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FATIGUE RESISTANCE, FRACTURE STRENGTH AND MARGINAL INTEGRITY OF THREE TYPES OF CAD/CAM HYBRID CERAMIC CROWNS

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ABSTRACT

Aim: To assess fatigue resistance, fracture strength and marginal integrity of three different CAD/CAM hybrid ceramic types.

Materials & methods: A maxillary premolar tooth was prepared to receive an all-ceramic crown, scanned with Omnicam intraoral scanner. A STL file was transferred to Formlabs 3D-printer to print fifteen resin dies. One die was scanned with Cerec Omnicam and fifteen hybrid ceramic crowns were milled with Cerec MCXL milling machine. Crowns were grouped into three groups (n=5); group A (Vita Enamic), group B (Brilliant Crios) and group C (Shofu Hc). Crowns marginal gaps were measured using a USB digital microscope. Crowns were bonded using Panavia F2.0 adhesive resin cement then their vertical marginal gaps were remeasured. Thermocycling of the crowns was done for 5000 cycles and crowns were subjected to fatigue using a chewing simulator by applying cyclic loading of 50 N for 250,000 cycles with a frequency of 1.6 Hz. Marginal gaps of survived crowns were measured. Survived crowns were tested for fracture strength using a universal testing machine at a crosshead speed of 1 mm/min. Data were analyzed by one way ANOVA and Post Hoc Tests at $p \leq 0.05$.

Results: There was a significant statistical difference between mean vertical marginal gap of all groups where group C showed the highest mean vertical marginal gap through all stages; before or after bonding and after thermomechanical aging. All crowns survived fatigue testing. Group C showed the highest mean fracture strength followed by group A then Group B.

Conclusions: Tested materials showed vertical marginal gaps, fatigue resistance and fracture strength within the clinically acceptable range.

KEYWORDS: Hybrid ceramics, Fatigue, Thermocycling, Marginal gap, CAD/CAM.

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INTRODUCTION

Hybrid ceramics were evolved into the dental field forming a new class of chairside CAD/CAM materials. These materials have some advantages of ceramics such as color stability and durability and some of composite resins ones such as good low abrasiveness, flexural properties, and the ability to be repaired intraorally.[1,2] They also have proper machinability due to their low brittleness, resiliency and high fracture strength. [3,4]

Elastic modulus of hybrid ceramics is near to that of dentin and some cements. So, stress during mastication may be distributed in a uniform way. Also, resiliency of hybrid ceramics elevates their withstanding ability to forces as they undergo elastic deformation before failure. On the other hand, repeated elastic deformation of these restorations' margins can cause microleakage followed by restorative failure at the margins with subsequent recurrent decay. [5]

Hybrid ceramics have a wide range of application as they can be used as inlays, onlays, veneers, anterior and posterior crowns. They are milled in the last stage then finished and polished without firing making these materials available for single visit restorations. Manufacturers have provided the range of indications for hybrid materials for use as.[6]

Main requirements for the success of any fixed restoration include precise marginal fit, fatigue resistance and good fracture strength. Microleakage is always related to high marginal misfit. It can result in irritation of the vital pulp. Improper margin fitting can also lead to recurrent caries and periodontal problems by increasing plaque deposition and gingival irritation. This can affect longevity of the restoration. [7]

On the other hand, clinical longevity of the fixed restoration is directly proportional to its fatigue resistance and fracture strength. Any restoration may fracture suddenly from a single concentrated overload but also, multiple cycles at low loads, damage accumulation can also alter their durability reducing their service life. [8-10]

Due to the limited availability of studies investigating hybrid ceramic CAD/CAM restorations, the current research was conducted to assess marginal fit and fatigue of three types of hybrid ceramic CAD/CAM crowns after thermodynamic aging.

MATERIALS AND METHODS

This study was approved by the research ethical committee of Faculty of Dentistry- Suez Canal University (n.117 /2018).

Samples preparation

A freshly extracted non-carious human upper first premolar was selected and mounted in epoxy acrylic resin. Tooth preparation was done using a 1mm tapered diamond stone with flat end under air water spray for cleaning of tooth debris. A contra-angle handpiece was fixed horizontally to the upper arm of a milling machine by using a custom-made adaptor to allow the diamond bur to be vertically hanging parallel to the longtudinal axis of the tooth. The preparation had (1 mm) shoulder finish line, 6 degrees convergence angle and. The length of the prepared axial walls was 3 mm for the mesial and distal surface, 3.5 mm for the palatal surface and 4mm for the buccal surface. 2mm occlusal reduction was made after removing the tooth from the milling machine using a cylindrical diamond stone. The prepared tooth was scanned with an intraoral scanner (Omnicam, Dentsply Sirona, USA).STL files were transferred to a 3D-printer (Formlabs Form 2, USA) to print fifteen identical resin dies.

Crowns constructions

Dies were scanned with an intraoral scanner (Omnicam, Dentsply Sirona, USA).STL files were transferred to a computer software (CEREC premium 4.5SW, Dentsply Sirona, USA). A standard design was employed for construction of all the crowns. CEREC Inlab MC XL milling machine (Dentsply Sirona, USA) was used for milling of the crowns. Crowns were grouped into three groups (n=5); group A: Vita Enamic (Vita Zahnfabrik Germany), group B: Brilliant Crios (Coltène, Switzerland) and group C: Shofu Hc (Shofu, Japan). Clinical finishing kit (Vita Zahnfabrik Germany) and polishing paste (Pearl surface, Kuraray Dental, Japan) was used for finishing and polishing of the crowns according to the manufacturers' instructions.

Vertical marginal gap measurement before bonding

Each crown was seated on its corresponding die and fixed using a special device for crown fixing. Photos were taken for each sample using a USB digital microscope with a built-in camera ((Scope Capture, China) connected with a computer using a magnification of 35X. A digital system for image analysis (Image J 1.43U, USA) was employed to measure crowns vertical marginal gaps. Eight points along each surface were recorded with a total of 32 reading for each crown.

Bonding of the crowns

All the crowns were bonded to their corresponding dies using Panavia F 2.0 adhesive resin cement (Kuraray dental, Japan) following the manufacturer's instructions. A special device was used to maintain a static load of three kg on the crown during bonding. Light curing was done using Elipar Deep Cure-L led curing unit (3M, USA) with 430–480 nm wavelength for 20 seconds for each crown surface.

Vertical marginal gap measurement after bonding

The vertical marginal gaps of the bonded crowns were recorded following the same technique used before bonding. The measured points were standardized before and after bonding with the help of an indentation done on the die as a reference point.

Thermodynamic aging

Bonded crowns were thermocycled between 5^0C-55^0C for 5000 cycles using a thermocycling machine (Robota automated thermal cycle, Turkey). Dwell times were 25 s. in each water bath with a lag time of 10 s. Fatigue cycling was performed for all the bonded crowns using a four stations masticatory simulator (Robota, AD-TECH Technology, Germany) simulating the vertical and horizontal movements in dynamic occlusion with 49 N force, 1.6 Hz frequency for 250,000 cycles.

Vertical marginal gap measurement after Thermodynamic aging

The vertical marginal gaps of the survived crowns were measured following the same technique used before thermodynamic aging.

Fracture resistance test

Bonded crowns were statically loaded to fracture using a universal testing machine (Instron 3345; Instron Industrial Products, USA) having 5 Kg load cell at a crosshead speed of 1mm/min with the use of a metallic rod with a 3.8 mm diameter rounded tip (figure 1). The readings were recorded in Newton and tabulated.

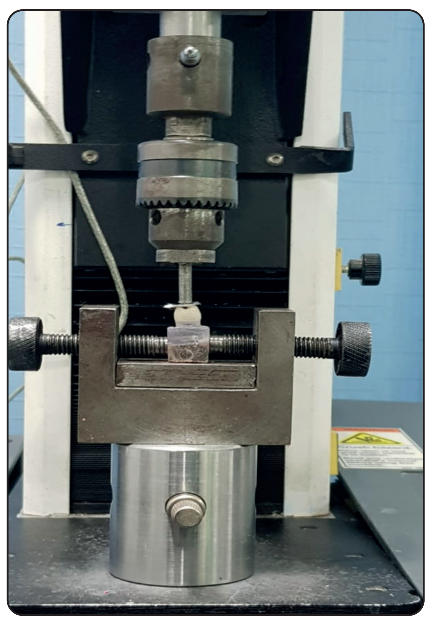

Fig. (1): Frecture resistance test

Statistical analysis

Data was analyzed using IBM SPSS software package version 20.0. (SPSS Inc., USA). ANOVA test was used to compare between more than two periods or stages, and Bonferroni-adjusted Post Hoc test was used in pairwise comparisons with a statistical significance of P-value ≤0.05.

RESULTS

Vertical marginal gap results

Mean and standard deviation (SD) values of vertical marginal gaps for the tested groups are represented in table1.

There was a significant difference statistically in mean gap before bonding between group C (shofu HC) and group A (Vita Enamic). Group C had a higher mean vertical marginal gap (41.5 ± 2.37 µm) than that of group A (35.30 ± 3.11 µm) (p = 0.041). However, there was no significant difference in the mean vertical gap between group B (Brilliant crios) (38.6 ± 4.77 µm) and either group A or group C.

After bonding, there was a significant difference statistically in mean vertical gap between groups A and C (p < 0.001), also between groups B and C (p < 0.001). Group C showed a higher mean vertical marginal gap (56.56±3.14 µm) followed by group B (43.70±2.97 µm) then group A (43.65±1.55 µm).

Furthermore, after thermodynamic aging, there was a significant difference statistically in mean vertical gap between the three tested groups (p <0.001). Group C had a higher mean vertical marginal gap (66.89±2.04 µm) followed by group A (51.16±1.70µm) then group B (46.01±1.94 µm).

Fracture resistance test results

There was not any sign of failure in any of the tested crowns after thermodynamic aging in the current study where all the crowns survived the 250,000 cycles of loading.

Means and standard deviations (SD) of fracture strength in Newton for the tested groups are tabulated in table2.

There was a significant difference statistically in mean fracture resistance between group C (755.30 ± 34.14 N) and group B (658.03 ± 37.06 N) (p = 0.006). But, there was no significant statistical difference in mean fracture resistance between group A (727.2 ± 31.47 N) and either group B or group C.

TABLE (1): Mean and standard deviation (SD) in microns of vertical marginal gaps before bonding, after bonding and after thermodynamic aging for the tested groups

Vertical marginal gap	Group (A) Vita Enamic		Group (B) Brilliant Crios		Group (C) Shofu HC		p-value
	Mean	±SD	Mean	±SD	Mean	±SD	
Before bonding	35.30	3.11	38.06	4.77	41.56	2.37	0.049*
After bonding	43.65	1.55	43.70	2.97	56.56	3.14	<0.001*
After thermodynamic aging	51.16	1.70	46.01	1.94	66.89	2.04	<0.001*

Significance level p ≤ 0.05 ***• Statistically significant***

TABLE (2): Mean and standard deviation (SD) in Newton of fracture resistance for the tested groups.

Group	Group (A) Vita Enamic	Group (B) Brilliant Crios	Group (C) Shofu HC	p-value
Mean ± SD	727.21±31.47	658.03±37.06	775.30±34.14	0.008*

Significance level p ≤ 0.05 **** Statistically significant***

DISCUSSION

Ceramics and composites are two common types of restorative materials available for use with CAD/CAM systems. Ceramics have excellent mechanical and optical properties and biocompatibility. However, they are fragile, rigid, and hard to repair. On the other hand, composites can be easily manipulated, repaired, more flexible, and less abrasive on the antagonist tooth. Still, their low wear resistance and difficulty obtaining good polish are the two main disadvantages of them. [11]

Therefore, Manufacturers thought of hybrid ceramics that intend to simulate the mechanical and optical properties of a natural tooth have been developed. The hybrid structure of these materials would reduce the restoration's fragility and superficial hardness, allowing for milling in a shorter time and predicting better clinical results [12].

In the current study, Stereolithography technology was used for the fabrication of the resin dies using Form labs form2 DLP (Digital Light Processing) 3D printer where a lot of thin layers of a resin material were added to build each resin die.[13,14] This excluded the human variations of dies formation by pouring an elastomeric mold with epoxy resin that usually leads to errors in the formed dies.[15]

For crowns of the current study to be identical, one of the prototyped dies was scanned by Cerec Omnicam. The 15 crowns had the same design using Cerec premium 4.5 software, and they were all milled using the same milling machine Cerec MCXL. The crowns were finished and polished using VITA Enamic clinical polishing kit and Pearl surface Kuraray polishing paste, to simulate the clinical situation.

Vertical marginal gaps were measured before bonding to evaluate the ability of the tested materials to reproduce an integrated margin. Also, they were measured after bonding to explore the affection of resin cement film thickness on the crowns' marginal quality because marginal gaps surely increased after bonding which is clinically relevant [16], where resin cement may hinder the complete seating of the crowns leading to their improperly sealed margins. Several investigations mentioned significant high marginal gaps after bonding in comparison to those before bonding. [17-19] Measuring the vertical marginal gaps after thermomechanical aging was performed to figure out if cyclic loading and thermocycling could affect the marginal integrity of such resilient category of ceramics after one year of service. Marginal debonding could be resulted from the low stiffness of these crowns as a result of flexure and thus affecting their marginal fit negatively.

Panavia F2.0 adhesive resin cement was the standard cement used in this study. After mixing the cement following the manufacturer instructions, seating of the crowns on the dies was standardized using a specially designed cementation device, which allowed static placement of 3 Kg load during the seating procedure to exclude any human variations in pressure. This load was chosen as recommended by Rinke et al. (1995) [20] and Groten and Probester (1997) [21] to avoid the danger of damaging the ceramic crowns.

The lowest mean vertical marginal gap among all the tested groups was observed in Vita Enamic group before cementation. This might be due to the microstructure of the materials where the dual network of Vita Enamics seems to be more homogenous.

After thermomechanical aging, Brilliant Crios group had a lower mean vertical marginal gap than the other groups. Cyclic loading could cause more deformation at the marginal areas of Shofu HC and Vita Enamic groups than Crios group. The highest mean vertical marginal gap observed in Shofu Hc group might be due to the poor bonded zirconia silicate particles that could be detached from the resin matrix leading to discrepancy to the diamond milling instruments and interference with the accuracy of the margins.

Mechanical failure of fixed restorations can happen after several service years, which means a failure due to fatigue not an acute fracture. Accumulation of stress after frequent contacts between upper and lower teeth affects the survival and longevity of any restoration. [22] Fatigue test has become common in last two decades due to its closer simulation to the clinical situation than the traditional laboratory testing involving static loading that can only predict the material strength and compare it with other material but still can't give accurate results about the long-term performance of the restorations. [9]

Loading force significantly affects the mechanical behavior of loaded objects in fatigue testing. [23] An occlusal load of 10 to 120 N was reported to be adequate during chewing and swallowing. [24,25] In the present study, a weight of 5 kg, which is equivalent to 50 N of masticatory force, was used per sample.

A reliable simulation of fatigue for fixed restorations requires employing a number of cycles equivalent to the number of years of clinical service. In the current study, 250000 cycles were chosen to represent one year of clinical service. [25-27] A frequency of 1.6 Hz was used in the present study as it lies in the middle of the most reported frequencies in fatigue testing, which is 1 to 2 HZ. [28]

The chewing simulator in the current study was moving in vertical and horizontal directions to simulate chewing. Kim et al. (2007)[29] recommended putting the lateral movements in consideration during any laboratory simulation because of its great effect due to the extension of stress field. In contrast, Rosentritt et al.[30] concluded that it might be necessary to simulate the lateral movement to study wear resistance not for fatigue testing.

In the present study, the periodontal ligaments were not simulated as silicone films when used, they commonly show quick damage leading to displacement of the tooth and hence affecting the control system.[31,32]

To simulate the oral cavity conditions, thermocycling needs to be done before fatigue testing. The chemical action of water to weaken ceramic and resin materials has been well documented. The tension and compression that occur periodically at cracks tips raises the level of damage after thermocycling. [33] In the conducted study, the used number of thermocycles was 5000 cycles with the parameters recommended by Gale and Darvell (1999). [34]

None of the crowns of any of the tested groups showed fatigue failure during the estimated number of cycles. The high fatigue resistance of the tested materials was probably because of their polymer network or matrix which decreases their modulus of elasticity making them more resilient and can absorb high load without failure. Also, absorbing water by the resin matrix during thermocycling may encourage the plasticization of the matrix, reducing its brittleness. This is in accordance with Carvalho et al. (2014) [35] who concluded that energy required to cause fracture, is inversely proportional to elastic modulus of the material.

One more factor that might lead to the high fatigue resistance is the underlying structure that supports the crowns. The crowns in the present study were bonded with an adhesive resin cement to resin dies with resiliency similar to that of dentin.[36] Most probably, the whole crown-die complex acted as one unit, and the applied forces were evenly distributed through crown, resin cement, and die without stress concentration on critical areas that lead to more damage tolerance.[37] The results of the current study are in accordance with Coldea et al. (2015)[3], Swain et al. (2016)[38], Vafaee et al. (2017)[39].

The dynamic fatigue resulted in significant decrease in fracture strength of the crowns evaluated in the current study.[103] Also, there was a significant difference in mean fracture strength between tested groups. However, the mean fracture strength of all the evaluated crowns surpassed the maximum masticatory force in the premolar area which is 450 Newton.[122]

Shofu HC crowns showed the highest mean fracture strength. This might be related to the dense packing of the strong nanofillers of zirconium silicate in its resin matrix, as reported by manufacturer. Also, its modulus of elasticity (9.6 GPa) is low which might increase deformation under the applied load, showing a greater capability of absorbing stress thus increasing fracture resistance.

No significant difference in mean fracture strength was shown between Vita Enamic and Shofu HC crowns. This might be due to the presence of interconnected phases within Vita Enamic material which led to the limitation of the crack propagation as a result of crack deflection. The phase with higher strain might enhance the fracture strength through bridging the cracks to the other phase.[2] The results of the current study were in agreement with Saleh et al. (2020)[81].

On the other hand, Brilliant Crios group showed the lowest mean fracture resistance with significant difference compared to Shofu HC group. This could be attributed to Brilliant Crios material's microstructure that has weak barium glass fillers. This contradicts with Jassim & Majeed (2018) 123 who concluded that Brilliant Crios crowns had a higher mean fracture strength than that of Vita Enamic ones. This inconsistency might be due to different restoration thicknesses and different bonding protocols used in both studies. Also, the crowns in their study were not subjected to fatigue testing and thermocycling before loading to fracture.

CONCLUSIONS

Under the conditions of the current in-vitro study, the following could be set as conclusions:

1. Tested hybrid ceramic crowns had marginal integrity within the clinically acceptable range.
2. Tested crowns withstood normal masticatory forces range in the premolar area.

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