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Fracture strength of all-ceramic crowns

L. CORRER SOBRINHO*
Department of Biomaterials, Eastman Dental Institute, 256 Gray's Inn Road, London, WC1X 8LD, UK

M. J. CATTELL
Department of Conservative Dentistry, St Bartholemew's and The Royal London School of Medicine and Dentistry, Turner Street, London, E1 2AD, UK

J. C. KNOWLES‡
Department of Biomaterials, Eastman Dental Institute, 256 Gray's Inn Road, London, WC1X 8LD, UK

This paper compares the fracture strength of three types of all-ceramic crown shape systems (In ceram, OPC™ and IPS Empress) cemented with either a commercial resin cement, zinc phosphate or glass ionomer. Twenty test crown shapes with 8 mm diameter and 8.5 mm height were fabricated for each type of ceramic. Ten In ceram crown shapes were luted on the die using zinc phosphate, while ten OPC™ and IPS Empress were luted using resin cement specified for the particular system. Another ten specimens each, of In ceram, OPC™ and IPS Empress, were luted on the die using a glass ionomer. The crown shapes were fractured in a mechanical testing machine (Instron) using a steel ball, 4 mm diameter, that contacted the occlusal surface and the resulting data were statistically analysed using a Mann–Whitney test. The results showed that: (1) In ceram crown shapes luted with zinc phosphate were significantly stronger than IPS Empress crown shapes luted with resin cement ($p < 0.05$), but no difference was observed compared with OPC™ crown shapes luted with resin cement. No statistical difference was found between OPC™ and IPS Empress crown shapes. (2) When the three ceramics were luted with glass ionomer, the In ceram was significantly stronger than OPC™ ($p < 0.05$) and IPS Empress ($p < 0.05$). OPC™ was significantly stronger than IPS Empress ($p < 0.05$).

1. Introduction

Metal-backed ceramics have shown good mechanical properties, but the metal core affects the aesthetics. New dental ceramics and techniques have been introduced with the objective of improving both the mechanical properties and aesthetics of restorations.

Alternative solutions have been introduced with the objective of eliminating the metal substrate and allowing better translucency and simulation of the appearance of a natural tooth. The metal substructure may be replaced by a high alumina core or fused vitreous ceramic that improves translucency and increases the strength [1]. For example, In ceram (Vita, Zahnfabrik, [2]) composed primarily of Al_2O_3, was introduced as a core material with high flexural strength; Dicor (Dentsply) is a glass–ceramic system utilizing tetrasilicic fluoramica and crowns are produced using a centrifugal casting procedure [3]. IPS Empress (Ivoclar–Vivadent [4]), a leucite reinforced ceramic, was introduced and crowns fabricated by a hot pressing technique. Recently, other systems using leucite reinforced ceramics have been introduced (Optimal™ Pressable Ceramic, OPC™, Jeneric Pentron) and crowns are fabricated by a similar process to that used in IPS Empress.

Several studies on fracture resistance of all-ceramic restorations have been described [1, 5–10] and different factors can be responsible for durability of all-ceramic restorations.

The selection of a luting agent can affect the strength of restorations. Grossman and Nelson [11] showed that glass–ceramic crowns luted using a resin luting agent were significantly stronger when luted with zinc phosphate. Other studies have also demonstrated increased fracture resistance of all-ceramic crowns when resin cement has been used [12–17].

The purpose of this paper is to evaluate the fracture resistance of In ceram crown shapes luted with zinc phosphate, and OPC™ and IPS Empress luted with resin cement; and to compare the fracture resistance of the three ceramics luted with one glass ionomer cement.

* *Present address*: Department of Biomaterials, Piracicaba Dental School (UNICAMP) Avenida Limeira, 901, Piracicaba-SP, Post code 13-414-900, Brasil
‡ Author to whom correspondence should be addressed.

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2. Experimental procedure

A master die with similar dimensions to a premolar was made from brass (Fig. 1).

All technical steps in the fabrication of IPS Empress, OPC™, and In Ceram crown shapes followed the procedures indicated by the manufacturers.

Wax patterns for the OPC™ and IPS Empress crowns were made using a split brass mould. Brass dies were coated with two layers of die spacer and molten wax was then applied to the brass die, which had been placed in a split brass mould (Fig. 2), to produce a complete crown shape of 8.0 mm in diameter by 8.5 mm in height. The wax patterns were sprued and attached to a muffle base with a surrounding paper cylinder.

IPS Empress wax patterns were invested using 200 g IPS Empress special investment mixed with 30 ml IPS Empress investment liquid and 12 ml distilled water for 60 s. The wax was eliminated in a burnout furnace (5635 Kavo, EWL) by heating at 3 °C min^{-1} to 850 °C and holding for 90 min, together with IPS Empress unshaded ingots and alumina plungers. Twenty specimens were pressed using IPS Empress unshaded ingots in an optimal autopress furnace (Jeneric Pentron) following the manufacturer's instructions at 5 bar pressure. After cooling the samples were devested using glass beads (50 μm) at 2 bar pressure. Sprues were removed using a diamond disc and ground with a diamond burr. Specimens were fired in a porcelain furnace (Multimat MC II, Dentsply) using three stain firings and two glaze firings, using the recommended glaze material and manufacturer's firing cycles.

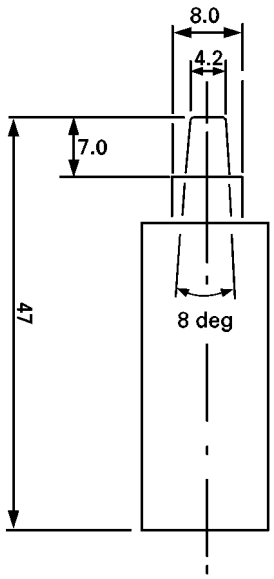

Figure 1 Schematic drawing of the brass master die (radius of curvature of corners 0.5 mm). Dimensions in mm.

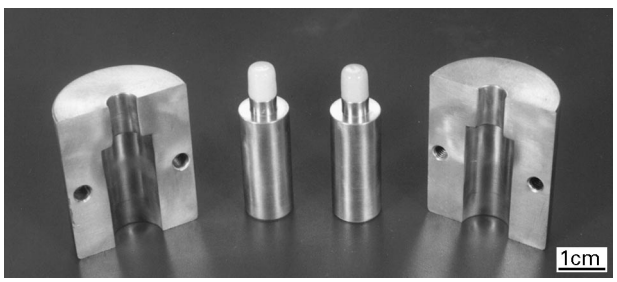

Figure 2 Split brass mould for making complete crown shapes with Vita Alpha dentine porcelain for In ceram and for casting wax crown shapes for OPC™ and IPS Empress. Samples of In ceram complete crown shape on the centre right and OPC™ on the centre left are also shown.

OPC™ wax patterns were invested using 200 g OPC™ special investment (Jeneric Pentron) mixed with 38 ml OPC™ investment liquid and 4 ml distilled water for 60 s. The wax was eliminated in a furnace (5635 Kavo, EWL) by heating the refractory at 3 °C min^{-1} to 950 °C and holding for 90 min, together with the alumina plungers. Twenty samples were pressed using OPC™ unshaded ingots, in optimal autopress furnace (Jeneric Pentron) using the manufacturer's instructions and 5 bar pressure. The OPC™ ingots were not preheated in the burnout furnace before the pressing procedure. After cooling the samples were devested using glass beads (50 μm) at 2 bar pressure. Sprues were removed with a diamond disc and ground with a diamond burr. Specimens were fired in a porcelain furnace (Multimat MC II, Dentsply) using two stain firings and one glaze firing, using the recommended glaze material and the manufacturer's firing cycles. An example of the finished crown shape is shown in Fig. 2.

In ceram specimens were produced by coating a brass die with three layers of die spacer (Vita, Zahnfabrik) and impressions were made using an additional polymerization silicone material with a metal ring. These impressions were poured with In ceram special plaster using a liquid : powder (1 : p) ratio of 0.23 ml g^{-1} to make refractory models. In ceram powder slip was prepared according to the manufacturer's instructions and was applied to the models. A sculpturing device similar to that used by Philp and Brukl [18] was utilized to ensure a uniform thickness of core (0.5 mm). After applying a stabilizer, the coping was fired on the plaster dies in a furnace (Inceramat, Vita, Zahnfabrik) for 6 h at 120 °C and for 4 h at 1120 °C. The copings were then glass infiltrated in a second firing process in the furnace (Inceramat, Vita, Zahnfabrik) for 30 min at 120 °C and 4 h at 1100 °C. Excess glass was removed with a diamond burr. The veneer porcelain (Vita Alpha, Dentine porcelain) was then applied to the core, which had been placed in a split brass mould to make a complete crown shape of 8.0 mm diameter and 8.5 mm height (Fig. 2). A total of 20 crown shapes were fabricated for the In Ceram system.

After glazing, the crown shapes were cemented on the brass die with either zinc phosphate cement (Orthostan, Darby Dental Inc., USA), glass ionomer lutting cement (Fuji I, GC Corporation, Japan) Variolink II (Ivoclar Vivadent) dual-curing resin cement, or Lute-it™ (Jeneric Pentron) dual-curing resin cement. All cements were mixed according to the manufacturers' instructions. With zinc phosphate and glass ionomer cement the crown shapes were filled with cement, seated with firm pressure and excess cement was removed. Crown samples were immediately

placed under a 2.7 kg static load for 10 min. The resin luted crown shapes were filled with resin cement, seated with firm pressure, light cured for a few seconds, excess cement removed and further light cured for 40 s per surface. All the samples were stored in distilled water at 37 °C for 24 h prior to mechanical testing.

The crown shapes were tested for compressive strength in an Instron universal testing machine. The point of force application was the centre of the occlusal surface of the crown shape with a 4 mm diameter stainless steel ball. A preload of 20 N was applied and then at a crosshead speed of 1.0 mm min^{-1}, the specimens were loaded until fracture occurred. The fracture surfaces of the crown shapes were then examined using a scanning electron microscope (SEM). The fracture strength data of the crown shapes were submitted to a Mann–Whitney statistical analysis.

3. Results

The mean loads at complete fracture of crowns luted with glass ionomer (Fuji) are shown in Table I. All In ceram, OPC™ and IPS Empress crowns showed complete fracture. The mean load at fracture for In ceram crowns was 2183 N (in the range 1877–2383 N); for OPC™ it was 1814.5 N (ranging from 1610 to 2032 N); and for IPS Empress it was 1609 N (ranging 1318 to 1774). The load at fracture of the In ceram crown shapes was significantly higher than the OPC™ ($p < 0.05$) and IPS Empress ($p < 0.05$) crown shapes. The load at fracture for OPC™ crown shapes was significantly higher than for IPS Empress ($p < 0.05$).

The mean load at complete fracture of In ceram crown shapes luted with zinc phosphate, OPC™ crown shapes luted with resin cement (Lute it™), and IPS Empress crown shapes luted with resin cement (Variolink II) are shown in (Fig. 3). The mean load at fracture for In ceram crown shapes was 2030 N (standard deviation, SD 133.4; ranging from 1820 to 2235 N); for OPC™ was 1995.5 N (SD 240.5; ranging from 1649 to 2344 N); and for IPS Empress was 1743.3 N (SD 217.3; ranging from 1440 to 2085 N). There were significant differences in the mean loads at fracture between In ceram and IPS Empress ($p < 0.05$). No statistical difference was found when In ceram was compared with OPC™ and OPC™ with IPS Empress ($p < 0.05$).

Fig. 4 shows an SEM image of the fracture surface of an In ceram crown shape, showing the bonding between the high alumina core and Vita Alpha dentine porcelain. Figs 5 and 6 show the microstructure of the OPC™ and IPS Empress specimens, respectively. As can be seen the microstructure for each sample, in general appears very similar at this magnification. These samples differ from the In ceram in that no discontinuities exist between core and veneer materials as they are pressed from a single ingot and then surface stained and glazed.

TABLE I Mean load at fracture for crown shapes luted with Fuji glass ionomer cement

Material	Mean fracture load (N)[a]	Standard deviation
In ceram	2183 (a)	159
OPC	1814.5 (b)	130.5
IPS Empress	1609 (c)	148

[a] Means followed by different letters indicate each group is statistically different at the 95% confidence level (Mann–Whitney, $p < 0.05$).

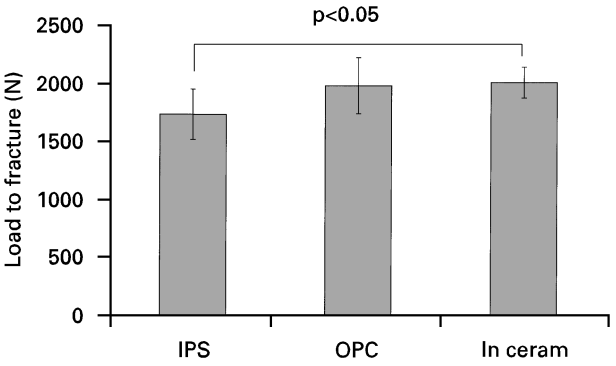

Figure 3 Mean load (in newtons) at complete fracture of crowns for (a) IPS Empress luted with resin cement (Variolink II). (b) OPC™ luted with resin cement (Lute it™); and (c) In ceram luted with zinc phosphate. The line indicates the statistically significant difference (Mann–Whitney), $p < 0.05$).

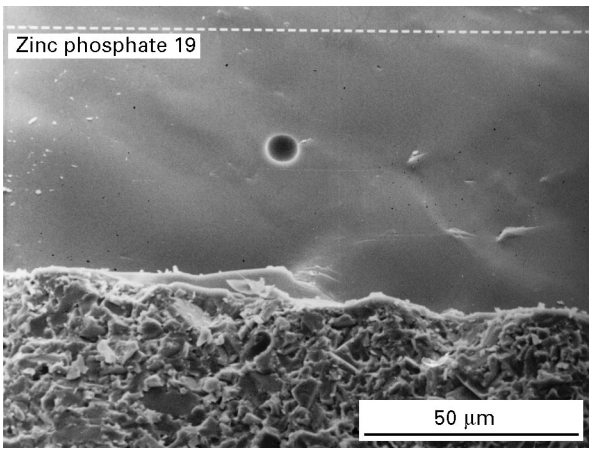

Figure 4 SEM image of fracture surface of In ceram crown shape.

4. Discussion

Several factors can contribute to the variation in fracture strength of a ceramic crown, for example, the shape of the prepared tooth, the luting agent, crown thickness and porosity [10, 19]. The presence of large flaws, material defects, porosity or a cement void in the occlusal region along the internal surface of ceramic crowns are major determinants of tensile stress that are responsible for failure, especially for a reduced occlusal thickness [20].

In this study 20 master dies were made with identical dimensions. An even thickness of the internal core is particularly important, as this has an influence on

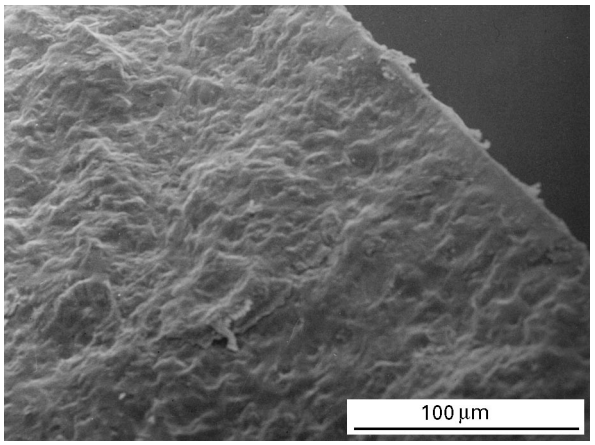

Figure 5 SEM image of fracture surface of OPC™ crown shape.

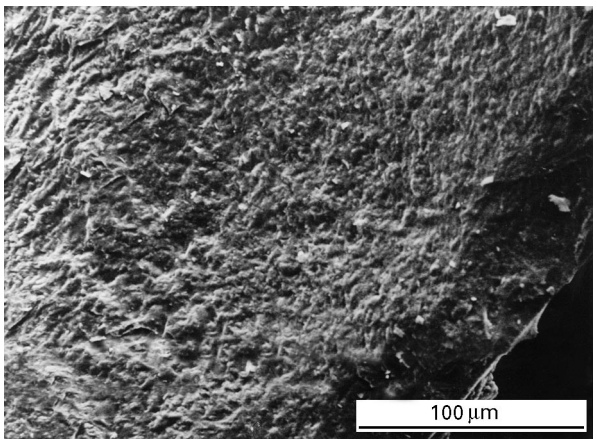

Figure 6 SEM image of fracture surface of IPS Empress crown shape.

deformation in a relationship to the third power. Small variations in thickness can have a considerable effect on the overall fracture resistance of the restoration [21]. In our study a sculpturing device similar to that used by Philp and Brukl [18] was utilized to ensure a uniform thickness of In ceram crown shapes and a split brass mould was utilized to produce wax crown shapes with the same dimensions for OPC™ and IPS Empress.

The apparent increase of fracture strength of ceramic crown shapes bonded to resin cement in relation to other cements has been reported by many researchers [11–16, 22]. The suggested reasons for this are:

1. reduction of the stress associated with an increased radius of curvature at the tip of flaws in the glass–ceramic surface by the acid etching treatment;
2. a reduction of the stress at the tip of the flaw by coating the area completely with a silane bonding agent and resin cement; and
3. a decrease in the flexural strain along the internal surface of the crown shapes through a chemical bond between the cement, crown and prepared tooth [20].

In one part of our study, In ceram crown shapes were luted with zinc phosphate, and OPC™ and IPS Empress luted with resin cement in accordance with manufacturers' recommendation. It was observed that In ceram crown shapes luted with zinc phosphate (2030 N) were significantly stronger than IPS Empress luted with resin cement (1743.3 N) ($p < 0.05$), but no statistical difference was found when In ceram crown shapes were compared with OPC™ luted with resin cement and OPC™ was compared with IPS Empress. Pröbster [5] showed that anterior In ceram crowns have a higher fracture strength (964 N) than IPS Empress (814 and 750 N) luted with zinc phosphate. Yoshinari and Derand [19] utilizing a preload obtained values statistically higher with posterior In ceram crowns (1060 N) than IPS Empress (891 N) luted with zinc phosphate. Baccetti *et al.* 1 investigating In ceram crowns showed a significantly higher average fracture strength than IPS Empress and other ceramics.

Conversely, when In ceram, OPC™ and IPS Empress were compared utilizing the same glass ionomer cement (Fuji), our study showed that In ceram crown shapes (2183 N) were significantly stronger than OPC™ (1814.5 N; $p < 0.05$) and than IPS Empress (1609 N; $p < 0.05$).

Under the same testing conditions OPC™ crowns were consistently stronger than IPS Empress crowns when bonded with the glass ionomer cement. However, comparing OPC™ and IPS Empress bonded with the manufacturers' recommended cements, no statistical difference was found. This may suggest that earlier assumptions concerning bonding are significant. The percentage volume or distribution of leucite suggested for OPC™ [23] compared with IPS Empress may account for the difference found between OPC™ and In ceram. From microstructural examination, it is surprising that the pressable ceramics are in some instances lower in mechanical strength than the In ceram. This may be accounted for by the presence of defects associated with leucite transformation, or the mode of cementation and water uptake. Because In ceram is made of two discrete layers, it hence contains a very obvious discontinuity as seen in Fig. 4, which may act to reduce the mechanical strength. Voids can also be trapped at this interface due to the manual nature of the preparation of crown shapes, both for research and clinical use. The disparity may be due to a combination of two factors. First, the In cream core has exceptional properties due to its construction of approximately 85% Al_2O_3 crystals [19]. Furthermore, the voids and/or flaws can be filled almost completely with molten glass during the infiltration process, providing a homogeneous, bubble-free core consisting of fine particles in a vitreous matrix [1]. This construction may negate the effects of the interface. Second, perhaps the leucite in the pressable systems does not offer as great a reinforcing effect as expected, particularly if it is not well dispersed, or bonded [24].

It was observed also that In ceram crown shapes luted with zinc phosphate or glass ionomer had a higher fracture strength compared with IPS Empress luted with resin cement or glass ionomer. The fracture strength of In ceram described demonstrated the good mechanical properties of this material, in agreement

with other work [25, 26]. The high strength of In ceram is thought to be the result of the In ceram core as previously described and this probably explains the greater fracture resistance of this material [1]. Stronger core materials offer many advantages, including the reduced probability of overload failure as well as a reduced likelihood of damaging the crown during fitting [27]. The optimal ceramics, when bonded, also provide a high strength option, without the opacity of an aluminous core material.

Although the use of a brass die does not reproduce natural teeth, because of the mismatch in mechanical properties compared to the teeth, the brass dies did provide a reproducible support. Furthermore, the brass dies do eliminate the variability seen with natural tissues and this was felt to aid this study, particularly due to the inherent unpredictability. Further research, however, aims at using natural tooth as a base.

5. Conclusions

From this study, it can be concluded that:

1. In ceram crown shapes luted with zinc phosphate cement were significantly stronger than IPS Empress crown shapes luted with composite resin (Variolink II) ($p < 0.05$), but not statistically different from the values obtained for OPC™ luted with composite resin (Lute it™). No statistical difference was found between OPC™ and IPS Empress.

2. When the three ceramics were luted with glass ionomer cement (Fuji), the In ceram crown shapes showed significantly higher mean fracture strength than OPC™ ($p < 0.05$) and IPS Empress ($p < 0.05$) crowns. OPC™ crowns were significantly stronger than IPS Empress ($p < 0.05$) .

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