A Comparison of the Marginal Fit of In-Ceram, IPS Empress, and Procera Crowns

The in vitro marginal fit of three all-ceramic crown systems (In-Ceram, Procera, and IPS Empress) was compared. All crown systems were significantly different from each other at \( P = 0.05 \). In-Ceram exhibited the greatest marginal discrepancy (161 \( \mu \)m), followed by Procera (83 \( \mu \)m), and IPS Empress (63 \( \mu \)m). There were no significant differences among the various stages of the crown fabrication: core fabrication, porcelain veneering, and glazing. The facial and lingual margins exhibited significantly larger marginal discrepancies than the mesial and distal margins. *Int J Prosthodont* 1997; 10:478-484.

All-ceramic dental restorations provide esthetics seldom rivaled by metal ceramic restorations. One all-ceramic system is fabricated using a slip-cast technique (In-Ceram, Vita Zahnfabrik)\(^a\)\(^6\) and another by a heat-press technique (IPS Empress, Ivoclar).\(^7\)\(^8\)

Slip casting is a technique derived from industrial technology and adopted for dental use.\(^9\) The slip-cast alumina is first partially sintered in a furnace, producing a porous framework that is then infiltrated with liquid glass in a second firing process. Crack propagation during failure is limited because of the densely packed alumina particles. Glass infiltration eliminates almost all porosities, which are potential sites for crack initiation. The difference in the coefficients of thermal expansion between alumina and glass produces compressive stresses at the alumina-glass interface that further enhance strength. Several studies have shown that a glass-infiltrated alumina crown may achieve a strength three to four times greater than the strength of earlier alumina core materials.\(^10\)\(^12\) The marginal integrity of this system has also been evaluated.\(^12\)\(^15\)

High-strength cores are also fabricated with a heat-press technique (IPS Empress).\(^7\)\(^8\) A feldspathic porcelain consisting of 63% \( \text{SiO}_2 \) and 18% \( \text{Al}_2\text{O}_3 \) is used as a basic material. In addition, leucite crystals are used as the crystalline part of the ceramic. A complete contour wax pattern for the restoration is placed on a specially designed cylindrical crucible former and invested in a phosphate-bonded investment. After the temperature of the mold has reached 850°C in a wax elimination furnace, a ceramic ingot and an \( \text{Al}_2\text{O}_3 \) pushing rod are placed in the mold. The cast is immediately preheated in the automatic press furnace (1150°C) (Empress EP 500, Ivoclar), and the plastic glass-ceramic material is pressed into the mold. Surface characterization may be performed to achieve the desired shade.\(^7\)\(^8\) This

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Table 1  Marginal Discrepancy of Various Crown Systems

<table>
<thead>
<tr>
<th>Investigators</th>
<th>Reference</th>
<th>Material</th>
<th>Mean marginal discrepancy (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chan et al</td>
<td>35</td>
<td>Cemented Cerestore crowns</td>
<td>84 ± 44</td>
</tr>
<tr>
<td>Ferrari</td>
<td>36</td>
<td>Uncemented Cerestore crowns</td>
<td>75 ± 37</td>
</tr>
<tr>
<td>Abbate et al</td>
<td>37</td>
<td>Dicor castable ceramic crowns</td>
<td>15–75 (range)</td>
</tr>
<tr>
<td>Grey et al</td>
<td>12</td>
<td>Metal facial metal ceramic crowns</td>
<td>60.6 ± 26.4</td>
</tr>
<tr>
<td>Pera et al</td>
<td>13</td>
<td>Porcelain facial ceramic crowns</td>
<td>57 ± 24.2</td>
</tr>
<tr>
<td>Sorensen et al</td>
<td>14</td>
<td>Ceramic crown</td>
<td>44.1 ± 12</td>
</tr>
<tr>
<td>Rinke et al</td>
<td>15</td>
<td>Metal ceramic</td>
<td>65.3 ± 17.5</td>
</tr>
<tr>
<td>Janenko and Smales</td>
<td>31</td>
<td>Chamfer margin In-Ceram crowns</td>
<td>95 ± 23</td>
</tr>
<tr>
<td>Felton et al</td>
<td>28</td>
<td>Porcelain jacket crowns</td>
<td>125 ± 30</td>
</tr>
<tr>
<td>Omar et al</td>
<td>38</td>
<td>Metal ceramic</td>
<td>154 ± 37</td>
</tr>
<tr>
<td>Strating et al</td>
<td>39</td>
<td>Metal ceramic</td>
<td>57 ± 24.2</td>
</tr>
<tr>
<td>Boyle et al</td>
<td>40</td>
<td>Metal ceramic</td>
<td>44.1 ± 12</td>
</tr>
<tr>
<td>Leong et al</td>
<td>41</td>
<td>Metal ceramic</td>
<td>65.3 ± 17.5</td>
</tr>
<tr>
<td>Baez et al</td>
<td>42</td>
<td>Metal ceramic</td>
<td>95 ± 23</td>
</tr>
<tr>
<td>Blackman et al</td>
<td>43</td>
<td>Metal ceramic</td>
<td>125 ± 30</td>
</tr>
<tr>
<td>Krajci et al</td>
<td>44</td>
<td>Metal ceramic</td>
<td>154 ± 37</td>
</tr>
</tbody>
</table>

core material possesses a high flexural strength in the range of 160 to 220 MPa.16-18

A new method of fabricating all-ceramic restorations was recently introduced as the Procera technique (Procera Sandvik). A densely-sintered, high-purity alumina (Al₂O₃ > 99.9%) is used in the technique. This same material has been used in a ceramic core for single-tooth implant replacement (CeraOne, Branemark system, Nobel BioCare) and in a ceramic abutment for implant-supported single crowns (CerAdapt, Branemark system, Nobel BioCare).19,20 The working die is first digitized in three dimensions. A duplicate of this die is then produced with a 12% to 20% enlargement using computer-aided design–computer aided machining (CAD-CAM) technology. High-purity alumina powder is compacted onto the enlarged die using a dry pressing technique.21 The coping is then sintered at 1550°C for 1 hour. It is then adjusted, ground, polished, and thermal-etched before porcelain application. Because of its high alumina content, the core material maintains a flexural strength of 650 MPa.22

In one study, the Procera all-ceramic crown (687 MPa) was found to have a 95% and 413% higher mean strength than the In-Ceram (352 MPa) and IPS Empress (134 MPa) crowns, respectively.23 In addition to mechanical strength, the characteristics of enamel wear24 and indentation fracture toughness25 of the Procera all-ceramic have also been studied.

Marginal adaptation is one of the important criteria used in the clinical evaluation of fixed restorations. The presence of marginal discrepancies in the restoration exposes the luting agent to the oral environment. The larger the marginal discrepancy and subsequent exposure of the dental luting agent to oral fluids, the more rapid is the rate of cement dissolution.26 The resultant microleakage permits the percolation of food, oral debris, and other substances that are potential irritants to the vital pulp.27 The longevity of the tooth could be compromised, not only by caries, but also by periodontal disease.28,29 Clinical studies have shown that poor marginal adaptation of a restoration correlates with increased plaque retention and reduced gingival health, as indicated by a higher Plaque Index (PI), an elevated Gingival Index (GI), and increased pocket depths (PD).30-33 A change in the subgingival microflora is also attributed to inadequate marginal adaptation.34

The marginal discrepancy of various restorations have been studied (Table 1).35-44 In-Ceram crowns

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Note: The table and text continue with further details and explanations regarding the marginal discrepancy and the characteristics of various crown systems.
Marginal fit of In-Ceram, IPS Empress, and Procera Crowns

Sulaiman et al.

Marginal distortion of metal ceramic restorations during various stages of fabrication is well-documented. The authors are unaware of any study that has been conducted to examine the effect of porcelain application on the marginal discrepancy of all-ceramic restorations.

The purposes of the study were to compare:

1. The marginal discrepancies of three all-ceramic crown systems at various surfaces of the restoration: mesial, distal, buccal, and lingual. The all-ceramic crown systems studied were the densely sintered high-purity alumina porcelain crown (Procera Sandvik), the heat-pressed feldspathic glass-ceramic crown (IPS Empress), and the slip-cast sintered alumina ceramic crown (In-Ceram).

2. The marginal discrepancies of these three all-ceramic systems at various stages of fabrication: at fabrication of the core material, after the application porcelain veneer, and after glazing.

Materials and Methods

An all-ceramic crown preparation of a maxillary central incisor was fabricated in a base metal alloy (Rexillium, Jeneric Pentron). The preparation followed commonly used textbook guidelines. The metal die was polished, and the marginal integrity of the die was carefully examined under a microscope. Four vertical lines were scribed onto the die approximately 0.5 mm below the margin on the midmesial, midbuccal, midpalatal, and middistal surfaces using a 0.25-mm round carbide bur. These vertical lines were used to help orient the digital microscope for the marginal discrepancy measurement. A poly(vinyl siloxane) index (Putty, Reprosil, LD Caulk, Dentsply) was fabricated using a complete contour wax pattern on the die. This index was used to facilitate porcelain application so that the dimensions of the crowns would be relatively identical.

Impressions of the master die were made using poly(vinyl siloxane) (Light-body and Putty, Reprosil) in custom trays. A total number of 30 impressions were made and poured using type IV dental stone (Silky-Rock, Whip Mix). The stone dies were divided into three groups of 10 dies each: Procera (Procera Sandvik) crowns; IPS Empress (Ivoclar) crowns; and In-Ceram (Vita Zahnfabrik) crowns. All crowns were fabricated according to their respective manufacturer's recommendations.

The Procera crowns were fabricated by Procera Sandvik in Göteborg, Sweden. The IPS Empress crowns were made by a commercial laboratory certified in the technique. The In-Ceram copings were provided by Vident in Baldwin Park, California, and the porcelain veneering and glazing were performed by the in-house laboratory at Northwestern University Dental School.

The marginal fit of each restoration was examined at 225 X magnification using a digital microscope (Nikon SMZ-U, Nikon). The calibrated spring of a 2-inch C-clamp held the restoration onto the master die with a standardized force of 3 lb (1.36 kg) when the spring was completely compressed. This force was estimated to be the mean force to seat a restoration. The spring had been previously calibrated by plotting the force and the length of the spring on a universal testing machine (Instron). All measurements were made on the master die. The marginal fit of each restoration was measured after the following stages of fabrication: (1) at fabrication of the core material, (2) after dentin and enamel porcelain applications, and (3) after glazing.

An angle level was used to ensure that the sample was perpendicular to the objective lens of the microscope during each measurement. Each surface was measured three times, and the mean value was obtained, resulting in 360 measurements for each stage of fabrication. The images were then identified and printed. The digital microscope was calibrated with the use of an objective micrometer (American Optical) prior to the experiment. All the measurements were made by one operator. To determine the consistency of the measurements of the operator, one randomly selected restoration was placed on the master die, and one randomly selected surface was measured 30 times. The measurement showed a standard error of 2.84 μm with a confidence level of 1.01 μm. This result was deemed acceptable for the purpose of the study.

A three-way analysis of variance (ANOVA) was computed for statistical significance among three variables at P = 0.05: (1) the crown systems, (2) the surfaces, and (3) the stages of fabrication. A Tukey post hoc analysis was used to evaluate the significant difference between interactions. The clinical relevance of the results was interpreted by comparison with the acceptable marginal discrepancy of 120 μm as proposed by McLean and von Fraunhofer.
Results

Three-way ANOVA revealed significant differences among the three ceramic systems, among the various surfaces, and among the system-surface interactions (P < 0.05) (Table 2). There were no significant differences in the marginal discrepancies among the three stages of porcelain applications (P > 0.05) (Table 2). One-way ANOVA and Tukey post hoc analysis showed that the In-Ceram group possessed significantly larger marginal discrepancy than either the Procera group or the IPS Empress group (P < 0.05). The Procera group had significantly larger marginal discrepancy than the IPS Empress group (P < 0.05) (Table 3). The mean marginal discrepancy of the Procera group and the IPS Empress group at 82.88 and 62.77 μm, respectively, met the criterion of an acceptable marginal discrepancy at 120 μm. The mean marginal discrepancy of the In-Ceram group at 160.66 μm exceeded the 120 μm criterion.

The one-way ANOVA and Tukey post hoc analysis showed that the lingual location had a significantly greater marginal discrepancy than either the mesial or the distal locations (P < 0.05). The marginal discrepancy at the lingual location was not significantly different from the facial discrepancy (P > 0.05) (Table 4).

Table 5 depicts the marginal discrepancies of the three crown systems at each marginal location. All marginal locations of the Procera group and the IPS Empress group met the 120-μm criterion; however, all margin locations of the In-Ceram group failed to meet this criterion.

Discussion

That significant differences were found among the systems but not at the various stages of fabrication suggested that the ceramic coping fabrication accounted for the different marginal discrepancy of the ceramic systems. Fabrication of the Procera all-ceramic restoration requires digitization of the stone die. The data input are determined by the sensitivity of the probe, which has a maximum shape-related error of 10 μm in a complete revolution. The maximum error encountered from the probe and the milling process has been shown to be less than 100 μm. The dimension of the stone die is mathematically recalculated to fabricate the enlarged refractory die. Therefore, the dimension of the refractory die is determined by the accuracy and the precision of the computer software.

To fabricate a Procera ceramic coping, a dense sintered aluminum oxide powder is compacted

Table 2 Three-Way ANOVA of Data

<table>
<thead>
<tr>
<th>Effect</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>184.1305</td>
<td>0.00000</td>
</tr>
<tr>
<td>Stage</td>
<td>1.69648</td>
<td>0.18277</td>
</tr>
<tr>
<td>Surface</td>
<td>7.28481</td>
<td>0.00024</td>
</tr>
<tr>
<td>System × Stage</td>
<td>2.1186</td>
<td>0.07702</td>
</tr>
<tr>
<td>System × Surface*</td>
<td>5.3305</td>
<td>0.00000</td>
</tr>
<tr>
<td>Stage × Surface</td>
<td>0.10638</td>
<td>0.99429</td>
</tr>
<tr>
<td>System × Stage × Surface</td>
<td>0.2840</td>
<td>0.99097</td>
</tr>
</tbody>
</table>

*Marked effects significant at P < 0.05.

Table 3 Means and Standard Deviations of the Marginal Discrepancies of Three Ceramic Systems

<table>
<thead>
<tr>
<th>System</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procera</td>
<td>120</td>
<td>82.88</td>
<td>41.45</td>
</tr>
<tr>
<td>IPS Empress</td>
<td>120</td>
<td>62.77</td>
<td>37.32</td>
</tr>
<tr>
<td>In-Ceram</td>
<td>120</td>
<td>160.66</td>
<td>45.98</td>
</tr>
</tbody>
</table>

All systems are significantly different from each other at P = 0.05 using one-way ANOVA and Tukey post hoc test.

Table 4 Means and Standard Deviations of the Marginal Discrepancies at Four Marginal Locations

<table>
<thead>
<tr>
<th>Surface</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facial</td>
<td>102.54</td>
<td>46.16</td>
</tr>
<tr>
<td>Mesial</td>
<td>96.11</td>
<td>62.07</td>
</tr>
<tr>
<td>Lingual</td>
<td>124.38</td>
<td>63.04</td>
</tr>
<tr>
<td>Distal</td>
<td>85.39</td>
<td>56.79</td>
</tr>
</tbody>
</table>

Vertical bars indicate statistically significant difference between pairs at P = 0.05 using Tukey post hoc test.

Table 5 Means and Standard Deviations of Three Ceramic Systems on Various Surfaces

<table>
<thead>
<tr>
<th>System</th>
<th>Surface</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procera</td>
<td>Facial</td>
<td>66.79</td>
<td>22.33</td>
</tr>
<tr>
<td></td>
<td>Mesial</td>
<td>93.48</td>
<td>41.00</td>
</tr>
<tr>
<td></td>
<td>Lingual</td>
<td>103.54</td>
<td>41.35</td>
</tr>
<tr>
<td></td>
<td>Distal</td>
<td>67.71</td>
<td>45.80</td>
</tr>
<tr>
<td>IPS Empress</td>
<td>Facial</td>
<td>86.80</td>
<td>29.70</td>
</tr>
<tr>
<td></td>
<td>Mesial</td>
<td>42.36</td>
<td>35.24</td>
</tr>
<tr>
<td></td>
<td>Lingual</td>
<td>76.80</td>
<td>37.42</td>
</tr>
<tr>
<td></td>
<td>Distal</td>
<td>45.13</td>
<td>26.23</td>
</tr>
<tr>
<td>In-Ceram</td>
<td>Facial</td>
<td>154.02</td>
<td>37.65</td>
</tr>
<tr>
<td></td>
<td>Mesial</td>
<td>152.48</td>
<td>51.19</td>
</tr>
<tr>
<td></td>
<td>Lingual</td>
<td>192.80</td>
<td>38.11</td>
</tr>
<tr>
<td></td>
<td>Distal</td>
<td>143.32</td>
<td>41.13</td>
</tr>
</tbody>
</table>
onto the refractory die. The amount of shrinkage of the aluminum oxide powder is compensated by the enlarged refractory die. Information on the magnitude of the firing shrinkage of the aluminum oxide powder and the percentage enlargement of the refractory die is not available from the manufacturer. A mistake in compensating the amount of shrinkage would result in poor adaptation of the coping onto the stone die and thus compromise its marginal integrity.

The lost wax technique is used for the fabrication of IPS Empress copings. The wax pattern is fabricated on a stone die with die spacer applied. The thickness of the die spacer recommended ranges from 25 to 40 μm. Shrinkage of 0.4% can be expected from the wax pattern upon cooling at room temperature. Thermal shrinkage of approximately 0.2% of the ceramic coping is also expected after casting. This thermal shrinkage is compensated by setting and thermal expansion of a phosphate-bonded investment at approximately 0.3% and 0.2%, respectively. Thus, the net dimension of a cast ceramic coping is the result of the expansion and contraction of various materials used in its fabrication. The intricate balance and control of the materials are necessary for an acceptable fit.

The fabrication of the In-Ceram aluminous core requires two stages: condensation of the aluminum oxide powder onto the refractory die followed by a glass-infiltration process. Aluminum oxide powder is applied onto the refractory die and fired in a special furnace at 1120°C. The aluminous substructure as fabricated is fragile, and careless removal of excess material at the margin could potentially lead to increased marginal discrepancy. During the glass-infiltration firing, the glass mixture tends to gravitate, and it creates an excessive bulk at the margin of the coping after the firing is completed and must be trimmed using a rotary instrument. This procedure must be performed extremely carefully to maintain marginal integrity.

The error incurred at each step of the fabrication of an all-ceramic system would either compound or offset previous errors. Although the number of steps involved in the fabrication of all-ceramic crowns was not a direct indication of the quality of the marginal integrity, one may suggest that the more the steps involved and the more sensitive the techniques, the more likely it is that technical errors will occur. The results of this study suggest that the mean marginal discrepancy of the all-ceramic systems follows in descending order: In-Ceram, Procera, and IPS Empress. The differences among the systems are attributed to the coping fabrication. This could be partially explained by technique sensitivity and the number of the steps in fabricating these copings.

The lingual margin of the all-ceramic crowns shows significantly higher marginal discrepancy than other surfaces. This may be explained by the larger amount of firing shrinkage at the lingual surface. Although it was not the initial intent of this study to investigate the relationship between the marginal discrepancy and the bulk of the porcelain around the margin, a measurement of the thickness of the all-ceramic crown shows the lingual bulk to be approximately 20% thicker than other areas. Since firing shrinkage is a function of the porcelain bulk, it is possible that the larger marginal discrepancy seen at the lingual margin could be related to the greater bulk of porcelain.

The mean marginal discrepancy of 161 μm of the In-Ceram crowns in this study was not in agreement with the finding of Pera et al, who found a mean glass-ionomer cement thickness for In-Ceram crowns on epoxy resin teeth in the range of 15 to 35 μm. Sorensen et al reported the mean marginal discrepancy of cemented In-Ceram crowns to be in the range of 24 to 67 μm with various designs of preparation. Rinke et al also found that the marginal discrepancy of cemented In-Ceram crowns ranged from 1 to 153 μm (median 32.5 μm) with a conventional technique, and from 3 to 153 μm (median 38 μm) with a copy-milled technique. Conversely, Grey et al found the mean cement space thickness of In-Ceram crowns to be 123 μm. An explanation of the lack of agreement is the variation in the method used by various investigators in studying marginal discrepancy. In contrast to the present experiment in which a digital microscope (×225 magnification) was used, others have used a digital microscope (magnification not reported) to measure the sectioned teeth, a stereomicroscope (×100 magnification), and a light microscope connected to a computer monitor (×180 magnification) for direct measurement.

The current findings on the IPS Empress crowns in this study (62.77 ± 37.32 μm) agrees with those findings on IPS Empress inlays by Krejci et al, who reported the value in the range of 62.3 to 101.0 μm (mean 78.2 ± 15.1 μm).

In an attempt to correlate the results of this study with published clinical studies, the authors can only find incomplete or short-term clinical data. In a study that evaluated the clinical outcome of IPS Empress inlays, the percentage of gap-free inlays decreased from 97.4% to 66.8% over a 1.5 year observation period. Two clinical studies of the In-Ceram crowns did not reveal the results on the
quality of the marginal adaptation. To the authors' knowledge, no in vitro or in vivo data are available for comparison with the Procera crowns in this study. Further investigation is necessary to examine the clinical outcome of these all-ceramic restorations.

Conclusions

Thirty all-ceramic restorations were fabricated and measured for the marginal integrity during various stages of fabrication. Within the conditions and limitations of this study, the following conclusions may be drawn:

1. The mean marginal discrepancy of the all-ceramic crowns was, in descending order: In-Ceram (161 ± 46 μm), Procera (83 ± 41 μm), and IPS Empress (63 ± 37 μm). Both Procera and IPS Empress met the criterion for acceptable marginal discrepancy of 120 μm.

2. The lingual surfaces of the ceramic crowns possessed significantly greater marginal discrepancies than all other surfaces. There were no significant differences among the other three surfaces: facial, mesial, and distal.

3. For all three all-ceramic systems, no significant difference in marginal discrepancy was observed during the various stages of fabrication: core fabrication, porcelain veneering, or glazing.

Acknowledgments

The authors would like to express their thanks to the following: Nobel BioCare AB, Göteborg, Sweden—Dr Robert Gottlander and the people involved in fabricating the Procera all-ceramic restorations; Nobel BioCare USA, Westmont, Illinois—Dr Bjørne Kvanstrom, Ms Anna Lettios, and Ms Kathleen Matke for lending tremendous help in using the digital microscope; Lords Dental Studio, Green Bay, Wisconsin—Kris van Laenen and his colleagues for their help in fabricating the IPS Empress all-ceramic restorations; Vident USA, Baldwin Park, California—Ray Marrow and Christ Herzog for their help and support in fabricating the In-Ceram copings; Central Laboratory, Northwestern University Dental School—Robert Borek, CDT, and Joyce Teleback, CDT.

References


Erratum

Please note the following correction to the article "Implant-Supported Overdenture Rehabilitation and Progressive Systemic Sclerosis" by Raviv et al (Int J Prosthodont 1996;9:440-444). The authors would like to acknowledge Dr Ronald M. Fisher's contribution to the prosthetic treatment of the case presented. As an instructor in charge of removable prosthodontics, Dr Fisher supervised the resident that treated the patient. The authors regret their failure to acknowledge Dr Fisher in the original article.