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Fracture Strength of Three All-Ceramic Systems: Top-Ceram compared with IPS-Empress and In-Ceram

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ABSTRACT

Purpose: The purpose of this study was to investigate the fracture loads and mode of failure of all-ceramic crowns fabricated using Top-Ceram and compare it with all-ceramic crowns fabricated from well-established systems: IPS-Empress II, In-Ceram.

Materials and methods: Thirty all-ceramic crowns were fabricated; 10 IPS-Empress II, 10 In-Ceram alumina and 10 Top-Ceram. Instron testing machine was used to measure the loads required to introduce fracture of each crown.

Results: Mean fracture load for In-Ceram alumina [941.8 (± 221.66) N] was significantly ($p < 0.05$) higher than those of Top-Ceram and IPS-Empress II. There was no statistically significant difference between Top-Ceram and IPS-Empress II mean fracture loads; 696.20 (+222.20) and 534 (+110.84) N respectively. Core fracture pattern was highest seen in Top-Ceram specimens.

Keywords: Fracture, Strength, Instron, IPS-Empress, In-Ceram, Top-Ceram.

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INTRODUCTION

Dentists are faced daily with challenges of making treatment decisions regarding their patients. As a healthcare provider, it is important that dentists offer the best possible care for their patients. It is not unusual that clinicians find themselves perplexed by the various factors involved in clinical decision-making, including increased patient demand for esthetic dentistry and the various new products introduced on daily bases. Amongst these products are all-ceramic restorations.

The unique properties of ceramic material in regards to its optical quality, stability and biocompatibility, coupled with the increased public awareness and demand on esthetic restorations have resulted in a significant increase in the use of all-ceramic restorations. This demand has fueled the development and introduction of numerous all-ceramic alternatives to metal ceramic restorations. All-ceramic restorations have been marketed to patients and dentists in an aggressive manner to a point where these types of restorations are becoming the standard of care.[1]

All-ceramic systems differ considerably in their esthetic potential, their physical properties and evidence base relative to longevity. In a systematic review of clinical complications in fixed prosthodontics, all ceramic crowns showed an 8% incidence of complications, with crown fractures being the most common.[2]

Many attempts have been made to increase the fracture strength of all-ceramic restorations. The newly developed ceramic materials use a wide variety of crystalline phases (oxide ceramics) as reinforcing agents. The nature, amount and particle size distribution of the crystalline phase based on method of fabrication, directly influence the mechanical and optical properties of the material.[3]

Pressable ceramics are available from manufacturers as prefabricated ingots made of crystalline particles distributed throughout a nonporous glassy material allowing for a well controlled homogeneous material.[4] IPS-Empress II is an example of such material, containing 60 to 70% lithium disilicate (SiO_2-Li_2O) crystals reinforcement.[5] With flexural strength up to 360 MPa,[6-9] initial clinical data for single restorations are excellent with this material, especially if it is bonded.[10]

Slip casting is another method introduces to fabricate all-ceramic restorations. It involves the condensation of an aqueous porcelain slip on a refractory die, which helps condensation by absorbing the water from the slip by capillary action. The piece is then fired at high temperature on the refractory die and later glass infiltrated a unique process in which molten glass is drawn into the pores by capillary action at high temperature. Materials processed by slip casting tend to exhibit reduced porosity, fewer defects from processing, and higher fracture resistance than conventional feldspathic porcelain, because the strengthening crystalline particles form a continuous network throughout the framework. Use of this fabrication method is tied to In-Ceram. Currently, the popular In-Ceram system is divided into three main types: In-Ceram spinel, In-Ceram alumina and In-Ceram zirconia. In-Ceram alumina is made up of 72% or more alumina crystals. With flexural strengths of approximately 450 MPa, several clinical studies report the use of In-Ceram alumina for single units placed anywhere in the mouth. In-Ceram alumina has the same survival rates as porcelain-fused-to-metal restorations up to first molar, with slightly higher failure rate for the second molar.[11-13]

Top-Ceram is an all-ceramic system introduced by Global Top Inc, Korea. No studies have been found to evaluate the clinical performance or the physical and mechanical properties of this system. The main foundation for information regarding its performance is its manufacturers. It seems to utilize the slip casting fabrication method and is introduced as an all-ceramic system for single crowns and fixed partial denture restorations.

The purpose of this study was to compare the fracture loads and mode of failure of crowns fabricated using three difference all-ceramic systems: IPS-Empress II, In-Ceram alumina and Top-Ceram.

MATERIALS AND METHODS

Tooth Preparation

An ivorine maxillary left first premolar was prepared to receive an all-ceramic crown, with a 2 mm occlusal reduction and a 1 mm rounded shoulder axial reduction with a 6 to 10° total angle of convergence. All line angles were smoothened to reduce stress concentration. The prepared tooth was used as a master die to fabricate 30 prepared tooth replicas using a highly filled epoxy resin (Viade Products, Inc. Camarillo, CA) with a modulus of elasticity similar to that of human dent.[5,15] A specially prepared silicon mold was made of the tooth prior to preparation and was used to fabricate 30 all-ceramic crowns of the same size and shape; 10 IPS-Empress II, 10 In-Ceram alumina and 10 Top-Ceram crowns (Table 1). All crowns were fabricated by a single dental technician according to manufacturers instructions.

Table 1: Materials used in the study

Trade name	*Manufacturer*
IPS-Empress II	Ivoclar Vivadent, Amherst, NY, USA
In-Ceram alumina	Vident, Brea, CA, USA
Top-Ceram	Global Top Inc, Goyang-si, Gyeonggi-do, Korea

Crown Fabrication and Cementation

Fabrication of IPS-Empress II Crowns

IPS-Empress crowns were waxed-up to the full contour with the aid of the silicone rubber index (Elite H-D+, Zhermack SpA, Italy) to control the size and shape of the samples. The waxed-up crowns were invested using special investment supplied by the manufacturer (Speed 2 investment, Ivoclar Vivadent, Liechtenstein). The molds were allowed to set for 60 minutes. Then the wax was burned out at 900°C for 60 minutes. IPS-Empress II ingots (IPS-Empress II Ivoclar Vivadent, Liechtenstein) and plunger were preheated prior to pressing. Using EP500 IPS-Empress pressing furnace (Progmat, Ivoclar Vivadent, Liechtenstein), the ingots were pressed in the mold at 1175°C. After cooling to the room temperature, the mold was divested and final adjustments of the crowns were carried out using diamond bur at reduced speed (<20,000 RPM) and under water cooling.

Fabrication of In-Ceram Alumina Crowns

The In-Ceram alumina (In-Ceram alumina, VITA Zahnfabrik, Germany) crowns were fabricated using the slip casting technique. The prepared die was duplicated using additional polyvinyl siloxane impression material (Elite H-D+, Zhermack, Italy).The mold was then poured with special plaster (VITA In-Ceram, VITA Zahnfabrik, Germany) to produce the refractory die. The slip material was mixed using 38 gm VITA In-Ceram alumina powder and the contents of one ampoule of VITA In-Ceram alumina liquid (5 ml) in addition to 1 drop of VITA In-Ceram additive. A thin layer of slip material was applied to the die and allowed to dry for 30 minutes to produce a 0.5 thickness alumina core. The core was sintered in VITA In-Ceram at furnace at 1120°C. After sintering, the fitting was adjusted and the crowns were checked for cracks. Then, glass infiltration was carried out using VITA In-Ceram alumina glass powder (In-Ceram glass powder, VITA Zahnfabrik, Germany). Special veneering ceramic (In-Ceram VM7, VITA Zahnfabrik, Germany) was used to build-up the crowns with the aid of the same silicon index used previously with IPS-Empress. Final adjustments of the In-Ceram crowns was performed with diamond grinding bur at a reduced speed (<20,000 RPM) and under water cooling.

Fabrication of Top-Ceram Crowns

A layer of paraffin wax was applied to the stone die to act as a separating medium. The ready mixed alumina material was applied to the die to produce the core. Paraffin wax was then heated to allow for removing the brittle core without breakage. The core was sintered at 1150°C and the glass infiltration was carried out. Then the core was ready for conventional porcelain build-up.

All crowns of the three systems were then cemented with glass ionomer cement on a special dies prepared using epoxy resin. This is to avoid any failure that may result from undetected cracks or defects in natural teeth. Furthermore, it should give more standardization in the size and form of the abutments.

All 30 crowns were cemented to their respective dies with glass ionomer cement (Super Dent, NY, USA) according to manufacturer's instruction. The crowns were initially seated using finger pressure and were immediately placed under static load of 20 N for 7 minutes. Excess cement was then removed.

Fracture Testing

All 30 ceramic crowns with their respective dies were attached to the loading jig of the lower member of a universal testing machine (Instron 1195, Instron Limited, Buckinghamshire, UK). Metal block resembling lower left quadrant (mandibular second premolar and first molar) was attached to the upper member of the testing machine. The metal block was constructed by first making a silicon impression of the ivorine teeth in that quadrant. The impression was filled with wax, which was then invested and cast into metal. This was done to standardize and simulate the occlusal relationship between the fabricated crowns and opposing teeth. The specimens were loaded axially at a cross head speed of 0.5 mm/min and a full scale load of 200 N. The fracture load needed to cause failure of the specimen, which was signaled as a peak in the strip-chart tracing, was recorded in Newtons. Mode of fracture was examined for each specimen and categorized according to the following failure modes: One fragment fracture of porcelain (1), two fragments fractures of porcelain (2), multiple fractures failure (3), and fracture of the core and/or die (4). Results were analyzed with a statistical software (SPSS version 17, Chicago, IL) using a one-way analysis of variance test (ANOVA) and Bonferroni post-hoc multiple comparison test ($p < 0.05$).

RESULTS

The mean fracture loads and standard deviations for the three all-ceramic materials used are shown in Table 2. In-Ceram alumina had the highest mean fracture load followed by Top-Ceram, then IPS-Empress II; 941.8 (+221.66), 696.20 (+222.20) and 534 (+110.84) Newtons respectively. The analysis of variance indicated overall significant differences ($p < 0.001$) between the three groups. Results of multiple comparison test are shown in Table 3. Mean fracture load for In-Ceram alumina was significantly ($p < 0.05$) higher than those of Top-Ceram and IPS-Empress II. However, there was no statistically significant difference between Top-Ceram and IPS-Empress II mean fracture loads.

Visual comparisons between ceramic patterns of fracture are reported in Table 4. All patterns of fracture were seen in each of the three ceramic system tested. Multiple fragments fracture (40%) and core and/or die fracture patterns (40%) were the most common patterns observed in IPS-Empress specimens. The most common fracture patterns for In-Ceram alumina were single fragment fracture of porcelain (30%) and core and/or die fracture (30%). For Top-Ceram, the most common fracture pattern was core and/or die fracture (60%).

DISCUSSION

The clinical data available regarding the success of some all ceramic systems is limited, particularly in terms of follow-up, because these are relatively new systems. Testing of newly introduced systems is considered important for validation of their use as advertized by manufacturers. Ceramic materials fail as a result of crack propagation and fracture, and hence it is generally felt that the use of ceramic materials with improved strength and fracture resistance is one mean by which their clinical performance is improved. Several approaches to strengthen ceramics have been identified in the past decades. These approaches generally involve manipulating and tailoring of the microstructure.[16]

Two of the all-ceramic systems in this study, In-Ceram alumina and IPS-Empress II, were selected as control for relative comparison reasons because of their long clinical track. Many previous studies have compared the flexural

Table 2: Mean fracture loads and standard deviations for the three all-ceramic systems (IPS-Empress II, In-Ceram alumina, Top-Ceram)

All-ceramic system	*n*	*Mean (N)*	*SD*	*Std. Error*	*95% confidence interval for mean*		*Minimum*	*Maximum*
					Lower bound	*Upper bound*		
IPS-Empress II	10	534.00	110.85	35.05	454.70	613.30	368.00	710.00
In-Ceram alumina	10	941.80	221.66	70.09	783.23	1100.37	728.00	1346.00
Top-Ceram	10	696.20	222.20	70.26	537.25	855.15	216.00	932.00

Table 3: Multiple comparisons between mean fracture loads of the three all-ceramic systems (IPS-Empress II, In-Ceram alumina, Top-Ceram)

Between groups	*95% confidence interval*		
	Sig.	*Lower bound*	*Upper bound*
In-Ceram *vs* IPS-empress II	0.000	627.16	188.44
In-Ceram alumina *vs* Top-Ceram	0.024	26.24	464.96
Top-Ceram *vs* IPS-Empress II	0.210	–57.1649	381.5649

Table 4: Frequency of fracture patterns in the all-ceramic systems (IPS-Empress II, In-Ceram alumina, Top-Ceram)

All-ceramic type		*Frequency*
IPS-Empress II	One piece fragment	1
	Two piece fragments	1
	Multiple fragments	4
	Core and/or die fracture	4
	Total	10
In-Ceram alumina	One piece fragment	3
	Two piece fragments	2
	Multiple fragments	2
	Core and/or die fracture	3
	Total	10
Top-Ceram	One piece fragment	2
	Two piece fragments	1
	Multiple fragments	1
	Core and/or die fracture	6
	Total	10

strength and fracture toughness of In-Ceram alumina and IPS-Empress II and came out with comparable results.[17,18] These results generally demonstrated that the strength and the ability to withstand occlusal loads of the In-Ceram are higher than that of IPS-Empress II; consistent with the results of the present study. The flexural strength values for IPS-Empress II ranged from 340 to 400 MPa with fracture toughness values from 2 to 3.3 MPa. m (1/2).[6] The reports flexural strength of In-Ceram alumina has been shown to be 2 to 3 times greater than that of conventional or high leucite ceramics 15, with ranges of 236 to 600 MPa and fracture toughness values of 3.1 to 4.6 MPa.m (1/2).

In this study, the mean fracture load for In-Ceram alumina was significantly higher than that of IPS-Empress II; 941.80 (± 221.66), 534 (± 110.84) N respectively. Both In-Ceram alumina and Top-Ceram are considered alumina systems according to their main composition and the incorporation of glass infiltration process. Based on this fact, it was expected that a close values of fracture loads of the two systems be found. Surprisingly, a significant difference between the two systems was found. The mean fracture load of Top-Ceram (696.20 ± 222.20 N) was significantly less than that of In-Ceram and comparable to that of IPS-Empress II. These recorded fracture loads are comparable to those measured during mastication and swallowing (approximately 5 to 364 N) [19-23] or maximum force recorded during clenching effort (approximately 216 to 890 N).[24-27]

General patterns of clinical failure of all-ceramic restorations include core fracture or chipping of porcelain.[28] Examination of clinically failed all-ceramic crowns reveals that failures initiated from flows and stresses existing at the cementation surface as opposed to damage on the occlusal surface.[29-31] Multiple fragments or powder-like debris is usually only seen in laboratory crushing tests. Although different fracture patterns were seen in all three ceramic systems, most Top-Ceram specimens (60%) demonstrated fracture of core mode of failure more than that seen in the other two systems. Alumina core ceramic is a typical example of strengthening by dispersion of a crystalline phase. Alumina has a high modulus of elasticity (350 GPa) and relatively high fracture toughness (3.5 to 4 MPa.m 0.5), compared to feldspathic porcelains. Its dispersion in a glassy matrix of similar thermal expansion coefficient leads to a significant strengthening of the core. It has been proposed that the excellent bond between the alumina and the glass phase is responsible for this increase in strength compared with leucite-containing ceramics. Seghi and Sorenson have showed using a scanning electron microscope that crack deflection mechanism occurs in such systems.[16] On the other hand, Ohyama et al in their study demonstrated that once cracks occur, the alumina system cannot prevent their propagation.[32]

An ideal experimental model to determine the fracture strength of ceramic restorations is difficult to achieve. This study attempted to isolate the ceramic system type as the only variable and minimize the variances while still simulating clinical setting. The so called 'crunch the crown' test has been widely utilized to examine the compressive load resistance of crowned teeth.[33] The die replicas provide standardized preparations and identical physical quality of materials used in comparison to natural teeth, yet of similar modulus of elasticity to that of human dentin.[14,15] Additionally, glass ionomer cement was used since the cement layer plays vital role in the fracture resistance of restorations by altering the stress distribution through the substructure and reducing the stress concentrations adjacent to internal surface flows in ceramic material.[34]

Although the results of this study provide comparative data on the fracture loads for three all-ceramic restorations, yet it has its limitations in regards to the nature of the compressive loading to failure test in dry environment.[35] It is more clinically relevant to test the specimens under wet cyclic loading of predetermined loads before applying the static load.[36] However, the use of static force instead of cyclic load provides the maximum limit force that the material can withstand before failure. These *in vitro* experiments can provide data on material applicability and performance in a short time period and under controlled and standardized conditions. Considering this as the first study to look at performance of Top-Ceram, it can give an insight to its behavior in comparison to the other two well known systems. Nevertheless, direct extrapolation of the current study results to clinical situations should be made with caution.

CONCLUSION

Within the limitations of this study, fracture loads of In-Ceram alumina crowns were significantly higher than the other two systems. Core fracture pattern occurred more frequently in Top-Ceram specimens.

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