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Fracture Resistance of Aluminium Oxide and Lithium Disilicate-based Crowns using Different Luting Cements: An *in vitro* Study

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Abstract

Aim: The aim of this study was to investigate the fracture resistance of two types of ceramic crowns cemented with two different cements.

Methods and Materials: Forty premolar crowns were fabricated using lithium-disilicate (IPS Empress-2) and glass-infiltrated aluminium-oxide (In-Ceram) ceramic systems. The crowns were divided into four groups (n=10) with Group 1 (IPS Empress-2) and Group 2 (In-Ceram) cemented with glass ionomer cement. Group 3 (IPS Empress-2) and Group 4 (In-Ceram) were cemented with resin cement. Crowns were tested in a universal testing machine at a compressive-load speed of 10 mm/min. Fracture modes were grouped into five categories. One way analysis of variance (ANOVA) and Bonferroni post-hoc tests were used to detect statistical significances ($p<0.05$).

Results: The mean (SD) fracture resistance (Newtons) for Groups 1 to 4 were: 245.35 (82.69), 390.48 (67.03), 269.69 (10.33), and 418.36 (26.24). The cement type had no statistical significant effect ($p>0.05$) on fracture resistance within each ceramic system tested. In-Ceram crowns cemented with either glass ionomer or resin cements exhibited a statistically significantly higher fracture-resistance than IPS Empress-2 crowns ($p<0.05$). Minimal fracture in the test crowns was the common mode exhibited.

Conclusion: Fracture resistance of IPS Empress-2 and In-Ceram crowns was not affected by the type of cement used for luting.

Clinical Significance: Both In-Ceram and IPS Empress-2 crowns can be successfully luted with the cements tested with In-Ceram exhibiting higher fracture resistance than IPS Empress-2.

Keywords: Fracture resistance, In-Ceram, IPS Empress-2, glass ionomer cement, resin cement

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Introduction

Metal-ceramic and all-ceramic restorations are widely used for restoring damaged and missing teeth. Metal-ceramic restorations have met the demand for high strength and long-term serviceability in the oral environment, but the quest for more esthetic, non-allergic restorations has led to the increased use of all-ceramic restorations.[1,2]

Traditional dental ceramics are brittle, have a low tensile strength, and a low fracture toughness while newer all-ceramic materials have improved properties making them suitable for the fabrication of crowns and fixed partial dentures in both anterior and posterior regions of the oral cavity. Several types of these all-ceramic materials have been introduced such as aluminum oxide ceramics,[3,4] castable ceramics,[2-5] leucite-reinforced ceramics,[6-9] and zirconium oxide ceramics.[10]

In-Ceram (Vita Zahnfabrik, Bad Säckinen, Germany) is made of a high-content aluminium oxide opaque core that is subsequently glass infiltrated to achieve its final strength.[3,11-14] The core is masked using veneer porcelain built up to create the desired contours of the prosthesis. Pressable ceramics include IPS Empress 1 and 2 (Ivoclar Vivadent, Schaan, Liechtenstein). IPS Empress 2 consists of lithium disilicate-based (Li_2O - $2SiO_2$) crystals with higher degree of crystallinity than in IPS Empress 1. The crystals are embedded in a glassy matrix resulting in improved mechanical properties.[7,15] *In vivo* studies showed restorations made out of both In-Ceram and IPS Empress 2 ceramics were serviceable in the long run.[11,15-17]

All-ceramic restorations can be bonded to prepared tooth structures using either conventional cement or adhesive resin cement. The clinical serviceability of glass-ceramic crowns vary among different cement types.[5] Resin luting cements provide adequate bond strength to glass-infiltrated aluminum oxide cores,[18,19] but problems regarding long-term bond durability at the tooth-resin and resin ceramic interfaces have been reported.[20,21] However, adhesive resin cements have improved mechanical properties in comparison to conventional luting cements.[22]

In vitro studies have revealed most clinical failures of all-ceramic restorations were initiated at the cement surface[23] or the internal crown surfaces.[24,25] The mode of clinical failure could be the result of internal surface flaws and cement voids.[26]

Reported values of fracture strength of all-ceramic crowns are highly variable since the fracture strength is influenced by several factors such as physical properties of the ceramic, crown thickness, die preparation design, method of luting, and applied force direction and position.[27-29] Furthermore, Neiva et al.[30] suggested the type of luting cement can affect the strength of the ceramic restoration. However, clinical studies have not yet compared the effect of luting cement on the clinical durability of such ceramic restorations.

The objectives of this *in vitro* study were to test the effect of two different luting cements on the crown-fracture resistance of two ceramic systems (IPS Empress 2 and In-Ceram) and to investigate the mode of fracture of these ceramic crowns. Accordingly, the study was conducted with the following hypotheses:

- Hypothesis 1- within each ceramic system used, the tested luting cements have no effect on the fracture resistance of ceramic crowns.
- Hypothesis 2- within each luting cement used, the fracture resistance of ceramic crowns is the same among the two ceramic systems tested.

Methods and Materials

Specimen Selection

Sixty premolars extracted for orthodontic reasons were stored in a 5% thymol solution. After inspection under x2 magnification, 40 of the 60 teeth free of caries and cracks were chosen for the study. The mesiodistal and buccolingual dimensions of the 40 teeth were measured at the level of the cervical margin using a digital caliper (Anglia, Microelectronics, Edinburgh, UK) in order to standardize the tooth-size distribution within each group.

Specimen Preparation

The selected teeth were embedded in cylindrical molds (15 mm in diameter, 30 mm in height) filled with autopolymerzing epoxy resin (Emperor, PSP Dental, Kent, UK) with their long axes positioned parallel to the long axis of the mold with the cementoenamel junction located 2 mm above the resin.

The mounted specimens were then prepared for complete coverage with ceramic crowns with a 1 mm deep shoulder finish line with a rounded internal line angle (1 mm above the cemento-enamel junction) and a tapered angle of 6-8 degrees.[29,31] All sharp angles were rounded using an aluminium oxide polishing disk (Soflex, 3M ESPE, St. Paul, MN, USA). A single-stage impression was made of each prepared tooth using light and heavy bodied vinyl polysiloxane impression material (3M ESPE, St. Paul, MN, USA). Duplicate impressions were poured with die stone (Elite Mode, Rovigo, Italy) to produce stone dies for fabricating the crowns.

Twenty IPS Empress 2 crowns were fabricated using the pressable ceramic technique described in detail by Wohlwend and Schärer.[32] The crowns were waxed up to full contours and invested using Express Speed investment (Ivoclar Vivadent, Schaan, Liechtenstein). Investment molds were pre-heated typical of the lost-wax technique. The glass-ceramic ingots (11 mm diameter and 8 mm long) were placed into an Empress pressing furnace and heated to 920°C (Ivoclar Vivadent, Schaan, Liechtenstien). The glass-ceramic ingots became viscous at this temperature and were pressed into the investment molds to form the crown. Then molds were divested, the crowns were finished using diamond burs, and then checked on their dies for fit.

For the In-Ceram crowns, the stone dies were duplicated with addition-cured silicone impression material and poured with Vita In-Ceram special plaster (Vita Zahnfabrik, Bad Säckinen, Germany). In-Ceram cores were built up over the plaster dies according to manufacturer's instructions. An In-Ceram slip was made by mixing 38 g of In-Ceram alumina powder with 5 ml of In-Ceram liquid and 1 drop of additive (Vita Zahnfabrik, Bad Säckinen, Germany). The slip was applied to the plaster dies and formed the cores. One coat of stabilizer (Vita Zahnfabrik) was applied and the cores were fired in the Vita-Inceramat furnace (Vita Zahnfabrik) at 1120°C. The sintered cores were then infiltrated with molten glass and fired at 1100°C. The substructure was then checked for microcracks, excess glass was removed, and the occlusal and axial walls were reduced where necessary using a diamond bur. The cores were steam cleaned and air dried and their fit was verified on the dies. The external core surfaces were air abraded with 50µm Al_2O_3 and steam-cleaned. Crowns were built to desired contours using Vita-dur alpha porcelain (Vita Zahnfabrik, Bad Säckingen, Germany).

Cementation of Crowns

Two types of luting cements were used: glass ionomer (Universal Glass Ionomer, Super Dent, Westbury, NY, USA) and resin composite luting cement (Illusion Universal Cementation System, Bisco Dental Products, Richmond, BC, Canada). The crowns were divided into four groups (n=10) with Group 1 (IPS Empress-2) and Group 2 (In-Ceram) cemented with glass ionomer cement. Group 3 (IPS Empress-2) and Group 4 (In-Ceram) were cemented with resin cement. All crowns were cemented according to manufacturer's instructions.

The glass ionomer cement used for luting the crowns of Groups 1 and 2 was prepared by mixing one scoop of powder with two drops of liquid on a mixing pad and mixed for 30 seconds at room temperature. Then a coating of cement was applied to the internal surface of each crown before it was seated over its die.

Prior to cementation of the crowns in Groups 3 and 4 with resin cement the prepared teeth were cleaned with pumice and rinsed with water leaving the dentin surfaces moist. Then they were etched with 32% phosphoric acid for 15 seconds (Uni-tech, Bisco, Schaumburg, IL, USA). Two consecutive coats of bonding agent were applied to the moist dentin without waiting between coats then air-dried thoroughly for 10 seconds to remove any excess solvent. Primed surfaces appeared glossy indicating sufficient coverage. Each surface was then light cured for 10 seconds and the internal surface of the crowns were air braded using a Precious sandblaster (Bego, Bremen, Germany) with an aluminium oxide abrasive (50µm Al_2O_3 at 80 psi) for 3 seconds. Then crowns were cleaned in an ultrasonic water bath for 10 minutes before etching the internal crown surfaces with 4% hydrofluoric acid (Bisco, Schaumburg, IL, USA) for 4 minutes and silanating for 30 seconds. A coating of light-cured paste (milky shade) was applied to the internal surface of the crowns which were seated over the dies and light cured for 60 seconds on each surface of the four surfaces (mesial, distal, buccal, and lingual).

All crowns were initially seated over the prepared teeth with a firm finger pressure. The specimens were then placed between the jaws of a custom-made jig designed to press the crowns in place under static load (≈ 20 N)[33] for 10 minutes. All specimens were stored in distilled water at room temperature for 24 hours prior to testing.
Testing Methodology

A stainless steel tube was used to hold each specimen in a custom-designed retaining arm of an Instron 1195 testing machine (Instron Ltd., Buckinghamshire, UK). The specimens were placed at a 45° angle from the horizontal plane to simulate clinical conditions.[29,34] A 3 mm stainless steel bar was placed across the mesio-distal fissure of the crowns and a compressive load was applied at a 10 mm/min cross-head speed. All crowns were loaded to failure (Figure 1).

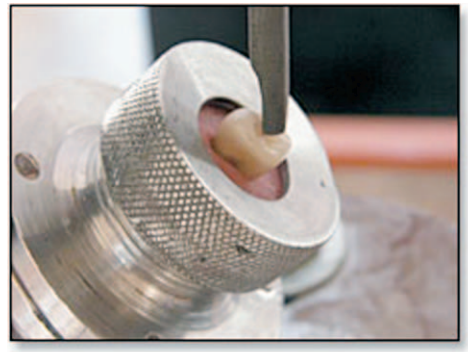

Figure 1. Load application on a specimen tilted at a 45° angle.

The maximum load at fracture was recorded for each specimen, and the mode of fracture was examined for each specimen then categorized according to failure-modes described by Burke.[35]

Statistical Analysis

A one-way analysis of variance (ANOVA) test (SPSS™ 11.0, SPSS Inc., Chicago, IL, USA) was used to detect statistical differences in fracture resistance among all groups ($p<0.05$). Bonferroni post hoc test was used for multiple comparisons between pairs of groups.

Results

The mean, SD, 95% confidence limits, and median of loads recorded at fracture are present in Table 1.

Fracture loads were in the range (in Newton) of 245.35- 418.36 (Figure 2).

Within each ceramic system no statistical significant differences were found ($p=1.00$) between crowns cemented with glass ionomer cement (Groups 1 and 3) and crowns cemented with resin cement (Groups 2 and 4) (Table 2). As a result, the first hypothesis (within each ceramic system used, the tested luting cements have no effect on the fracture resistance of ceramic crowns) was accepted.

Table 1. Failure loads of each group in Newtons.

Group	Crown type/Cement type	Fracture load (N)		95% Confidence Limits		Median
		Mean	SD	Minimum	Maximum	
1	IPS Empress 2 / Glass Ionomer	245.35	82.69	186.20	304.50	232.98
2	In-Ceram / Glass Ionomer	390.48	67.03	342.53	438.43	402.87
3	IPS Empress 2 / Resin cement	269.69	10.33	262.21	277.08	268.05
4	In-Ceram / Resin cement	418.36	26.24	301.47	360.47	411.13

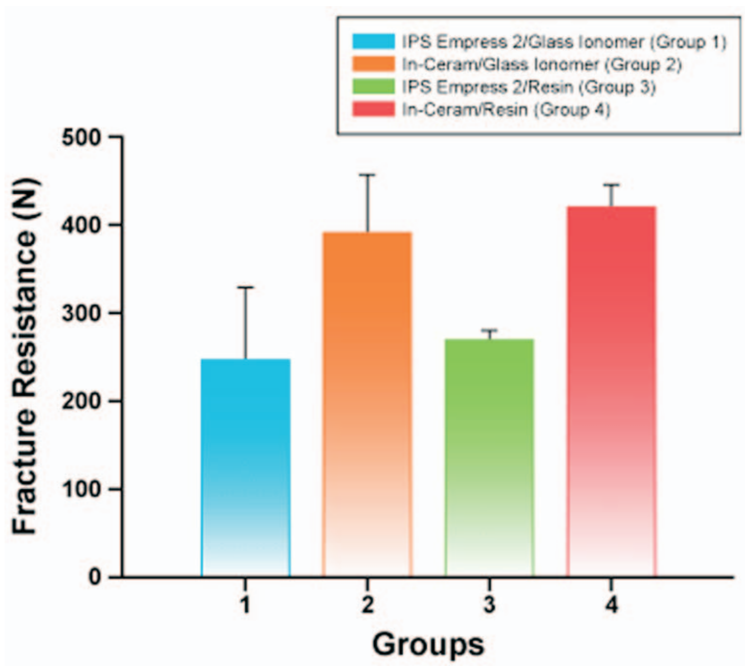

Figure 2. Error bars presenting failure loads of the four groups in Newtons.

Within the luting cements used, the In-Ceram crowns cemented with either glass ionomer or resin cements exhibited a statistically significantly higher fracture resistance (p=0.00) than the corresponding-cemented IPS Empress 2 crowns (Groups 1 and 2 and Groups 3 and 4) (Table 2). Hence, the second hypothesis (within each luting cement used, the fracture resistance of ceramic crowns is the same among the two ceramic systems tested) was rejected.

Four modes of fracture were predominantly recorded (Table 3), with the majority of crowns exhibiting minimal fracture in the crowns (35%).

Discussion

An ideal experimental model of an *in vivo* situation to determine the fracture resistance of all-ceramic crowns is difficult to achieve. However, the so called “crunch-the-crown” test has been widely utilized to examine the compressive-load resistance of sound and crowned teeth. However, most of the studies have utilized different experimental protocols making direct comparisons impossible. The present study was conducted to investigate the fracture resistance of crowns fabricated using two ceramic systems and the crowns bonded to prepared teeth using two different luting cements. Such an *in vitro*

Table 2. Statistical significances presented between group pairs.

Groups	Sig.	Comparison Type
1 & 2	*0.000	Within cement type (Glass Ionomer cement).
1 & 3	1.000	Within ceramic system (IPS Empress 2).
2 & 4	1.000	Within ceramic system (In-Ceram).
3 & 4	*0.000	Within cement type (Resin cement).

* The mean difference is significant at the 0.05 level.

Table 3. Failure modes exhibited and categorized according to Burke FJ (1999)

Fracture mode	Fracture frequency number (%)	Load at fracture (N)			Fracture frequency (by group)			
		Mean	SD	Median	1	2	3	4
I	14 (35%)	281.63	87.95	259.42	3	4	4	3
II	12 (30%)	317.73	80.15	340.64	3	3	4	2
III	3 (7.5%)	316.95	81.86	274.68	2	0	0	1
IV	0	0	0	0	0	0	0	0
V	11 (27.5%)	406.95	72.24	450.71	2	3	3	4

I: Minimal fracture or crack in coping, II: Less than half of coping lost, III: Coping fracture through midline (half of coping displaced or lost), IV: More than half of coping lost, V: Severe fracture of die.

study did not require a unrestored control group for comparison of results,[29,36,37] since the stress distribution in restored teeth is significantly different than in unrestored teeth. Kelly[38] indicated failures are likely to occur at the crown-cement interface. Also, FEA (Finite Element Analysis) and clinical studies confirmed stress distribution and fracture incidence/patterns in unrestored teeth are different than those found in prepared or restored teeth.[39] Furthermore, there are vast inherent variances in the fracture resistance loads of extracted unprepared/non-restored natural teeth.[40]

The present study attempted to isolate the cement layer as the only variable and minimize the variances from the prepared teeth structures by strictly examining the teeth and matching tooth size (bucco-lingual) in each group. The

ceramic crowns in the study were cemented to natural prepared-teeth to replicate fracture load results more related to clinical scenarios than using ceramic discs[41] or crowns cemented to resin or metal die replicas.[28,30] Such replicas fail to reproduce the actual force distribution at the inner surface of the crown[29] or to reliably produce the characteristics of bonding between crowns and prepared teeth.[38] However, die replicas provide a standardized preparation and identical physical qualities of materials used in comparison with natural teeth.[42,43]

In-Ceram crowns cemented with resin composite luting cement had a statistically significantly higher fracture resistance than IPS Empress 2 crowns cemented with the same cement. In-Ceram crowns cemented with glass ionomer cement also had a statistically significantly greater fracture resistance than IPS Empress 2 crowns cemented with glass ionomer cement. This result is in agreement with some,[28,44] but not all previous studies.[45]

The increase in fracture resistance might be related to several factors such as the inclusion of sandblasting along with the use of a resin luting agent which likely decreased the flaw associated with stresses.[46] Moreover, an increased fracture resistance of In-Ceram crowns was reported in other studies.[47,48]

Fracture resistance within groups of similar luting cements was not statistically significantly different, which is in agreement with another study.[30] Several studies have reported differences in the fracture load of crowns cemented following different experimental protocols and utilizing different types of luting agents. Such results indicate certain combinations of materials are likely to affect fracture strengths making direct comparisons between studies impossible.[27,28,33,35,42,49]

Waltimo and Konenen[50] reported biting forces in the molar region are in the range of 597 N and 847 N for young women and men, respectively. Normal masticatory forces were reported to range from 37%[51] to 40%[52] of the biting force.

In the present study the mean fracture loads ranged from 245 N to 418 N which is within masticatory force range but less than the anticipated biting forces. This would appear to be consistent with reports indicating a die replica with a material having a high modulus of elasticity can result in an increased fracture load of ceramic material.[53] Furthermore, the crowns tested in the present study were premolars which are expected to have lower biting forces than in the molar region. Also, the crowns were tested at a 45° angle from horizontal which placed them under tensile forces which are likely to be less than compressive forces.[54] Normal masticatory forces are applied at angles of 20-28° to the long axis of the teeth[55] and bruxism or clenching patients exert greater physiological forces than biting forces during tooth grinding/clenching behavior.[56]

The fracture load for both IPS Empress 2 and In-Ceram crowns exhibited a large standard deviation indicating uncertainty in the prediction of a success or failure rate for ceramic restorations.[57] This large variability in strength could be due to the number of pre-existing ceramic cracks of different sizes along with the low fracture toughness of ceramics.[58]

Minimal fracture of crowns in the form of cusp chipping was the most common failure exhibited among both types of ceramic crowns. However, 11 crowns (27.5%) exhibited fractures completely through their dies which is in agreement with another study.[29] Die fracture can likely be attributed to the 45° angle of the specimens during testing which exposes them to bending and deformation in addition to the accumulation of tensile forces at the cervical region of the crowns.[54]

Conclusion

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

1. Fracture resistance of IPS Empress-2 and In-Ceram crowns was not affected by cement type.
2. In-Ceram crowns exhibited a higher fracture resistance than IPS Empress 2 crowns regardless of cement type used.

Clinical Significance

Both In-Ceram and IPS Empress-2 crowns can be successfully luted with the cements tested with In-Ceram exhibiting higher fracture resistance than IPS Empress-2.

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