Precision of Marginal Adaptation of the Incisor and Molar Procera® AllCeram Crown Copings

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**Abstract:** The primary objective of this *in vitro* study was to compare the absolute marginal discrepancy (AMD) of CAD/CAM produced Procera® AllCeram crown copings, fabricated on die stone master models of two different tooth groups, incisor and molar. Two maxillary central incisors and two first molars typodont teeth were prepared with 0.8 mm of circumferential chamfer, duplicated 9 times to obtain 36 die stone models and allotted into three groups of 12 models (incisors = 6 & molars = 6). Procera® AllCeram 0.6 mm copings were fixed with zinc phosphate (AZ), glass ionomer (AG) and resin (AR) cement accordingly under 50 N static finger force. The AMDs were measured using the scanning electron microscope (SEM) on four axial walls with 4 measurements on each wall to obtain 16 readings for one tooth. Statistical analysis of the data was performed using the non-parametric test of Kruskal-Wallis and Mann-Whitney test. The analysis did not find any significant differences in the mean AMD of incisor and molar crown copings, and in different axial surfaces too \((p \leq 0.05)\). Recorded mean AMD of incisor copings were AZ group 59 µm, AG 37.9 µm, and AR 44.4 µm and molar copings were AZ 48.8 µm, AG 27 µm, and AR 50.2 µm. It can be concluded that AMD of Procera® AllCeram copings were within accepted level of 100 µm. Incisors showed higher AMD than molars. Molars demonstrated the higher AMD on mid-distal and mid-lingual surfaces whereas for incisor it was mid-buccal and mid-lingual surface.

**Introduction**

Aesthetically oriented modern dentistry frequently utilizes high strength, biocompatible all-ceramic materials to satisfy the clinical demand of a patient. However, all these materials have to meet with three important criteria like high fracture resistance, aesthetics and marginal fit [1] for long-term survival in complex oral environment. The marginal fit of the all-ceramic systems can be a critical factor to its long-term success. Inaccurate marginal adaptation is potentially detrimental to the tooth and the supporting periodontal structures [2, 3, 4]. Recent introduction and popularity of CAD/CAM designing and production of substructures for fixed partial dentures have minimized the human errors during production stage which can influence the marginal fit of the restorations [5]. A well accepted and popular among a plethora of CAD/CAM based all-ceramic system is Procera® AllCeram system (Procera®, Gothenberg, Sweden) which was introduced in 1993 by Andersson and Oden [6].

Procera® is a versatile CAD/CAM system, with in-office facility to digitisation of tooth preparation model using contact scanner with an accuracy of \(\pm 10 \mu m\) [7] and custom designing the substructure of FPD using user friendly software program. These data are transferred to the production centre at Nobel Biocare, Gothenberg, Sweden. In production centre, using CAD/CAM technology, duplicate of die is produced with 12–20 % enlargement to compensate the sintering shrinkage of \(Al_2O_3\). Procera® AllCeram copings are fabricated from 99.9 % densely...
sintered high-purity aluminium oxide powder and dry pressing and sintering at 1550 °C for 1 hour. Excess is trimmed and ground polished. Compatible feldspathic porcelain is fired at 920 °C. On investigation it was not found that different stages of firing ceramics onto alumina coping neither reduced nor influenced the fit of the final restoration [8].

Marginal integrity of the Procera® AllCeram copings have been investigated by multiple investigators (Table 1) by means of direct viewing, sectioning, tactile and visual perception and epoxy replica techniques. It was a consensus among the investigators to accept the optimum marginal misfit for CAD/CAM produced restoration to be 100–120 µm [17]. All the published study results are within the biologically accepted limit. However, there is a wide variation in measuring instrument employed, magnification factor and number of readings per sample. Groten et al. strongly suggested using SEM for direct circumferential marginal discrepancy assessment to obtain clinically relevant result [18].

Several researchers have reported that marginal fit of CAD/CAM restoration was dependent on multiple factors [8, 9, 11] Clinical and laboratory studies have investigated these different affecting factors, which can contribute to the final fit of cemented All Ceramcopings, such as type of finish line, die spacing and different cements and cementation techniques [12, 13, 14, 15]. There have been suggestions that scanning, software & machining can also have detrimental effect on the final fit of CAD/CAM produced restoration [19]. Chamfer finish line is the most accepted marginal design for Procera® AllCeram crown, because of ease of digitisation and an even stress distribution on the tooth [10, 20]. The uniformity and accuracy of the tooth preparation is most vital to obtain accurate fit of Procera® AllCeram crown. In clinical setting, the tooth preparation and impression making can be more accurate in anterior teeth than the posterior teeth, because of compromise visibility and other associated factors. Distant surfaces like palatal

Table 1 – Previous study results of marginal fit value for Procera® AllCeram crown copings, Nobel Biocare, Gothenberg, Sweden

<table>
<thead>
<tr>
<th>Marginal fit value</th>
<th>Investigator</th>
<th>Year</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>83 µm</td>
<td>Sulaiman et al.</td>
<td>1997</td>
<td>[8]</td>
</tr>
<tr>
<td>64 µm</td>
<td>Lin et al.</td>
<td>1998</td>
<td>[9]</td>
</tr>
<tr>
<td>80 µm [Molar]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54 µm</td>
<td>Albert et al.</td>
<td>2004</td>
<td>[12]</td>
</tr>
<tr>
<td>44 µm</td>
<td>Quintas et al.</td>
<td>2004</td>
<td>[13]</td>
</tr>
<tr>
<td>17 µm [anterior]</td>
<td>Bindle et al.</td>
<td>2004</td>
<td>[14]</td>
</tr>
<tr>
<td>41 µm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26 µm</td>
<td>Naert et al.</td>
<td>2005</td>
<td>[16]</td>
</tr>
</tbody>
</table>
surfaces of incisors and proximal surfaces of molars are more arduous to prepare with uniform finish line.

The general aim of this investigation was to find the absolute marginal discrepancy of Procera® AllCeram crown copings. The working hypotheses studied were:

1. the marginal discrepancy of AllCeram crown copings would be influenced by the tooth group variations (incisor and molar),
2. there would be variation in absolute marginal discrepancy on different axial surfaces (mid-buccal, mid-mesial, mid-lingual, and mid-distal).

**Materials and Methods**

**Tooth preparation**

Two maxillary right central incisor and first molar typodont teeth (AG 3, Frasaco, Germany) were prepared for Procera® AllCeramic crown according to manufacturers instruction, using All-ceram crown preparation set (Meisinger, Hager & Meisinger GmbH., Neuss, Germany). All the teeth were prepared with 0.8 mm of circumferential chamfer finish line, 2 mm of occlusal reduction with 6° of total axial taper under copious water spray. Before the tooth preparation, a polyvinyl siloxane matrix was prepared and sectioned into half along bucco-lingual direction and used as a guide for uniform tooth preparation. All sharp line angles were removed and final finishing of the tooth preparations was performed with 30 µm diamond bur.

**Impression and die fabrication**

Four prepared teeth were mounted in individual self-cured resin blocs (Premacryl® Plus, Spofa Dental, Czech Republic) 2–3 mm away from chamfer finish line. The mid point of individual axial surfaces were scribed onto base of the resin block 4 mm below the gingival finish line on the mid-buccal, mid-mesial, mid-lingual and mid-distal surfaces using bard parker blade. Using custom made acrylic impression tray and additional silicon, two steps putty wash technique (Aquasil™ soft putty and, Aquasil Ultra LV, Dentsply DeTrey, Germany) was employed to make impression of the original models. The impressions were poured using the type 4

![Image](image_url)

*Figure 1 – Six anterior and six molar die models were grouped after the application of die hardener solution (Hardening Bath, Renfert GmbH, Germany).*

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die stone (Japan stone, Dr Böhme and Schöps Dental GmbH, Goslar, Borsigstrasse) to obtain 36 die stone models. These models were checked for any defect, and coated with the die hardening solution (Hardening Bath, Renfert GmbH, Germany). Three sets of four original tooth preparations were allotted into three groups of 12 teeth (Figure 1).

Fabrication of Procera® AllCeram copings
One die model of each original tooth was selected to be prepared for scanning using Procera® scanner. The bases of these models were trimmed to have parallel sides and the areas immediately below the chamfer margins were made more pronounced using a large pear-shaped laboratory bur according to the manufacturer’s instructions. The dies were scanned at the Charles University in Prague, Faculty of Medicine in Hradec Králové, Department of Dentistry, Czech Republic (Procera® Piccolo scanner, serial no 34666, software version 1.6, Procera® system; Nobel Biocare, Sweden) and data were transferred by modem to Procera® Nobel Biocare, Gothenberg, Sweden, where 99.9 % pure, densely sintered Al₂O₃ copings were prepared for 36 die models. Each coping was designed and fabricated with uniform internal cement space of 50 µm, to accommodate the thickness of cementing media. The deficiencies at the margins of all the fabricated copings were visually inspected on the respective tooth die model.

Cementation of AllCeram copings
All 36 samples were divided into three groups of 12 teeth zinc phosphate cement (AZ), glass ionomer cement (AG) and resin cement (AR) respectively. Inner surfaces of all the copings were cleaned and dried with water free and oil free air. For all the samples the areas immediately below the finish line of the die models were isolated using a thin layer of petroleum jelly (Johnson and Johnson, South Africa) carefully to aid in easy removal of the excess cement. The copings of group AZ, AG, and AR were cemented with zinc phosphate cement (Adhesor®, Spofa Dental, Czech Republic), Type 1 glass ionomer cement (Kavitan® Cem, Spofa Dental; Czech Republic) and resin cement (Dual®Cement, Ivoclar Vivadent AG, Schaan, Liechtenstein), according to the manufacturers instructions. The cements were applied to the inner surfaces of coping using micro brush (Ivoclar Vivadent AG, Schaan, Liechtenstein). The copings were held in place under calibrated static finger force of 50 N with aid of weighing scale (Salter, Czech Republic) during initial 4-5 minutes of cement setting. After the complete setting, removal of cement flash and tactile inspection of the margin was performed using explorer (EXD 11/12, Hu-Friedy, USA) (Figure 2).

SEM evaluation of absolute marginal discrepancy
Circumferential direct marginal evaluation of the cemented specimens was conducted for Procera® copings on die stone models using scanning electron
microscope (Leica Leo S 440 I, Leica Cambridge Ltd, Cambridge, England, UK) imaging. All the specimens were prepared for viewing in SEM by desiccating and sputter coating with 50 nm of gold palladium alloy in sputter coater (Model SC 7640, Polaron, Quarium technologies Sussex, UK) for 4 minutes. All axial surfaces were first viewed for pre-indent mid axial surface. Four potential measuring sites were selected at an interval of 200 µm along the marginal finish line on each axial surface for a total of 16 readings for each individual crown coping (Figure 2). The width of absolute marginal discrepancy was measured using a pre-calibrated electron-measuring bar of SEM, which depicts the actual marginal width in microns taking the magnification factor into consideration. The sensitivity of this electron-measuring bar was calculated beforehand and found to be 0.02 µm. The absolute marginal discrepancies of all the samples were measured by single a SEM operator. The operator’s measuring accuracy was ascertained by measuring the known

![Figure 2 – SEM picture (36 × magnification) of potential predetermined measuring spots of absolute marginal adaptation. Total of 16 readings were circumferentially measured for each Procera® AllCeram crown copings, four measurements on each axial surface.](image1)

![Figure 3 – Absolute marginal adaptation of Procera® AllCeram crown copings were measured in electronic measuring bar of SEM (Leica Leo S 440I, Cambridge, UK) from cavosurface margin of chamfer finish line to external edge of crown coping margin.](image2)
dimensions to eliminate the possibility of inducing variation during measurement. To master SEM measurement technique, a pilot study with metalo-ceramic copings were conducted at the beginning of the experiment (Figure 3).

**Statistical analysis**
To assess the marginal accuracy of Procera® AllCeramic crown copings, first mean axial surface marginal width of mid buccal, mesial, lingual and distal surface were calculated from four recorded readings, to find the individual axial surface mean marginal width. All these four axial surface means were used to calculate the mean width for each tooth in each group, finally, mean absolute marginal width for individual study group were calculated. Statistical analysis of intra and inter group variations were assessed using the Kruskal-Wallis test and the Mann-Whitney U-test. In all the above tests at $p \leq 0.05$ was considered to be statistically significant. The data was analysed using SPSS software package (Statistical Package for the Social Sciences for Windows 8.0, SPSS Software Corp, Chicago, USA).

**Results**
Mean absolute marginal discrepancies between cavosurface of chamfer finish line and edge of Procera® AllCeram copings were calculated for individual tooth sample using direct scanning electron microscopy (SEM) technique. The mean absolute marginal adaptation of incisors and molars are presented in Table 2.

In AZ group, incisors had 59.0 µm gap, molars 48.8 µm, and they did not differ significantly from each other ($p = 0.24$), in AG group incisors had 37.9 µm gap,

**Table 2 – Mean marginal adaptation of incisor and molar crown copings on each axial surface (in µm)**

<table>
<thead>
<tr>
<th>Group</th>
<th>Surface</th>
<th>Incisors</th>
<th>Max</th>
<th>Molars</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min</td>
<td>Mean (± SD)</td>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>AZ</td>
<td>B</td>
<td>55.0</td>
<td>85.4 (± 32)</td>
<td>134.6</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>29.8</td>
<td>50.8 (± 18)</td>
<td>73.6</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>30.2</td>
<td>45.7 (± 12)</td>
<td>60.5</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>34.3</td>
<td>53.4 (± 13)</td>
<td>75.8</td>
<td>D</td>
</tr>
<tr>
<td>AG</td>
<td>B</td>
<td>0.0</td>
<td>44.3 (± 25)</td>
<td>73.8</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>9.1</td>
<td>32.5 (± 20)</td>
<td>58.1</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>16.7</td>
<td>36.3 (± 19)</td>
<td>63.7</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>14.5</td>
<td>38.4 (± 17)</td>
<td>59.9</td>
<td>D</td>
</tr>
<tr>
<td>AR</td>
<td>B</td>
<td>19.9</td>
<td>36.7 (± 13)</td>
<td>50.5</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>26.1</td>
<td>40.6 (± 13)</td>
<td>62.5</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>33.5</td>
<td>60.8 (± 36)</td>
<td>42.1</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>21.5</td>
<td>39.7 (± 16)</td>
<td>63.9</td>
<td>D</td>
</tr>
</tbody>
</table>

Min = minimum, Max = maximum
and molars 27.0 µm, and did not differ significantly with each other ($p = 0.24$) while with AR group the incisors had 44.4 µm and molars 50.2 µm gap and hence did not differ significantly from each other ($p = 0.49$). Individual axial surface (buccal, mesial, lingual and distal) comparison of marginal fit of incisor and molar teeth are depicted in table. 2. Mann-Whitney U-test showed that there was no statistical difference in acceptability as function of tooth group variation on marginal fit of alumina coping ($p > 0.05$) (Table 2).

The comparison of the average mean value of incisor and molar of all the study group (AZ, AG & AR) on individual axial surface, incisors demonstrated highest marginal gap on mid-buccal and mid-lingual surfaces and least on mid-mesial surface. Meanwhile, molars had the highest marginal gap on mid-distal and mid-lingual surfaces and least on mid-buccal surface. However, when average mean absolute marginal gap of entire group was considered, incisors demonstrated 47.8 µm while for molars it was 43.4 µm (Table 3, Figure 4).

**Discussion**
Marginal accuracy is very critical for the longevity of indirect restorations. There were multiple researchers who investigated the role of various contributing factors, which directly influence the marginal fit of CAD/CAM fabricated restorations [8, 11, 12, 14, 21]. This *in vitro* study, investigated the accuracy of

| Table 3 – Statistical comparison (within the group) of marginal adaptation widths in anterior and molar crown copings (z and p value) |
|-----------------|---|---|---|---|---|---|---|---|---|---|
| Group | Buccal | Z | P | Mesial | Z | P | Lingual | Z | P | Distal | Z | P | Circumferential | Z | P |
| AZ | –1.92 | 0.07 | –0.64 | 0.59 | 0.00 | 1.00 | –0.48 | 0.70 | –0.20 | 0.24 |
| AG | –1.22 | 0.24 | –0.32 | 0.82 | –1.28 | 0.24 | –0.48 | 0.70 | –1.28 | 0.24 |
| AR | –0.32 | 0.82 | –0.32 | 0.82 | –0.80 | 0.49 | –1.44 | 0.18 | –0.80 | 0.49 |

*Figure 4 – Mean marginal discrepancy of incisor and molar crown copings comparison within the group ($p \geq 0.05$).*

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marginal fit of incisor and molar Procera® AllCeram copings with different luting agents using direct circumferential scanning electron microscope (SEM). In this study absolute marginal discrepancy was employed [22] as a tool to determine the accuracy of Procera® AllCeram crown copings. The absolute marginal discrepancy according to Holmes et al. is an angular combination of vertical and horizontal marginal discrepancy (over-extension and under-extension) and is measured from the margin of crown coping to cavosurface angle of chamfer preparation. He also mentioned that the absolute marginal discrepancy is the largest measurement of errors and hence is the most appropriate parameter for determining the accuracy of a given crown system [22].

It was ascertained by earlier studies that SEM is the most reliable and realistic method to quantitatively measure the marginal fit of indirect restorations [18, 24]. However, there have been earlier investigations, which employed digital microscopes, stereomicroscopes and profile projector to analyse the marginal fit of CAD/CAM fabricated crowns. Differences in measuring methodology can complicate the comparison of the study results [21]. All the earlier studies investigated the effect of finish line design, production technique of all-ceramic restoration, scanning technique and luting agents over the accuracy of marginal fit of Procera® AllCeram copings. But, to date, there are very few studies [10, 15] which have investigated the effect of tooth group variation (incisor and molar) over the marginal fit of Procera® AllCeram copings.

Result of this investigation demonstrated that in the incisor group, mean absolute marginal discrepancy calculated from mid-buccal, mesial, lingual and distal surfaces in the entire study group ranged from 23.3–73.2 µm, while in molars, mean absolute marginal discrepancy ranged from 17.1–65.3 µm. The mean absolute marginal discrepancy of incisors and molars are presented in Table 2. All the values of incisors and molars in the individual study groups were within the biologically acceptable value of 100 µm [17]. The data of incisors and molars were statistically compared; and it was found that there was no statistical significant difference (\( p \geq 0.05 \)) in the absolute marginal discrepancy. The main research hypothesis of this study was that the differences in tooth group influenced the mean absolute marginal discrepancy, but it was not supported by the current study results.

The results are not in accordance with the values in the study conducted by Bindl et al. [15] for molars 17 ± 16 µm. In this study Bindl et al. used only molar teeth and the cement used was Panavia 21Tc (Kuraray, Düsseldorf, Germany). The number of predetermined readings per sample was 8. But Boening et al. in his in vivo study reported that there were no significant differences in the mean marginal gap of anterior, premolar, and molar teeth [11]. However, the posterior crowns had a tendency to have a greater marginal gap compared to the anterior teeth, which is not in accordance with current study result. The deviations in the reported value may be explained by the differences in the test method used.
However, there is no study which has been conducted in vitro, to compare the tooth group variation affecting the marginal fit of Procera® AllCeramic.

Further interpretations of the data revealed that absolute marginal discrepancy value of incisors of all the respective groups were lower than that of the molars except for the AG group. This could be explained by the presence of larger surface area of the molar coping compared to the incisor during the static finger load of 50 N during cementation procedure.

Incisors showed highest marginal discrepancy on mid-buccal (85.4 µm) and mid-lingual (60.8 µm) surfaces when compared to the mid-mesial and mid-distal surfaces. However, for the molars mid-distal (59.8 µm) and mid-lingual (57.3 µm) surfaces had the highest marginal gap value when compared to mid-buccal and mid-mesial surfaces. The hypothesis that marginal discrepancies can be influenced by the differences in axial surface was not confirmed by the current study. This insignificance did not dismiss the possibilities of difficulties in tooth preparation and impression technique depending upon the location of tooth in the dental arch.

The results of the present study are in accordance with the findings of Sulaiman et al. [8]. In his study maxillary incisor die stone models were used and he found that the incisors had 83 ±41 µm marginal gap. However, in the same study he showed that lingual and buccal sides had a wider gap compared to the other two axial surfaces. But from the clinical perspective, chamfer finish line and impression making is more accurate on buccal or labial surfaces than the other axial surfaces and tooth preparation procedure is easier in the incisors than the molars.

A clinical study result of Kokubo et al. [15] on the marginal fit also proved that there were no differences in mean marginal gaps among the anterior, premolar and molar tooth groups and the values were 36, 32, 35 µm respectively. A similar study by Suarez et al also did not demonstrate any difference in the marginal fit values from buccal to lingual surface [24]. Deviations in the reported value may be explained by different test methods, type of tooth and luting media used in the earlier studies.

Even though, this in vitro investigation was carefully designed to simulate the clinical and laboratory condition of tooth preparation and CAD/CAM production of restoration there were some limitations to this study. For example, impression making would be more difficult in clinical scenario due to gingival retraction and presence of oral and sulcular fluid. Moreover, we have employed die stone models instead of natural tooth that eliminated the clinical situation of bonding to dentin and enamel in case of glass ionomer and resin cement group. During SEM measurement of marginal width we could not measure the absolute marginal discrepancy in horizontal direction due to limitation in SEM imaging. However, we have measured marginal width only in vertical direction, since it was proved that post cementation vertical elevation of crown from earlier studies [16, 25] and vertical marginal width is more critical for long term crown survival [22], since it exposes a wider area of the luting cement to oral fluids. Also, we have not
considered the measuring of the internal fit of the cemented coping. This requires the samples to be sectioned in mesio-distal and labio-lingual direction. This eliminates the possibilities of circumferential marginal evaluation. Finally, the small number of samples \((n = 6)\) used to compare the effect of incisors and molars teeth on the marginal adaptation can also affect the statistical analysis and also the final interpretation of the results. A future study will be planned with a larger sample size and collective investigation of marginal and internal width of Procera® AllCeram crown copings. The second part of this study was focused on finding out the effect of different luting media on the marginal discrepancy of Procera® AllCeram crown copings.

**Conclusion**

Within the limitation of this *in vitro* experiment, the following conclusion can be drawn:

- Mean absolute marginal discrepancy of Procera® AllCeram copings \((n = 6)\) were \(\text{AGI} = 37.9\, \mu\text{m}, \text{AGM} = 27\, \mu\text{m}, \text{ARI} = 44\, \mu\text{m}, \text{ARM} = 50\, \mu\text{m}, \text{AZI} = 59\, \mu\text{m}, \text{AZM} = 48\, \mu\text{m}.\)
- All the absolute marginal adaptation gap sizes were within the biologically acceptable standards for all-ceramic restorations \((100\, \mu\text{m})\).
- Incisors showed wider marginal gap on mid-buccal and mid-lingual surface, but for molars there was wider marginal gap on mid-distal and mid-lingual surfaces.
- There was no statistically significant difference \((p \geq 0.05)\), in absolute marginal discrepancy of incisor and molar Procera® AllCeram crown copings as a function of tooth group variation.

**References**


