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An In-Vitro Investigation of the Accuracy of Fit of Procera and Empress Crowns

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Abstract - *The current study aimed to investigate the accuracy of fit and the reproducibility of inner crown profile for two types of high strength ceramics, IPS Empress and Procera. Procera and Empress crowns with four different morphologies were cemented to dies using zinc phosphate dental cement. Vertical and horizontal sections were made through each of the crown/die preparations and images of the vertical sections were compared for curvature reproduction by alignment using image processing. Measurements were made on horizontal sections to determine cement layer thickness. Alignment of the crowns using image analysis identified quantifiable variations in the inner surface profile compared with the outer surface of the die. The largest differences occurred from the cusp tips to the occlusal adaptation area and differences in surface profile were less pronounced for Procera than Empress crowns. Marginal gap varied independently of ceramic or internal crown shape from 7-529 µm for Procera and 26-548 µm for Empress. IPS Empress has a superior ability to reproduce the inner surface profile of the crown morphologies investigated compared with Procera. The reduced reproduction of surface profile was associated with an increased cement thickness at the occlusal contact area that may inadvertently lead to failure of the crowns functional characteristics.*

KEY WORDS: Accuracy of fit, Procera, IPS Empress, Inner crown surface profile, Image analysis

INTRODUCTION

Metal-ceramic crowns have been employed successfully in dentistry since 1962 when they were first patented by Weinstein *et al.*[1]. The combination of the aesthetics of a low firing porcelain veneer and adequate strength and toughness provided by the metal alloy coping allowed them to be used in all regions of the mouth unlike the pure metal alloy crowns which are preferred for use posterially because of aesthetic considerations. Porcelain has excellent aesthetics and its combination of colour and translucency has yet to be matched in producing a natural tooth-like appearance. However, the metal coping alters the aesthetics even when an opaque porcelain layer is applied firstly to the coping[2]. The high alkali content required in the opaque porcelain layer may cause re-crystallization and a subsequent decrease in aesthetics[2]. All-ceramic crown materials possess excellent aesthetics, strength and favourable wear characteristics, however, the ceramic material with the highest fracture strength will not necessarily give the best clinical performance for dental crowns[3]. Ceramics are fundamentally brittle and failure generally occurs at much lower loads than the theoretical values quoted in the literature[4]. The apparent reduction in strength is due to the presence of microstructural defects on the surface of the sample or within the internal structure of the material[4]. Defects can be compared with sharp notches where the crack tips can result in fracture of the material even when the stress across the specimen is less than the theoretical fracture strength[4]. Crack growth through the bulk of the material is almost instantaneous leading to catastrophic failure.

Recent developments in processing techniques attempted to reduce the occurrence of flaws, resulting in a stronger ceramic[5–11] with the average fracture strengths of all-ceramic crown materials have been variously reported as 80-180MPa for aluminous porcelain[1–3], 130–300MPa for Dicor[3,6], 350–450MPa for Empress[3,7–9], 350–680MPa for In-Ceram[4,5] and 650–800MPa for Procera[5,10]. Interestingly the annual clinical failure rate of crowns produced from these materials remains remarkably consistent at approximately 3%[3] despite the increase in average fracture strengths which emphasises that there is poor correlation between the average fracture strength determined by conventional material science techniques and the resultant clinical performance.

IPS Empress (Ivoclar, Schaan, Liechtenstein) crowns employ a glass-ceramic material, which is essentially a leucite reinforced (40–50%) feldspathic porcelain, formed by forcing the heated plasticised glass-ceramic under pressure (0.3–0.4 MPa) into a mould[8]. IPS Empress produces average fracture strengths of 350–450 MPa and clinical trials have shown adequate survival rates after 3 years[9]. The Procera system (Nobel Biocare AB, Göteborg, Sweden) introduced in 1993 by Andersson and Odén[10] uses the concept of computer-assisted design and computer-assisted manufacture (CAD/CAM) to fabricate ceramic crowns from 99.9% alumina powder. During sintering of the alumina, shrinkage in the region of 15–20% occurs, however, with the development of an enlarged copy milling machine copies of the tooth preparation can be produced to compensate for the shrinkage. Copy milling of the outer tooth is also controlled by CAD/

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CAM and accuracy has been verified as ±10 μm[11]. A low temperature fining porcelain veneer is applied to the surface of the aluminous core and fired at 910°C – below the melting temperature of alumina (2050°C).

The aim of the current investigation was to demonstrate that the accuracy of fit could compromise performance and thereby provide a reason for the poor correlation of fracture strength with clinical performance of all-ceramic crown materials. The study investigated the accuracy of fit and the reproducibility of inner surface profile for two types of high strength ceramic crown materials, namely IPS Empress and Procera.

MATERIALS AND METHODS

Die replication

Procera and Empress crowns with four different crown morphologies (I-IV) and four original dies (one for each crown morphology) were supplied by the manufacturers for investigation in the current study (*Figure 1*). Replicas of each die were manufactured using silicone impression material (Coltene® Rapid, Altstätten, Switzerland) and GC Fujirock die stone (GC Belgium, Belgium) prepared under vacuum conditions for improved accuracy. One replica of each crown morphology was prepared for the Empress and Procera crowns. A second replica of the Procera crown morphology III was used to reveal if significant differences occurred between the mean cement thickness of the acrylic resin die and stone die replica.

Reproduction of crown inner surface profile

The crowns were cemented to the appropriate dies using zinc phosphate dental cement (Zinc Cement Improved Liquid, S.S. White, Gloucester, England) manipulated according to the manufacturers' instructions in accordance with the American Dental Association Specification Number 8[12]. For each crown, 0.625 g of powder was incrementally mixed into 0.5 ml of phosphoric acid stained with methylene blue to allow differentiation of the cement layer from the tooth die and crown when viewed during subsequent image analysis. A cooled glass mixing slab (approximately 19 ± 1°C) was used to dissipate the exothermic heat of reaction and the cement powder was added to the liquid incrementally[13,14] according to the manufacturers instructions to increase the working and setting times. The cement was mixed for 90 s and a further 30 s was allowed to transfer the cement into the crown to cover the whole inside surface. The corresponding tooth die was inserted into the crown and pressure applied by hand to ensure a minimal cement layer and correct seating alignment. This pressure was constantly applied for 7 minutes until the cement had fully set, after which the excess cement was removed from the marginal edge.

The tooth dies and cemented crowns were then placed in polypropylene mounting moulds measuring 30 mm diameter and 30 mm height. A cold-setting resin, Epofix HQ (Struers, Glasgow Scotland) based on two fluid epoxy components, was prepared by mixing 15 volume parts of resin with 2 volume parts of hardener in a paper cup for 120s. The mix was then poured over the crown/die preparation and allowed to set for 24h. A vertical section was made through each of the crown/die preparations using a diamond cutting saw (Struers, Glasgow, Scotland) with a ceramic disc at a speed of 125 rpm with an applied load of 100g. A further horizontal cut was made through the middle of the crown on one of the vertical sections per crown to determine cement layer thickness. Each crown/die preparation was mounted a second time (as described above) and after setting each sample was removed from the mounting moulds and the surface displaying the crown/die preparation ground with successively finer grades of Silicon Carbide abrasive papers using an alcohol based lubricant (DP-Blue, Struers, Glasgow, Scotland) on a Dap-7 Pedemin grinding and polishing machine (Struers, Copenhagen, Denmark). A grade of P500 (the coarsest) was used to remove the initial layer of resin, followed by P800 and P1200 for 25s and finished using P2400 and P4000 (the finest) for 45 s. The samples were completed by polishing using a DP Dac cloth with 6 μm diamond paste and lubricated with DP-Blue at a force of 10N for 240s.

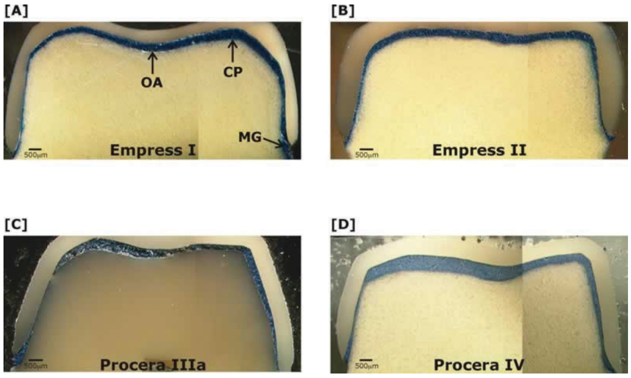

Figure 1. *Images illustrating the four crown morphologies investigated including (A) crown I (Empress cemented to the replica die) highlighting the occlusal adaption area (OA), cuspal peak (CP), marginal gap (MG) and blue cement layer; (B) crown II (Empress cemented to the replica die); (C) crown IIIa (Procera cemented to the original die); and (D) crown IV (Procera cemented to the replica die).*

The mounted sections were viewed through an Olympus BX50 microscope (Olympus Optical Co. Ltd, Tokyo, Japan), with an objective lens magnification of x1.25. Surface illumination of the specimen was achieved with an Intralux® 4000-1 reflected light source (Volpi, Switzerland) which produced clear contrasting images for subsequent analysis using a JVC KY-F55B 3-CCD colour camera (JVC, Tokyo, Japan) and an image-processing package (Optimas, Media Cybernetics, Silver Spring, MD, USA). Frames were pasted together to produce a mosaic of images for each crown morphology.

Accuracy of fit

20 random cement thicknesses were taken from both the Procera crown morphology III crowns mounted on the original acrylic resin die and the stone replica die to verify the accuracy of the stone die replicating technique. Further image analysis studies investigated the accuracy of fit and curvature reproduction of the four crown morphologies for the Empress and Procera all-ceramic crowns. Images of the vertical sections were compared for curvature reproduction by alignment of the crown and die surfaces using the image processing package.

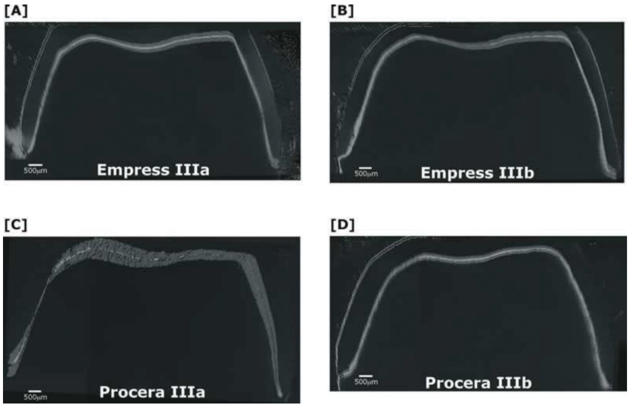

Figure 2. *The accuracy of the die replication technique for (A) Empress crown morphology III crown cemented to the replica die; (B) Empress crown morphology III crown seated to the replica die; (C) Procera crown morphology III crown cemented to the original die; and (D) Procera crown morphology III crown cemented to the replica die.*

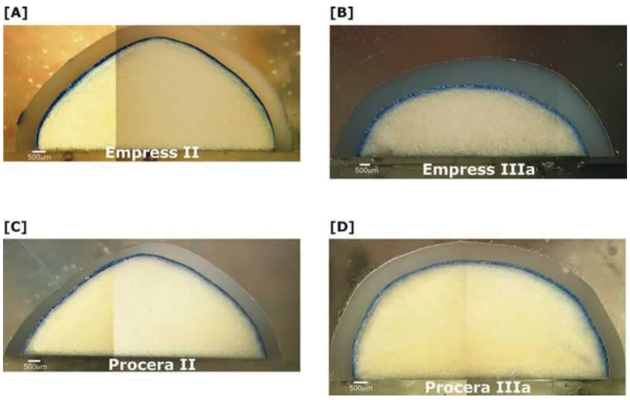

Figure 3. *Images demonstrating how the cement thickness varied in the horizontal crown sections for (A) Empress crown morphology II crown cemented to the replica die; (B) Empress crown morphology III crown cemented to the replica die; (C) Procera crown morphology II crown cemented to the replica die; and (D) Procera crown morphology III crown cemented to the original die.*

Corresponding fiducial points were marked on each surface (internal crown and external die) and then aligned to remove as much cement layer as possible. To ensure continuity, the marginal ridge on the die and the marginal edge of the crown were the preferred points. If alignment was poor, it was repeated using prominent corners to determine the location of ill-fit. Each image encoding was changed from RGB to HSB (hue stauration and brightness) colour space, duplicated and the images were aligned according to the fiducial points, so after alignment and averaging the blue colour (hue) of the cement that did not coincide with the two images would shift to a green hue. After alignment, blue bands were visible where the cement layers of the two surfaces had overlapped and green where it did not. The central blue cement indicated an area where the crown had not reproduced the die accurately based on hue thresholding. It was possible to highlight these bands and produce a clearer image in black and white that was used to determine changes in the occlusal cement thickness and identify other areas of poor adaptation (*Figure 2*). Measurements were made to determine changes in the cement thickness of the horizontal sections (*Figure 3*).

Table 1. *The variation in cement thickness between the cuspal tips and the occlusal adaptation area (OA) for Procera and Empress crown morphologies investigated. The asterisk (*) indicates the crown cemented to the original die as received from the manufacturers.*

	Procera			Empress		
	Cement thickness after alignment (μm)					
Crown	*Cusp 1*	*OA*	*Cusp 2*	*Cusp 1*	*OA*	*Cusp 2*
I	35	101	30	45	22	40
II	56	246	130	66	181	125
III*	23*	21*	18*	n/a	n/a	n/a
III	30	29	25	20	11	35
IV	115	271	119	43	216	15

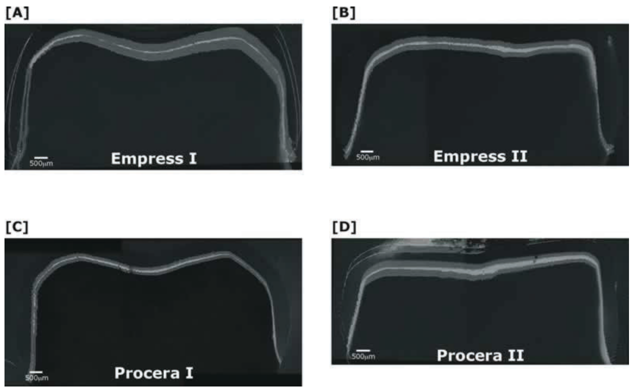

Figure 4. *The accuracy of fit from the cuspal peaks to the occlusal adaption area for (A) Empress crown morphology I crown cemented to the replica die; (B) Empress crown morphology II crown cemented to the replica die; (C) Procera crown morphology I crown cemented to the original die; and (D) Procera crown morphology II crown cemented to the replica die.*

RESULTS

Die replication

The cement film thickness under the occlusal surface of the Procera crown morphology III crown seated on the original acrylic die (*Figure 3*) varied from 5–40 mm with a mean thickness and standard deviation of 24 ± 7 μm after image alignment. Alignment of the Procera crown morphology III crown cemented to a replica stone die produced occlusal cement thicknesses of 5–57 μm with a mean and standard deviation of 35 ± 10 μm. The Student's-t-test analysis revealed no significant difference between the mean cement thickness of the acrylic die and stone die replica at the 99% significance level.

Reproduction of crown inner surface profile

Alignment of the crowns using image analysis identified variations in the inner surface curvature compared with the outer surface of the die. The largest differences occurred from the cuspal peaks to the occlusal adaptation area. The Procera crown morphology I crown seated to the die stone replica produced an occlusal cement thickness of 30 μm at the cuspal peaks, which increased to a maximum of 101 μm at the occlusal adaptation area (*Table 1*). Similar trends were observed for the Procera crown morphologies II and IV (*Table 1*). Empress crown morphologies II and IV seated crowns also identified differences in curvature from the cuspal peaks to the occlusal adaptation area but these were less pronounced than for the Procera crowns of identical morphologies (*Table 1*). The reproduction of the curve adjacent to the marginal ridge of Procera crown morphologies II, III and IV crowns were poor compared with the Empress crowns investigated (*Figure 4*).

Table 2. *The variation in angle of tilt and marginal gap for Procera and Empress crown morphologies investigated. The asterisk (*) indicates the crown cemented to the original die as received from the manufacturer.*

	Procera			Empress		
Crown	*Angle (°)*	*Marginal gap (μm)*		*Angle (°)*	*Marginal gap (μm)*	
I	0.17	120	54	2.49	78	548
II	1.156	352	23	0.23	201	274
III*	2.55*	437*	7*	n/a	n/a	n/a
III	0.03	121	35	0.83	60	228
IV	2.55	529	86	1.39	471	319

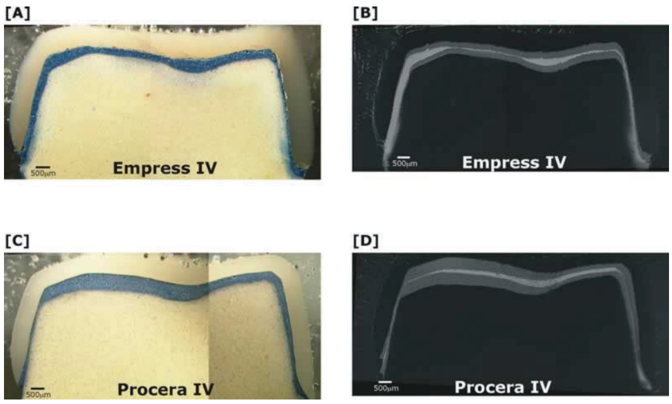

Figure 5. *The clinical fit of (A) Empress crown morphology IV crown cemented to the replica die; (B) the theoretical fit of Empress crown morphology IV crown; (C) the clinical fit of Procera crown morphology IV crown cemented to the replica die; and (D) the theoretical fit of Procera crown morphology IV crown.*

Accuracy of fit

In the current investigation all the crowns tilted when fitted, to varying degrees independent of the type of ceramic used or the internal shape of the crown. The angles of tilt varied from 0.03–2.55° for the Procera crown morphologies investigated compared with 0.64-2.49° for the Empress crown morphologies investigated (*Table 2*). The marginal gap was also highlighted to vary independently of ceramic type or internal shape of the crown (*Figure 5*). The marginal gap varied from 7–529 mm for Procera crown morphologies compared with 26–548 μm for Empress with mean marginal gaps of 176.4 and 237.5 μm, respectively (*Table 2*).

DISCUSSION

Die replication

No significant differences were identified between the mean cement thickness of the original acrylic die and stone replicas for the Procera crown III morphology crowns indicating uniformity and consistency of replication (*Figure 2*). These results highlight that the replication technique used could be applied to produce copies of the original dies provided by the manufacturers throughout the current study.

Reproduction of crown inner surface profile

Variations in the reproducibility of the profile of the inner surfaces of Procera crowns can be explained by sintering theory. As described earlier, Procera crowns are manufactured from 99.9% alumina powder that is then densified by solid-state-sintering. During the firing of alumina ceramic powder, a welding effect occurs at the points of contact between adjacent oxide particles, giving rise to partial fusion[15]. There is a difference in free energy between the neck area and the surface of the particle and this provides the driving force for atoms to diffuse to areas of contact between the particles. The migration of atoms leads to an increased fusion area with an associated decrease in porosity and movement of grain boundaries. Therefore, the sintering process is energetically driven toward reduction of surface free energy by material transport, which occurs by a variety of mechanisms[15], and is apparent in the less defined occlusal adaption observed for the Procera system (*Figure 4*).

Empress crowns are formed by a process known as hot pressing and uses liquid-state-sintering and the aid of outside pressure and high temperature to sinter objects to full theoretical density[8]. The advantages of this method compared with solid-state-sintering are the elimination of the need for very fine particles and the removal of large pores caused by non-uniform mixing. The high glass content of Empress ingots (approximately 63%) results in a material that can be melted and injected under pressure into a mould. The pressure applied ensures shrinkage of the final crown is minimised and results in the superior surface profile reproduction of the marginal ridge, cuspal tips and occlusal adaptation areas of the Empress crowns compared with the Procera crowns in the current investigation (*Figure 4*).

Clinical fit

Christensen[16] suggested that in clinical situations, marginal gaps should be in the range of 25–40 μm. McLean and Fraunhofer[17] suggested a marginal gap of 120 μm was clinically acceptable, but more recent studies have shown marginal gaps can often be as large as 300 μm[18]. Some of the marginal gaps observed in the current study were clearly not acceptable (*Table 2*) and could affect the long-term viability of the crowns in question[19,20]. The zinc phosphate used to seat the crowns is susceptible to disintegration in the oral environment[21], which could lead to failure of the material at the margin where the crowns are unsupported and the possible formation of secondary caries. Tilting of the crowns (*Table 2*) is connected with the marginal gaps and resulted in non-uniform cement thickness. Occlusion would result in non-uniform stress patterns across the cement[22] that could lead to an increased likelihood of crown failure. A previous investigation into the precision of fit of Procera[23] highlighted that cement thickness was no more than 70 μm. A light bodied silicone impression material was used as the luting agent by May *et al.*[23] in the study to obtain an impression of the inside surface of the crown after seating on the corresponding die. While using this method it would be impossible to identify if the correct seating alignment had been clinically poor, for example the crown may be sitting high on the die or may have been rotated, emphasis was placed on the depth of the cement margin at fixed points, rather than the reproduction of the profile of the die. Recent clinical results for Procera crowns[24] again examined precision of fit and emphasis was also placed on the depth of the cement margin rather than profile reproducibility. However, Odén *et al.*[25] reported a 97% success rate for the clinical use of Procera after five years. These results may be slightly misleading due to their selection of criteria in determining “successful”. In a small study of one hundred crowns, three were lost due to patient availability during evaluation times. If a crown experienced fracture of the porcelain veneer it was repaired and still considered successful. Although it is not stated in any literature by Andersson, it would appear the manufacturers understand that sintered high-alumina will result in poor inner surface profile reproduction because they advise that teeth should be prepared for restoration with rounded, smooth curves. A consequence of this is that the marginal edge of the Procera crown is very thin, resembling a knife-edge that may contribute to the failure in this area of the aluminous cores and porcelain veneers applied to them. To achieve the smooth rounded contours of the tooth preparations excessive grinding of healthy natural tooth is required and it has been suggested previously[26] that a 1.2 mm marginal shoulder is required to ensure adequate crown thickness and resistance to fracture. While the marginal gap was highlighted to vary independently of ceramic type or internal shape of the crown, the occlusal adaptation area for the Procera crowns were generally markedly higher than the Empress crowns which again could affect the long-term viability of the Procera crowns more than the Empress crowns[18]. *Figure 5* illustrates the clinical fit of Procera crown morphology IV compared with Empress crown morphology IV in terms of theoretic fit highlighting the susceptibility of Procera to poor crown inner surface reproducibility with the associated increases in cement thickness at the occlusal adaptation area.

It should however be noted that despite the interesting results achieved caution should be noted since the small sample sets examined would require further investigation to confirm the findings of the current preliminary study. Whilst the authors have attempted to eliminate as many variables as possible, the accuracy of fit and the inner surface curvature measurements were dependent upon the dimensional accuracy and stability of the impression material and the accuracy of the stone material employed during replica manufacture. However, the aim of the current investigation was to demonstrate that the accuracy of fit of different all-ceramic crown materials could compromise performance and thereby provide a reason for the poor correlation of fracture strength with clinical performance of all-ceramic crown materials. The study highlighted the accuracy of fit and the reproducibility of inner surface profile of Procera crowns was poorer than Empress crowns. The associated increase in cement layer thickness as a result of the reduced accuracy of fit and reproducibility of inner surface profile may, within the limitations of the current study, emphasise the poor correlation between average fracture strength and performance of all-ceramic crown materials.

CONCLUSIONS

Within the limitations of sample size in the current study the results indicate that IPS Empress has a superior ability to reproduce the curvature of the crown morphologies investigated compared with the higher strength alumina ceramic Procera. The increased reproduction of curvature was associated with a reduction in the occlusal contact area for the crown morphologies investigated.

ADDRESS FOR CORRESPONDENCE

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