR. Clinically relevant approach to failure testing of all ceramic restorations. J. Prosthet Dent 1999; 81: 652-61.

16. Lorenzoni f, martins L, Silva N, Coelho P, Guess P, Bonfante E. Fatigue life and failure modes of crown systems with a modified framework design. J Dent 2010; 38(8); 626- 634.

17. Kim JH, Park JH, Park YB, Moon HS. Fracture load of zirconia crowns according to the thickness and marginal design of coping. J. Prosthet Dent 2012; 108 (2) : 96- 101.

18. Beuer F, Steff B, Naumann M, Sorensen JA. Load bearing capacity of all ceramic three unit fixed partial dentures with different computer – aided design / CAM fabricated framework materials. Eur J Oral Sci 2008; 116: 381-386.

19. Albrecht T, Kirsten A, Kappert HF, Fischer H. Fracture load of different crown systems on zirconia implant abutments. Dent Mater 2011; 27: 298- 303.

20. Hosseini MI, Kleven E, Gotfredsen K. Fracture mode during cycling loading of implant- supported single- tooth restorations. J. Prosthet Dent 2012; Aug 108 (2): 74-83.

21. Cho HY, Wona HY, Choeb HC, Sonc MK. Fracture characteristics of dental ceramic crown according to zirconia coping design. Prac Eng 2011; 10: 1561 – 1566.

22. Burke FJ, Watts DC. Fracture resistance of teeth restored with dentin bonded crowns. Quintessence Int 1994; 25: 335-40.

23. Pelekanos S, Koumanou M, Koutayas S: Micro-CT evaluation of the marginal fit of different In-Ceram alumina copings. Eur J Esthet Dent 2009; 4: 278-292.

24. Ahlowalia MS, Patel S, Anwar HMS, Cane G, Austin RS, Wilsin R. Accuracy of CBCT for volumetric measurement of simulated periapical lesion . Int Endod J 2013; 46:538-46.

25. Groten M, Axmann D, Pröbster L. Determination of the minimum number of marginal gap measurements required for practical in vitro testing. J Prosthet Dent 2000; 83:40-49.

26. Gonzalo E, Suárez MJ, Serrano B. A comparison of the marginal vertical discrepancies of zirconium and metal ceramic posterior fixed dental prostheses before and after cementation. J Prosthet Dent 2009; 102: 378-384.

27. Kyu-Bok Lee, Charn-Woon Park, Kyo-Han KiM, Tae-Yub Kwon. Marginal and Internal Fit of All-ceramic Crowns Fabricated with Two Different CAD/CAM Systems. Dent Mater 2008; 27: 422-426.

28. Kohorst P, Brinkmann H, Li J. Marginal accuracy of four unit zirconia fixed dental prostheses fabricated using different computer aided design / computer aided manufacturing systems. Eur J Oral Sci 2009; 117: 319-25.

29. Pera P, Gilodi S, Bassi F. In vitro marginal adaptation of alumina porcelain ceramic crowns. J Prosthet Dent 1994; 72: 585-90.

30. Bindl A, Mormann WH. Fit of all ceramic posterior fixed partial denture frameworks in vitro. Int J Rest Dent 2007; 27: 567- 75.

31. Yildirim G, Uzun I H, Keles A. Evaluation of marginal and internal adaptation of hybrid and nanoceramic systems with microcomputed tomography: An in vitro study. J Prosthet Dent 2017; 118: 200- 207.

32. Mously HA, Finkelman M, Zandparsa R, Hirayama H. Marginal and internal adaptation of ceramic crown restorations fabricated with CAD- CAM technology and the heat-press technique. J Prosthet Dent 2014; 112: 249 -56.

33. Schriwer C, Skjold A, Gjerdet N R, Øilo M. Monolithic zirconia dental crowns. Internal fit, margin quality, fracture mode and load at fracture. Dent Mater 2017;33:1012- 20.

34. Tinschert J, Natt G, Mautsch W, Spiekermann H, Anusavice KJ. Marginal fit of alumina- and – zirconia based fixed partial dentures produced by a CAD/CAM system. Oper Dent 2001 Jul- Aug;26 (4): 367-74.

35. Reich S, Wichmann M, Nkenke E, Proeschel P. Clinical fit of all ceramic three unit fixed partial dentures, generated with three different CAD/CAM systems. Eur J Oral Sci 2005 Apr; 113 (2): 174 – 9.

36. Yildiz C, Vanlioglu BA, Evren B, Uludamar A, Ozkan YK. Marginal- internal adaptation and fracture resistance of CAD/CAM crown restorations. Dent Mater J. 2013; 32 (1):42- 7.

37. Lee B, Oh KC, Haam D, Lee JH, Moon HS. Evaluation pf the fit of zirconia copings fabricated by direct and indirect digital impression procedures. J Prosthet Dent. 2018; Article In Press.

38. Rekow ED, Silva NR, Coelho PG, Zhang Y, Guess P, Thompson VP. Performance of dental ceramics: Challenges for improvement. J Dent Res. 2011;90:937-952.

39. Jalalian E, Atashkar B, Rostami R. The effect of preparation design on the fracture resistance of zirconia crown copings (Computer associated design/ computer associated machine) CAD/CAM system. J Dent (Tehran). 2011;8:123-129.

40. Burke FT, Fleming GT, Abbas G, Ritcher B. Effectiveness of a self adhesive resin lutin system on the fracture resistance of teeth restored with dentin bonded crowns. Eur J Prosthodont Restor Dent. 2006;14:185-8.

41. Slaverry A, Borges GA, Mota EG, Burnett Junior LH, Spohr AM. Effectof resin cements and aging on cuspal deflection and fracture resistance of teeth restored with composite resin inlays. J Adhes Dent. 2013;15:561-8.

42. Wang H, Aboushelib MN, Felizer AJ. Strength influencing variables on CAD/CAM zirconia frameworks. Dent mater. 2008;24:633-8.

43. Gargari M, Gloria F, Napoli E, Pujia M. Zirconia: cementation of prosthetic restorations. Literature review. Oral Implantol (Rome). 2010;3(4):25-29.

44. Johansson C, Kmet G, Rivera J, Larsson C, Vult Von Steyern P. Fracture strength of monolithic all-ceramic crowns made of high translucent yttrium oxide stabilized zirconium dioxide compared to porcelain veneered crowns and lithium disilicate crowns. Acta Odontol Scand. 2014;72:145-153.

45. Nakamura K, Harada A, Inagaki R, Kanno T, Niwano Y, Milleding P, Ortengren U. Fracture resistance of monolithic zirconia molar crowns with reduced thickness. Acta Odontol Scand. 2015; 73: 602-608.

46. Zhang Y, Mai Z, Barani A, Bush M, Lawn B. Fracture resistance of monolithic dental crowns. Dent Mater 2016;32(3):442-449.

47. Nordal N, Von Steyern PV, Larsson C. Fracture strength of ceramic monolithic crown systems of different thickness. J Oral Sci 2015;57:255-261.

48. Elsaka SE, Elnaghy AM. Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. Dent Mater 2016;32(7):908-14.

49. Sherrer SS, Denry IL, Wiskott HW. Comparison of three fracture toughness testing techniques using a dental glass and a dental ceramic. Dent Mater 1998;14:246-55.

50. Kruger S, Deubener J, Ritzberger C, Holand W. Nucleation kinetics of lithium disilicate glasses for dental application. Int J of applied glass science 2013;4(1):9-19.

51. Choi S, InYoon H, Park EJ. Load-bearing capacity of various CAD/CAM monolithic molar crowns under recommended occlusal thickness and reduced occlusal thickness conditions. J Adv Prosthodont 2017;9:423-31.

52. Rosentritt M, Behr M, Gebhard R, Handel G. Influence of stress simulation parameters on the fracture strength of all ceramic fixed partial dentures. Dent Mater 2006; 22:176-82.

53. Ferrario VF, Forza CS, Zanolti G, Trataglia GM. Maximal bite forces in healthy young adults as predicted by surface electromyography. J Dent 2004;32(6):451-457.