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FATIGUE PERFORMANCE & FRACTURE MODE ANALYSIS OF TWO AVAILABLE HIGH STRENGTH GLASS CERAMICS

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ABSTRACT

Objective: As the high strength glass ceramics had attained a profound contribution in prosthodontics, it was aimed to evaluate the fatigue performance of two machinable high strength glass ceramics with further fracture mode analysis. **Materials and methods**: Twenty crowns were fabricated using Cerec in-Lab CAD\CAM system, ten crowns were fabricated from IPS. E.max CAD: group **(EM-LDS)** as control group and ten crowns were fabricated from VITA SUPRINITY: group **(VS-ZLS)**. The completed crowns were cemented on epoxy resin dies. The cemented crowns were subjected to thermomechanical cycling for 75000 cycles, then loaded until fracture by using universal testing machine. Failure mode were assesses guided by Brukes' classification for all specimens. The collected data was statistically analyzed using Student t-test and Paired t-test while the significance level was set at $P \leq 0.05$, in addition to descriptive statistics of the fracture mode analysis. **Results:** There was no statistically significant difference in fatigue performance between the two tested groups with the major fracture occurrence in type III central fracture. **Conclusion**: both tested high strength glass ceramics are considered as acceptable modalities for restoration of single tooth restoration as both materials have comparable strength and exceeded the reported range of human masticatory forces.

KEY WORDS: Glass ceramics, LDS, ZLS, Fatigue testing, Fracture resistance

INTRODUCTION

Advanced ceramic systems as a metal-free prosthesis have been labeled with excellent aesthetics, mechanical and friendly biocompatible to the oral tissues [(1-2)]. At the end of twentieth century with the emergence of polycrystalline ceramics and coupled with CAD/CAM fabrication, it revealed continuous surge in popularity relaying on high mechanical properties [(3)]. A major concern was raised toward zirconia-based restorations regarding the optical properties as an opaque substrate which hindered further consideration as an absolute solution for esthetics [(4)]. Although with recent alteration of zirconia structure to enhance the esthetic outcome, further cutback with minimal porcelain application is deemed [(5)].

A breakthrough with the advent of high strength glass ceramic has established profound participation of lithium disilicate (LDS) in in both the conventional and the advanced prosthesis rehabilitation [(6)]. Later introduction of zirconia reinforced lithium silicate (ZLS) has resulted in expansion of the high strength glass ceramic family [(7,8)]. Desirable optical properties of such materials along with sufficiently high strength, gave the chance for improved esthetics when compared to zirconia restorations in addition to implementation of adhesive resin bonding [(9)]. Whatever presentation of glass ceramic either as pressable ingots or machinable blocks, the

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restorations have satisfactorily served as monolithic restorations without further veneering [10]. The extended range of glass ceramic application falls within single anterior and posterior restoration or short spans fixed dental prosthesis only with (LDS) while the long spans is solely managed by tetragonal zirconia [11,12].

On the level of microstructure, the original demand for improving the mechanical properties of glass ceramics is the motive for the introduction of (ZLS). This glass ceramic is enriched with zirconia nano particles approximately 10 percent of its weight to combine the positive benefits of both esthetics with mechanical survivability. Incorporation of zirconia nano particles is claimed to post the mechanical properties by interruption of crack propagation especially on conservative thin restoration [13]. A lot of controversies have emerged regarding the mechanical performance of (ZLS) when compared to (LDS). Some claims about superiority [14], while slight deterioration in performance was also reported [15].

In vitro testing with aim of exploring the mechanical performance of prosthetic materials is traditionally directed toward static loading [16]. Static loading applied on the test specimens until failure is still inadequate to predict the long-term survivability of the dental restoration during function and the material related factor, attributes to unrealistic extravagant values in relation to the physiologic forces exerted by the masticatory system [17]. Aging in the form mechanical cyclic loading test is aimed at simulating the conditions of mastication by inducing alternate stresses in the samples thus partially reflects the behavior of restorations under function [18,19]. Specimens under fatigue testing shall be subjected to cycles of thermomechanical loading and further static loading released by failure of the specimen [20].

The aim of the present study was to assess fatigue performance of (ZLS) as compared to (LDS) with further failure mode analysis. The null hypothesis was that there will be no difference in the fracture resistance values between (ZLS) & (LDS) glass ceramics after cyclic loading.

MATERIALS AND METHODS

In the present study invitro testing of two types of high strength glass ceramics: **(EM-LDS);** Lithium disilicate group:IPS e.max CAD (Ivoclar Vivadent, Liechtenstein), n =10 and **(VS-ZLS);** Zirconia reinforced lithium silicate group, VITA SUPRINITY (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Germany), n=10. The total number of the fabricated crown shaped specimens: N= 20.

An upper premolar typodont tooth was mounted in custom cylindrical mold filled with acrylic. To assure proper vertical orientation tooth, dental surveyor was used for holding the tooth till hardening of the mold material. Tooth was prepared as to receive all ceramic crown using a milling surveyor to ensure accurate preparation parameters. Laboratory diamond stones with 6° taper were used in the preparation to guarantee resultant total occlusal convergence of 12°. The axial preparation was firnished with a 1.0-mm deep chamfer, & occlusal reduction of 2 mm. Occlusal reduction was controlled by placing pre-preparation guiding grooves and checked via rubber index taken before reduction. The tooth after preparation and finishing was duplicated by polyvinyl siloxane impression material (Elite HD, Putty &light body, Zhermack SpA, Italy) & poured using epoxy resin materials.

The resin dies were used in fabrication of the test specimens for both glass ceramics. A CAD/ CAM system; (Sirona dental system GmbH, Bensheim, Germany) was used in the scanning, designing and fabrication of the crown specimens with the following components: Indirect laboratory scanner (In Eois Blue), Designing software (Cerec 3D, 4.2 software) and milling machine (In lab MCXL). Each die was scanned separately, crown designed with the aid of preparation scan of the typodont tooth. The resultant raw milled crowns were subjected to post milling heat processing in porcelain furnace (Programat 310, Ivoclar Vivadent, Liechtenstein.)

Surface treatment for the finished crowns were executed with application of hydrofluoric acid etching (BISCO's PORCELAIN ETCHANT 9.5%, BISCO, Inc., USA) for 20 seconds then thoroughly rinsed and dried. Etched crowns were subjected to salinization (Monobond Plus, Ivoclar Vivadent, Liechtenstein) of the intaglio surface which maintained for 60 seconds while unevaporated residues were gently dried. Final resin cementation of crown specimens (TOTALCEM Self-etching, self-adhesive resin cement, ITENA, France). To assure consistent complete seating of all crowns, each one was statically loaded under load of 70 N till setting of the cement [(21)].

Testing of samples were conducted on two levels; the first level is fatigue testing, and the second level is the failure mode analysis. Fatigue testing were executed in two stages, initial thermomechanical cyclic loading followed by final static loading till failure of the specimens. Thermomechanical cyclic loading mimicking intraoral 6 months in function was implemented by application of 50 N load along 75000 cycles using chewing simulator (ROBOTA, Egypt; powered by servo motors model ACH-09075DC-T, AD-TECH TECHNOLOGY CO., LTD., Germany). The second stage was followed by application of static load as performed for fracture resistance testing induced by universal testing machine (Instron®, Illinois Tool Works Inc., USA). Resultant values were recorded for further statistical analysis. The failure mode was analyzed according to Burke's Classification.

RESULTS

Student t-test and Paired t-test with a significance level was set at $P \leq 0.05$ were used for the statistical analysis of fracture resistance value after cyclic loading. The mean, standard deviations (±SD), minimum (Min), maximum (Max) and mean values of the fracture resistance (**FR**) in Newton (N) for both ceramic materials; (**EM-LDS**) & (**VS-ZLS**) (are presented in **(Table 1)**. It was revealed that there is non-significant difference between the two studied groups.

The fracture mode was analyzed with descriptive statistics, all specimens were visually examined and classified according to Brukes' classification **(Figure 1)**. Frequency (N) and percentage (%) of fracture mode for the two tested groups were presented in **(Table 2)**.

TABLE (1) Comparison between facture resistance measurements of the two studied groups represented by Min, Max, Mean and SD values.

FR (N)	EM-LDS **(n=10)**	VS-ZLS **(n=10)**	**t**	**P**
Min. – Max.	1390.40 – 1605.3 N	1399.3 – 1630.2 N		
Mean ± SD.	1457.29 ± 64.6 N	1459.1 ± 67.9 N	0.058	0.955
Median	1445.7 N	1.2 N		

TABLE (2) Frequency (N) and percentage (%) of fracture mode for the two tested groups:

	Brukes' Classification									
GROUPS	**Class I**		**Class II**		**Class III**		**Class IV**		**Class V**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
EM-LDS	-	-	1	10	5	50	2	20	2	20
VS-ZLS	1	10	1	10	4	40	3	30	1	10

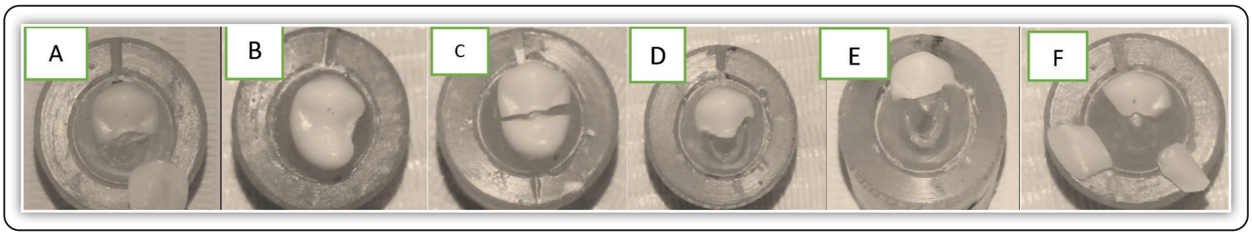

FIG (1) Fracture mode: (A) Class I: Minimal fracture or crack in the crown. (B, C, D) About half of the crown fractured, (E) More than half of the crown fractured, (F) Severe fracture of the restoration.

DISCUSSION

High strength glass ceramics has achieved strong participation in restoration of complex cases, thanks for the balanced esthetic and mechanical properties which is superseded with convenient etchable pattern for durable adhesive bonding [22,23]. Digital fabrication has added a lot of consistency in prosthesis fabrication leading to accurate reproduction, fast, & easier integration in the interdisciplinary approach became more feasible [24].

Compromised survival rate of restorations was attributed to its existence under fluctuated impacts, damp atmosphere and oscillating temperatures. Such collapse is directly correlated to the mechanical properties and structure of the material. In vitro fatigue testing was advocated as valuable resort in mimicking of the intraoral load exerted on functioning restoration by chewing and thermal cycles applied [25,26].

During specimens' preparation, standardization of fabrication was followed along the course of the study to obtain as much as consistent results. This was evident in many aspects and guided by previous studies. Initially, selecting typodont tooth to be duplicate after preparation as it is difficult to collect natural teeth with similar dimensions for all specimens while proper and aligned mounting of the tooth using the dental surveyor [27]. Also, the die material selection resembling the modulus of elasticity of the actual dentin structure [28]. Also, During the cad designing preparation scan was used to obtain matchable design with all specimens [29].

As the aim of the present study was focused on exploration of fatigue behavior of the two tested high strength glass ceramics and proposed null hypothesis of the absence of significant difference, the results of the study were aligned with the null hypothesis confirming non-significant difference between both materials. The numerical values have revealed slight but nonsignificant higher resistance to fatigue fracture for VS-ZLS group.

Generally, both types on the structural level have the crystal phase within glassy matrix but for ZLS its matrix has characteristic zirconia oxide in a homogeneous manner clammed for improved strength [14]. One of the reflections arose from the zirconia addition in ZLS is being harder in grinding as indication of inferior machinability when compared to LDS. The forces involved in grinding showed surging in magnitude up to 30% but it is indicative of its strengthening effect [30].

Microstructure of ZLS showed extra fine crystals namely the metasilicate or the disilicate one which reported to be in a range between 0.5and 0.7 μ supporting enhanced esthetics. Consequently, polishabilty and gloss was reported to be higher with ZLS than LDS and attributed to partial enhancement of strength. [31]. Weibull modulus is also reported to be high in case of ZLS in concomitant with our previous justification as indicative parameter for microcrack and flaws resistance [14], but care should be taken to avoid adding more time to the firing cycle as this could jeopardize the Weibull value [32].

Regarding the fracture mode analysis, the most common fracture pattern occurs in this study according to Burkes' classification were the restorations fracture through midline into two parts buccal half and palatal half (Class III). This could be mainly a response to centrally loaded occlusal forces, an effect which is jeopardized indirectly by tension created on thin cervical margin leading to bucco–palatal expansion of the circumference cervically and consequently more central load collected.

Behavioral difference between epoxy die material and ceramic specimens has impact on the values obtained. Although the epoxy die material bearing similarity to modulus of elasticity of dentin, it responds to the applied static and dynamic load with more deformation before failure. (33) Consequently, resiliency of the die material will show sustained support to the brittle ceramic specimens. Thus, the invitro mechanical testing usually will reveal exaggerated higher load values than physiological biting force limits (34). From the other side, the reported physiological biting force is highly variable and correlated to numerous factors as age, gender & position of the tooth in the arch with prevalence of first molar biting force usual assessment in the literature reaching up to 800 N (35). The catastrophic failure, which includes complete loss of crown or combined fracture of the crown, and the epoxy resin die could be also correlated to the same behavioral difference between the die material and the test specimen.

While material behavior during the conducted invitro testing may vary from the actual intra oral condition, it is considered as indicative of survival rather than stating definite limit. The resultant mean fracture load for EM-LDS is (1457.2 N), and for VS-ZLS is (1459.1 N) superseding the reported normal physiologic range, which supports that both materials tested can withstand the maximum bite force without fracture.

Limitations of this study

The use of loading cycles representative of 6 months within function (75000) could be extended to assess performance over longer intervals. CAD/CAM parameter applied single spacer thickness of (60 microns) could be modified to tackle the effect other thicknesses implementation. Justification of in vitro testing is difficult compared to the physiological scenario. As related to fatigue testing parameter settings modification and combination with other testing as finite element analysis could add more reliability.

CONCLUSION

Within the limitations of this study, crowns made of IPS e.max CAD and VITA SUPRINITY, are considered as acceptable modalities in restoration of single tooth restoration, they revealed comparable strength and exceeded the reported range of human masticatory forces.

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