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FRACTURE STRENGTH AND MARGINAL GAP OF TWO DIFFERENT TYPES OF HYBRID CERAMIC CROWNS

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Fracture Strength, Hybrid Cermics, Lithium disilicate, Lithium Silicate, Marginal Gap, Polymer infiltrated ceramic

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ABSTRACT

Introduction: Although ceramics are routinely used for dental restorations, a major drawback is their high clinical failure rate in the posterior area of the mouth. **Aim:** The aim of this study was to evaluate the fracture strength and marginal gap of two different types of hybrid ceramics in comparison to lithium disilicate ceramic crowns using a CAD/ CAM system. **Materials and Methods:** Crowns were fabricated from Vita Enamic (a polymer-infiltrated ceramic-network, Vita Suprinity (a zirconia reinforced lithium silicate), and IPS E.Max CAD (lithium disilicate) using the Cerec in lab 3D system (n=5) for each group. The Vertical marginal gap was measured before the cementation using a metallurgic microscope. The inner surfaces of the crowns were then etched and luted to epoxy resin dies with Panavia F2 resin cement. Single load-to-failure tests were performed using a universal testing machine. Statistical analysis was performed using one-way ANOVA and post-hoc Tukey's HSD test. **Results:** Vita Suprinity crowns (80.14 ± 7.64 μm) had a statistically significant higher marginal gap than that of E.Max (60.13 ±3.63 μm) and Vita Enamic (55.56 ± 7.20 μm).The difference in marginal gap between Vita Enamic and E.Max was not stasistically significant. The mean fracture strength values were highest for E.Max crowns (1761.6±101.0 N), slightly lower for Vita Suprinity (1633.5 ±149.5 N) and both had a significantly higher fracture strength value than Vita Enamic (1002.8 ± 78.9 N).**Conclusion:** Vita Enamic and E.Max had better marginal adaptation than Vita Suprinity crowns. All values of vertical marginal gaps of the used materials were in the range of clinical acceptability. E.mMx CAD and Vita Suprinity had higher fracture strength values than Vita Enamic crowns. The fracture strength values of the tested materials were above the maximum masticatory forces.

INTRODUCTION

Due to increasing concerns about the aesthetics and biocompatibility of dental restorations, patients and dentists have become more and more interested in metal free tooth-colored materials. Ceramic materials were developed in response to this increasing demand [(1)].

Although ceramics are routinely used for dental restorations, a major drawback is their high clinical failure rate in posterior area of the mouth [(2)]. All-ceramic crowns are often replaced because of bulk fracture. A catastrophic failure mode noted in both monolithic and layered crowns[3]. The fracture resistance of layered ceramic crown can be influenced by its core design and the thickness of the core or veneering ceramic [4]. Most dental ceramics are considered brittle because of their low tensile strength and fracture toughness, which can be influenced by the presence of inherent flaws within the material. Tensile stresses caused by external loading can lead to a propagation of cracks starting at these inherent flaws and other defects. Therefore, cracks usually initiate from the inner surface of ceramics, and then propagate through the material to the outer surface, ultimately leading to bulk fracturing [5].

In an attempt to improve the mechanical properties, industrially made CAD/CAM ceramics blocks have been introduced to dentistry [1]. Processing ceramics under industrial conditions resulted in remarkable reduction in voids, flaws, and cracks in comparison with laboratory processing [6]. Fracture resistance along with esthetic value and crown fit, is important for the clinical success and longevity of crown restorations [7]. An increase in the marginal or internal gap can increase cement dissolution, thereby increasing the potential for microleakage, recurrent caries, and periodontal disease[8]. Adhesive bonding systems were introduced in dental practice not only to improve the retention but also to achieve better aesthetic results and maintain high ceramic strength. According to some studies, bonded all-ceramic restorations show a higher fracture resistance than conventionally cemented restorations [9-11]. This arises from the fact that resin cement used in bonded restorations is elastic and it tends to deform under stress conducting to a higher resistance to fracture [12]. Hybrid ceramics were introduced to the market to overcome the drawbacks of the present all ceramic restorations. A ceramic network structure was infiltrated with a polymer material to combine the advantages of the two materials to obtain better mechanical properties and better machinability for CAD/CAM than those of glass-ceramics [13]. In another approach, dissolving 10% zirconia inside the lithium silicate glass matrix to give zirconia reinforced lithium silicate, claimed to be more translucent and stronger material than the conventional lithium disilicate ceramic [14]. To investigate whether the hybrid ceramics and zirconia reinforced lithium silicate can overcome the drawbacks of the present all ceramic restorations or not, this study was conducted to evaluate the fracture strength and marginal quality of two different types of ceramic materials in comparison to lithium disilicate crowns.

MATERIALS AND METHODS

This study was waived by the research ethical committee of Faculty of Dentistry- Suez Canal University. One extracted permanent upper first premolar was used after cleaning and sterilization and prepared to receive an all-ceramic crown following dimensions recommended by the ceramic manufacturer.

A dental surveyor (paramil2, Dentaurum, 75104 Pforzheim, Germany) was used to adjust the tooth in the milling machine (AF30, Nouvay AGST,Gallesr str, ch-9403 Goddach,switzer land)**.** The tooth had an occlusal reduction of 2 mm and a minimum axial reduction of 5 mm with a 6° to 8° total angle of convergence (3° to 4° on each side). The gingival margin was prepared with a circumferential shoulder 1 mm wide finish line. Lingual and facial surfaces were prepared in two planes, and all line angles were smoothed to reduce stress concentration.

The prepared tooth was duplicated into fifteen epoxy resin [15] (Viade Products ,Inc .Camarillo, CA) working dies using silicon duplicating molds (Dupililex, duplicating silicone vilamalla (girona), Spain).

The epoxy resin dies were divided into three groups (n=5). The Omnicam camera (Cerec Omnicam Sirona Dental Systems, Benshei, Germany) was used to take an optical impression for each die.

According to the used ceramic material, five crowns from each type of material were constructed on five epoxy resin dies. Full anatomical crowns were fabricated using the Cerec 3D system with in-lab software 4.2 and lab MCXL milling machine (Sirona, Bensheim, Germany).

After saving the optical impression by Cerec software, a virtual model of the prepared die was constructed and displaced on the screen. Automatic tracing of the finish line of the preparation was done. The Cerec software was used to design the crowns on the virtual die. The type of block, site of sprue and the cutting tools types were selected on the software. Five Vita Enamic (Hybrid ceramic, VITA Zahnfabrik, Bad Säckingen, Germany) crowns, five Vita Suprinity (Zirconia reinforced lithium silicate glass-ceramic, VITA Zahnfabrik, Bad Säckingen, Germany) and five IPS E.Max Cad blocks (Lithium disilicate glass-ceramic, Ivoclar Vivadent Schaan, Liechtenstein) were used to fabricate full anatomically crowns for each group. Each block was inserted in the workplace spindle and tightened, and the machine was given an order to mill the crowns. Each crown was then separated from the block at the end of milling and checked on its corresponding die to ensure proper seating and fitting. Any crown with marginal or fitting discrepancy had been excluded and remade.

After complete milling of each Vita Enamic crown, the sprue was cut then the crown was carefully and gently polished using a specific polishing set (VITA Enamic polishing set, VITA Zahnfabrik, Bad Säckingen, Germany). Pre-polishing was performed using the pink polishing tools included in the set (7.000-10.000 rpm). High-gloss glass polishing was performed using the diamond-coated, gray polishing tools included in the set (5.000-8.000 rpm).

After milling of Vita Suprinity and IPS E .Max CAD crowns, the sprues were cut, and the pre-crystallized crowns were placed in a ceramic furnace (Programt P 310 furance, IVOCLAR VIVADENT) for crystallization. For the Vita Suprinity crowns; the crowns were first pre-dried at 400 ^{o}C for 4 minutes and the heating temperature was then increased at 55 ^{o}C /min until it reached 840 ^{o}C and heled for 8 minutes. For the IPS E.Max CAD crowns; the crowns were first pre-dried at 403 ^{o}C for 6 minutes and the heating temperature was then increased at a rate of 90 ^{o}C /min until a firing temperature of 820 ^{o}C was reached and held for 10 minutes. The temperature was increased at a rate of 30 ^{o}C /min until the firing temperature reached 840 ^{o}C and held for 7 minutes.

A metallurgic microscope (Olympus BXYIM, San-E bulding, 22-2, Ni shinyuku, 1- Cheme, shinyuku-ku Tokyo, Japan, (resolution of 1400 x 1200 pixels) was used to measure the marginal gap at a magnification of 20 x. The vertical marginal gap was measured before cementation [16-18].

Each crown was put on its die and a specially designed device used to fix the crown on its die during the measurement. Eight points were randomly selected for each surface of the crown and the gap was measured at these points ending by 32 readings for the whole crown [19,20]. The measurement was taken from the end of the crown to the finish line of the die, then computer software used to calculate the gap in (μm).

The inner surfaces of all crowns were acid etched according to manufacturer's instruction with 5% hydrofluoric acid (Dentobond etch ITENA France). Vita Enamic crowns were etched for 60 seconds, Vita Suprinity for 20 seconds and E.max crowns for 20 seconds according to the manufacturer's instructions. The etched internal surfaces were thoroughly rinsed using air -water spray for 60 seconds then dried with oil-free compressed air for 30 seconds. The etched surfaces were then silanized by applying silane coupling agent (Dentobond ceramic silane ITENA France) for 60 seconds followed by air thinning.

Cementation was done using Panavia F 2.0 adhesive resin cement (Kurary Medical, Traumi cho, Suita, Osaka 504-8650 Japan),the mixing, placement, and final curing were done according to the manufacturer's recommendation.

Two drops of the primer were mixed, applied on the die, left for 30 seconds then air dried for 10 seconds, then a 1:1 base-to-catalyst ratio was mixed for 20 seconds, and applied to the inner surface of the crown. After seating of each crown on its corresponding die a fixed 3 kg load was applied to each crown for 5 minutes by using a special device to standardize the pressure during cementation [21]. Initial Light-curing for 2 second was done, then the excess cement was removed using a sharp explorer. Each crown surface was then light-cured (blue phase C5 LED Coltene, Whaledent, Switzerland, wavelength 450-470 nm) for 20 seconds.

All specimens were loaded in a universal testing machine (TIRA test 2805, Tira Gmbh, Eisfelder Strable 23 /25 D -9528, Schaikau, Germany) until fracture occurred**.** A steel indenter (r = 5 mm) was placed in the central fossa to establish a three-point contact to achieve a homogenous distribution of the applied force [22-24].

A piece of tin foil sheet was applied over the occlusal surface to achieve homogenous stress distribution [25]. The applied load was perpendicular to the long axis of the specimens at a cross head speed of 1.0 mm/min until catastrophic fracture occurred. The fracture load for each specimen was recorded in Newton (N) with the testing system's computer software.

Statistical analysis

All results of vertical marginal gab and fracture strength were tabulated and statistically analyzed using one way ANOVA test to detect if there were any significant difference between the results of the tested groups.

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0**.** (Armonk, NY: IBM Corp). The Kolmogorov-Smirnov test was used to verify the normality of distribution. Quantitative data were described using range (minimum and maximum), mean, standard deviation and median. The significance of the obtained results was judged at the 5% level.

RESULTS

Vertical marginal gap

The mean vertical marginal gap in (μm) and standard deviation for the three groups are shown in (Table 1) and presented in a bar chart diagram (Figure 1). The vertical marginal gap results were measured. The results showed that the highest mean values of the vertical marginal gap were reported for Vita Suprinity (group A), while the lowest mean value was reported for the Vita Enamic (group C). Statistical analysis of one-way ANOVA and post-hoc Tukey's HSD test showed that there was a statistically significant difference between Vita suprinity (group A) samples and the rest of the groups ($p < 0.001$). While there was no statistically significant difference between E.Max (group B) and Vita Enamic (group C).

Table (1) *Comparison between the three studied groups according to marginal gap in (µm)*

Group no.	Material	N	Marginal gab in (µm) Mean	± SD.	P- value
Group A	SUPRINITY	5	80.14[a]	7.64	
Group B	E.MAX	5	60.13[b]	3.63	<0.001*
Group C	ENAMIC	5	55.56[b]	7.20	

P- value for ANOVA test, Pairwise comparison bet. each 2 groups were done using Post Hoc Test (Tukey) *Means with* **Different letters** *are significant *: Statistically significant at p ≤ 0.05*

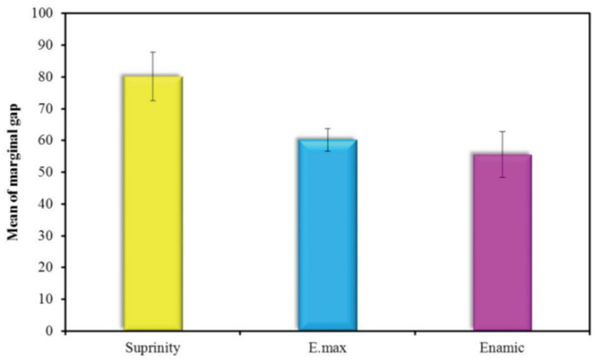

Fig. (1) Comparison between the three studied groups according to marginal gap in (µm)

Table (2) *Comparison between the three studied groups according to fracture strength in (N)*

Group no.	Material	n	Fracture Strength (N) Mean	± SD.	P- value
Group A	Suprinity	5	1633.5[a]	149.5	
Group B	E.Max	5	1761.6[a]	101.0	<0.001*
Group C	Enamic	5	1002.8[b]	78.9	

p-value for **ANOVA test**, *Pairwise comparison bet. Each 2 groups were done using* **Post Hoc Test (Tukey)** *Means with* **Different letters** *are significant *: Statistically significant at p ≤ 0.05*

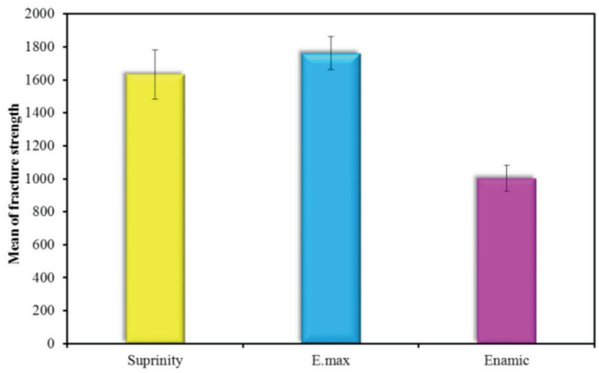

Fig. (2) Comparison between the three studied groups according to fracture strength in (N)

Fracture strength results:

The results showed that the highest mean fracture strength values were recorded for E.Max (group B), while the lowest mean values were recorded for Vita Enamic (group C). Statistical analysis of one-way ANOVA and post-hoc Tukey's HSD test showed that there was a statistically significant difference between Vita Enamic (group C) samples and the rest of the groups (p <0.001). While there was no statistically significant difference between Vita Suprinity (group A) and E.Max (group B) presented in (Table2) and in bar chart diagram (Figure2).

DISCUSSION

Predictable mechanical performance, high esthetics, and accurate marginal adaptation are among the most critical requirements for the fabrication of prosthetic dental crowns. To achieve these characteristics, computer-aided design and manufacturing (CAD/CAM) technology has been employed in recent decades, enabling the standardized manufacturing of highly accurate monolithic crowns with a more homogenous composition and fewer imperfection voids compared to their traditional porcelain-veneered counterparts[26]. In this study the marginal gap and fracture strength were evaluated for vita Enamic and Vita Suprinity in comparison to lithium disilicate ceramic crowns. Lithium disilicate glass-ceramic (IPS e. Max CAD) was selected in this study as a control group due to long clinical success, stability and less laboratory steps, in addition the good bonding characteristics as it is etchable ceramic[27-29].

Vita Enamic is a polymer infiltrated ceramic, was developed in order to mimic the physical properties of natural teeth and to overcome the brittleness of ceramics causing wear on the antagonistic tooth[30]. Vita Suprinity is a zirconia-reinforced lithium silicates also introduced to overcome the drawbacks of the present ceramics. The material supposedly has improved optical and mechanical properties through the introduction of tetragonal zirconia in its composition [31].

Tooth preparation was done using a dental milling machine to ensure properly tapered walls with rounded shoulder finish lines as recommended by the ceramic manufacturers. To standardize the dies used in this study, all the dies were duplicated from the same prepared tooth. Epoxy resin rather than metal dies were selected for fracture strength evaluation because it had a modulus of elasticity comparable to that of dentin. This model was used instead of natural teeth for the fabrication of tested samples to overcome the variation among the natural teeth in terms of dimensions, individual structure, and subsequently the effect of storage time after extraction. These variables could have caused difficulties in standardizing the final crowns and affected the results of fracture strength measurements as mentioned by Sheen CY et el [15]. All the dies were scanned using the Omnicam camera, and all the crowns were designed and milled using the same software with Cerec in lab machine. All the steps were done by one well trained operator to avoid human variations. In the present study the vertical marginal gap distance measurement of each crown were evaluated between the outer cervical margins of each crown and the surface of the die finish line using a metallurgic microscope[32].

The marginal gab was measured before cementation, to detect the primary precision of each crown restoration and to eliminate any variables which could occur during cementation such as mixing technique, cement viscosity and cement film thickness that would complicate the possibility of obtaining proper information about the precision of marginal gab of the restoration as noted by other authors [16-18]. Eight measurement points were taken for each surface, ending with 32 measurements. Some other studies [19] evaluated the vertical marginal gab, only four readings per specimen were taken: one measurement for each surface. These multiple numbers of readings that were randomly selected allowed for comprehensive and subsequently accurate results without the need for pre determinant measuring points [20].

Strict adherence to the bonding protocols for each material was followed according to the manufacture's recommendations in order to eliminate variables during the bonding procedures. Cementation was done using Panavia F2.0 adhesive resin cement, and mixing of the cement were done according to the manufacturer instructions. Seating of the crowns on each die was standardized using a specially designed cementation device, which allowed static placement of 3kg load during the setting procedures. This load was chosen as recommended by Spohr AM et al. [21] to avoid the risk of damaging the ceramic crowns. The fracture strength test was done by applying a compressive load using load applicator in the form of a stainless-steel round tip with a 5 mm diameter centered in the occlusal surface between the buccal and lingual cusp at a crosshead speed of 1 mm/min until fracture[22-24]. During the fracture test, a piece of tin foil sheet was applied over the occlusal surface to achieve homogenous stress distribution [25].

Most authors agree that marginal openings of less than 120 μm are in the range of clinical acceptability regarding longevity [33,34]. The mean marginal gab of different crown systems reported in the current study was 55.56 μm for Vita Enamic, 60.13 μm for E.Max and 80.14 μm for Vita Suprinity.

These findings agree with the clinical acceptance of the marginal openings range (120 μm). The mean marginal gap measurements in this study within the Vita Enamic group were non significantly lower than that of the lithium disilicate group. This difference could be due to differences in their physical properties. Vita Enamic blocks are softer (dual network of ceramic and composite) than lithium disilicate CAD/CAM blocks which resulted in smoother margins during milling of crowns which gives better marginal adaptation, these findings agree with many studies [33,35] which found that Vita Enamic and resin-based blocks exhibited visibly smoother margins and superior marginal adaptation compared to lithium disilicate. Moreover, E-Max and Vita Suprinity crown required further crystallization firing after milling, which might cause an increase in the marginal gap following crystallization due to shrinkage, while Vita Enamic crowns don't need any crystallization after milling, this could be in agreement with Gold et al., [36] who found that lithium disilicate CAD/CAM crowns experienced an increase in marginal gap following crystallization than before crystallization. The Vita Suprinity group showed a significantly higher marginal gap than Vita Enamic and E.Max, this may be related to the increased brittleness index and chipping factor of Vita Suprinity, probably due to the presence of zirconia in its microstructure [31,37] . These findings are in accordance with Elsaka and Elnaghy [14], who reported that E.Max CAD showed a lower brittleness index than Vita Suprinity which denotes that E.Max has superior machinability and lower marginal chipping rates than Vita Suprinity. These results also agree with Gomes et al., [38] who evaluated the misfit of zirconia-reinforced lithium silicate and lithium disilicate crowns and found that zirconia-reinforced lithium silicate crowns showed higher misfit in the cervical region than did lithium disilicate crowns.

The mean fracture strength value in this study for E.Max (1761.6 N) was higher than Vita Suprinity (1633.5 N) with no statistical significance. Both materials were significantly higher than Vita Enamic group (1002.8 N). These results suggested that all the monolithic crowns used in the present study were sufficient for clinical use because they can experimentally withstand the average (700 N) or the maximum physiological masticatory forces (1000 N) exerted on posterior human teeth [39,40].

The fracture strength value recorded for E-Max was significantly higher than Vita Enamic, these results could agree with many previously published studies [41,42,43,44,], it is obviously due to Vita Enamic having a major feldspathic-based phase infiltrated by a polymer-based network, both phases have lower mechanical properties than lithium disilicate and involve crystals have the characteristics of preventing fracture formation and progress [45]. The fracture strength value for E-Max was higher than Vita Suprinity with a non-significant difference, and this might be due to the high number of interlocking, needle-like crystals that are embedded in the glassy matrix of E-Max, the volume of the crystalline phase is (70%) which resulted in a structure which is more resistant to crack propagation. Additionally, the monolithic structure of lithium disilicate ceramic facilitates a proper etching pattern using hydrofluoric acid, so that a stronger bond with the adhesive resin cement may be achieved (46). Moreover, the presence of zirconia in the microstructure of Vita Suprinity, might increase the material hardness, making it more prone to chipping during milling (31), which could indirectly compromise the fracture strength of the material (47).

The fracture strength values of Vita Suprinity were comparable to that of E.Max, this could be attributed to the presence of the reinforcing zirconia (ZrO_2) in the glassy phase of Vita Suprinity, which transformed from a metastable tetragonal phase to a stable monoclinic phase with increased grain volume, which strengthened the material through a crack interruption mechanism (14). These findings could be in agreement with Mendonca et al.(48) ,who evaluated the fracture strength of lithium disilicate, a zirconia-reinforced lithium silicate and a hybrid polymer-infiltrated ceramic crowns and found that lithium disilicate had non-significant higher fracture strength value than zirconia-reinforced lithium silicate and both materials had significantly higher fracture strength than the hybrid polymer-infiltrated ceramic network materials. On the other hand, the results of the present study seemed to disagree with the study of Schwindling et al(49), they found that the mean fracture loads were highest for zirconia-reinforced lithium silicate than lithium disilicate monolithic incisor crowns before ageing. The differences between their results were not statistically significant. These differences in the results might be due to; they used a die material of cobalt chromium (CoCr) alloy which have a modulus of elasticity different than that of the acrylic die we used in our study, and they used a different cement for cementation of crowns.

CONCLUSION

It was concluded from this study that, Vita Enamic crowns had a better marginal fit than E.Max and both had a better marginal fit than Vita Suprinity crowns. All values of vertical marginal gaps of the tested materials were in the range of clinical acceptability ($<120\ \mu m$) moreover, E.Max CAD crowns had higher fracture strength values than Vita Suprinity and both had higher fracture strength values than Vita Enamic crowns. The fracture strength values of the tested materials were above the maximum masticatory forces.

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