Clinical and laboratory evaluation of CAD/CAM All-ceramic crowns
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CHAPTER 5

Precision of Two CAD/CAM Systems to Fabricate All-Ceramic Copings

Catherine C. Begazo, Irene H.A. Aartman, Albert J. Feilzer. Precision of two CAD/CAM systems to fabricate all-ceramic copings. Submitted for publication.
Abstract

Purpose: The aim of this study was to compare the design parameters; namely, accuracy of internal fit and coping thickness, of two CAD/CAM systems used for the production of all-ceramic copings with the final manufacture parameters of the produced restoration. Moreover, the influence of the scanning and the production methods on the accuracy of the design parameters of the produced restoration was evaluated.

Materials and Methods: A master metal die prepared for an ordinary all-ceramic restoration was the pattern to create 40 epoxy-working dies. Under manufacturer’s conditions 40 (20 Cicero and 20 Procera) copings were produced. Two scanning procedures were followed to scan the dies: scanning the master die once and scanning the epoxy-working dies one by one to produce the three-dimensional images of the preparations. Independently, the two CAD/CAM systems selected produced the aluminum oxide copings at their manufacture center. The copings were cemented (Panavia F) on their respective epoxy-working die and after that sectioned in three horizontal planes creating three different slices at top, middle, and bottom. The slices were analyzed under scanning electron microscopy. The cement space and the coping thickness were measured at Mesial, Distal, Buccal, and Lingual in each slice.

Results and conclusions: Cicero and Procera systems could produce copings with the pre-established coping thickness. The Cicero system could produce cement spaces as pre-established within acceptable borders, while the Procera system creates significantly thicker cement spaces. The scanning procedure was of influence for the Cicero system.
Introduction

The use of ceramic materials is attractive because of their aesthetics and biocompatibility characteristics. Nevertheless, the indication area of all-ceramic restorations is limited to single crowns in low stress bearing areas, because of their lack of strength. Amongst the different factors that influence the longevity of all-ceramic crowns, the precise internal fit of the crown on the prepared tooth is of importance as a strong linear correlation was shown between the fit of the crowns and their compressive strengths. The cement functions as intermediate layer for the distribution of biting forces onto the tooth. Qualtrough and Piddock\(^1\) showed that a close fit of the crown results in higher compressive strength of the tooth restoration complex. However, not only a close fit, but also the overall accuracy of fit is important, since correct seating may help to increase restoration longevity by offering improved mechanical support\(^2\).

A range of methods exists for determination of the fitting accuracy of all-ceramic restorations, with each technique providing limited information. Colored impression materials have been used to judge the fit of crowns both in the clinic and the dental laboratory. Reflection photometry, a non-destructive three-dimensional method, appears to be a valid technique for the quantitative mapping of crown fit\(^3\). Eisenburger\(^4\) described another non-destructive radiographic method, which makes use of X-ray inspection. This method allows checking the quality of dental crowns and bridges by detecting many types of imperfections, including the fit. Mechanical techniques\(^5\--\^7\) often proved to be insufficient in detecting areas with too small dimension. Nakamura \textit{et al.}\(^8\) described the use of a profile projector (V-12 Nikon) to study the marginal and internal fit of aluminum copings. There exists no standard method for either the assessment of marginal adaptation or the overall accuracy of fit\(^1\).

To overcome the intrinsic weakness of all-ceramic restorations, new all-ceramic restorative systems based on CAD/CAM production methods are developed to produce strong all-ceramic copings (based on aluminum oxide or zirconium oxide), which can be covered with conventional veneering porcelain. The production of this type of restorations is based on new methods that probably may have an influence on the final accuracy of fit. Generally two production approaches are applied, both
based on the firing of a coping on a heat resistant investment die. These methods differ in the choice of the thermal expansion behavior of the die material (Table 1).

The Proceras system of Nobelpharma is based on a die material that shrinks during the firing process to compensate the sintering shrinkage of the aluminum oxide coping that is fired on it. As a consequence, the die is larger than the original preparation.\textsuperscript{9,17} The Cicero system of Elephant Dental Industries is sintered on an investment die that is principally equal in size compared to the original preparation. Here the aluminum oxide based glass ceramic coping material can only shrink to the die during sintering. After the sintering process, the inner shape of the coping has equal dimensions as the original die.\textsuperscript{18-21} For that reason, it was hypothesized in this study that the production method of the Cicero system may lead to better fitting accuracy than the method used for the production of Proceras crowns.

However, the accuracy of fit of Proceras and Cicero copings may not only be influenced by the way of manufacturing but also by the scanning and design phase of the CAD/CAM procedure. For both methods a gypsum die of the tooth preparation has to be scanned. Proceras makes use of a contact scanner with a sapphire ball of 2.5 mm diameter; Cicero uses a laser line scan. The first method does not enable the determination of sharp inner preparation angles and will only scan the extrusions of rough surfaces. Laser scanning will reproduce more surface irregularities when compared to a contact scanner. In the design phase a coping is designed according to parameters pre-established by the manufacturer. At this step the ‘design values’ of the cement space and the coping thickness are decided upon. However, most manufacturers have preset these design parameters to reduce the chance on premature clinical failing of the restoration. Moreover, corrections of possible shortcomings of the later manufacturing phase can be handled. All phases of the CAD/CAM process do have a certain degree of inaccurateness due the different kind of limiting factors, (e.g. scanner resolution, wear of manufacturing tools etc.). Some of these factors may have an intensifying effect on each other while others may have an attenuating effect. Both influences and the interaction of each other are hard to predict. As a consequence the questions remaining are: do we get what was designed and what are the most determining factors in a dental CAD/CAM production process?

Therefore, the aim of this study was to compare the design parameters, namely, accuracy of internal fit and coping thickness, of two CAD/CAM systems used for the production of all-ceramic copings with the same parameters of the produced
restoration. Moreover the influence of the scanning and the production methods on the accuracy of these parameters of the produced restoration was evaluated.

Table 1. Characteristics of the CAD/CAM systems selected for this study.

<table>
<thead>
<tr>
<th></th>
<th>CICERO</th>
<th>Procera AllCeram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determination of the finish line</td>
<td>The area that does not represent the preparation is blackened.</td>
<td>The die is ditched prior to scanning under the finish line.</td>
</tr>
<tr>
<td>Scanning Procedure</td>
<td>Fast laser-stripe with 0.05 mm scans lines.</td>
<td>A sapphire ball of 2.5 mm diameter contacts the die with a pressure of 20 g.</td>
</tr>
<tr>
<td>Production of the working model</td>
<td>A replica of the preparation is produced in a refractory block without any enlargement.</td>
<td>A replica of the preparation is produced with an enlargement between 12% and 20%.</td>
</tr>
<tr>
<td>Composition of the coping</td>
<td>66% Al₂O₃, 20% SiO₂, 14% rest. 99.9% Al₂O₃</td>
<td>The scan and CAD procedures are made at a dental lab that is equipped with the Procera scan anywhere. The information is sent via modem to the production station in Sweden.</td>
</tr>
<tr>
<td>Place of the scanning and CAD/CAM procedures</td>
<td>The process of coping production is made at one specific place, the Central Cicero lab in the Netherlands.</td>
<td>A default of 600 µm is customary. The relief space for the luting agent is automatically established by a computer algorithm (50 – 60 µm).</td>
</tr>
<tr>
<td>Coping thickness (data excluding the margin)</td>
<td>For this study 600 µm was selected.</td>
<td>For this study 140 µm was selected.</td>
</tr>
<tr>
<td>Cement space (data excluding the margin)</td>
<td>For this study 140 µm was selected.</td>
<td>For this study 140 µm was selected.</td>
</tr>
</tbody>
</table>

Materials and Methods

A master die of a right maxillary central incisor tooth prepared for an ordinary all-ceramic crown was made of a non-precious alloy (Wiron 99, Bego, Germany). The master die was impressed four times with addition of silicone based elastomeric impression material (Provil novo, Heraeus Kulzer, Germany). Each impression was poured with a resin precision model material (Quartz Die, Zhermack, Italy) 10 times to create 40 epoxy-working dies. To avoid the formation of voids, the impressions were kept under pressure for a period of one hour. For each epoxy-working die an aluminum oxide ceramic coping was produced according to two different scanning
procedures and two different production procedures. Therefore the epoxy-working
dies were divided into four groups of 10 copings each (Table 2). For Group 1 and 2
the master metal die was scanned once: Group 1 with the laser line scanner for the
fabrication of Cicero copings and Group 2 with the Procera contact scanner for the
fabrication of Procera copings. For Group 3 and 4 not the master metal die but each
epoxy-working die were scanned: Group 3 for the production of Cicero copings and
Group 4 for the production of Procera copings.

Table 2. Distribution of the copings fabricated per scanning procedure and per manufacturer.

<table>
<thead>
<tr>
<th></th>
<th>Procedure 1</th>
<th>Procedure 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Master metal die</td>
<td>Epoxy-working die</td>
<td></td>
</tr>
<tr>
<td>CICERO</td>
<td>Group I (n = 10)</td>
<td>Group III (n = 10)</td>
<td>20</td>
</tr>
<tr>
<td>Procera AllCeram</td>
<td>Group II (n = 10)</td>
<td>Group IV (n = 10)</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>20</td>
<td>40</td>
</tr>
</tbody>
</table>

The three-dimensional images obtained were used to design the copings
according to the specifications of the manufacturer as presented in Table 3.
Therefore for Group 1 and 2 respectively, one design was used to fabricate ten
copings for each group; while for Group 3 and 4 respectively each scan was used to
design and produce a new individual designed and manufactured coping.

Table 3. Design specifications (μm)* used for the fabrication of the CAD/CAM copings.

<table>
<thead>
<tr>
<th></th>
<th>Cement space (CS)*</th>
<th>Coping thickness (CT)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CICERO</td>
<td>140</td>
<td>600</td>
</tr>
<tr>
<td>Procera AllCeram</td>
<td>50-60</td>
<td>600</td>
</tr>
</tbody>
</table>

Cementation
After checking the fit of each coping visually, they were cemented on their respective
epoxy-working die. No correction was made to the inner surfaces of the copings. A
dual cure dental luting cement (Panavia F) was used.
Measurement of the internal fit

Each of the specimens (cemented coping on the epoxy-working die) was embedded in PMMA resin; thereafter it was sectioned (Isomet 1000, Buehler Ltd, Lake Bluff, IL, USA) on three horizontal parallels planes (top, middle and bottom) creating three slices (Figure 1). The cement space and the coping thickness at four locations: Mesial, Distal, Buccal and Lingual (Figure 2) were measured on images (100x to 180x magnification) obtained with a scanning electron microscope (Phillips SEM XL 20, Eindhoven, NL) by using the measuring software of the SEM. All measurements were repeated 3 times by the same operator. The mean values (M) and standard deviations (SD) were calculated for cement space and coping thickness at each slice (top, middle and bottom) at four measured points: Mesial, Distal, Buccal and Lingual. These four measured points were averaged, resulting in three values for cement space and three for coping thickness (top, middle and bottom). Due to the preparation angle and the sectioning angle being different, the data obtained were slightly larger than the actual tangential values, therefore the data were corrected from this error.

Figure 1. Graphic representation of a specimen (cemented coping on the epoxy-working die). The arrows show the three levels (top, middle and bottom) where each specimen was sectioned. The cement space is represented in black and the coping thickness in dark gray color.
Statistical analysis
The two scanning methods were compared with respect to cement space and coping thickness using independent sample t-tests. A significance level of $\alpha=0.05$ was used. In addition, one-sample t-tests were used to determine whether cement space and coping thickness fulfilled the design specifications as shown in Table 3. Because of the high number of tests, a significance level of $\alpha=0.01$ was used here.

Figure 2. The cement space and the coping thickness were measured at four points of each slice (Mesial, Distal, Buccal and Lingual) under the SEM. In the study, they were measured on images at 100x to 180x magnification. For reasons of clarity it is shown an overall view instead of four separate images.

Results
The results are reported in Table 4 and graphically presented in Figures 3 and 4.

Coping thickness
The frequencies of the thickness data showed for the Procera copings a bimodal distribution that was clearly related to the time of fabrication of the copings. The Procera copings were produced in two time periods with a year in between. The first copings made on the base of a scan of the master metal and epoxy-working dies were significantly thinner compared to the copings made in the second period ($p<0.01$). Therefore the Procera copings made at the two times were treated separately. For Cicero and Procera at time 1, there were no statistically significant
Precision of Two CAD/CAM Systems

differences between the master metal die and the epoxy-working die for top, middle and bottom values. For Procera at time 2, the thickness at the top was higher \((t=2.89, df=6, p=0.028)\) for the master metal die \((M=577\mu m, SD=9.1)\) than for the epoxy-working die \((M=554.3\mu m, SD=14.0)\).

The coping thickness of all Cicero copings did not differ statistically significant from the design specification of 600 \(\mu m\). For Procera at time 1, all copings were thinner than 600 \(\mu m\) \((p<0.001)\), and at time 2, only the copings based on a scan of the master metal die were thinner than 600 \(\mu m\) \((p<0.005)\).

**Table 4.** Average values \((\mu m)\) at three horizontal planes (top, middle and bottom) \((\mu m)\). SD is shown in parenthesis.

<table>
<thead>
<tr>
<th>Coping Thickness (CT)</th>
<th>Procera AllCeram</th>
<th>CICERO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metal/time 1</td>
<td>Metal</td>
</tr>
<tr>
<td>Top</td>
<td>356.1 (20.0)</td>
<td>577.5 (9.1)</td>
</tr>
<tr>
<td>Middle</td>
<td>348.9 (7.7)</td>
<td>566.5 (5.5)</td>
</tr>
<tr>
<td>Bottom</td>
<td>381.4 (33.8)</td>
<td>565.6 (10.5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cement Space (CS)</th>
<th>Procera AllCeram</th>
<th>CICERO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metal/time 1</td>
<td>Metal</td>
</tr>
<tr>
<td>Top</td>
<td>162.2 (29.8)</td>
<td>126.2 (15.9)</td>
</tr>
<tr>
<td>Middle</td>
<td>141.0 (10.5)</td>
<td>119.6 (16.1)</td>
</tr>
<tr>
<td>Bottom</td>
<td>143.2 (20.2)</td>
<td>117.0 (15.6)</td>
</tr>
</tbody>
</table>

**Cement Space**

For Procera at time 1 and 2, there were no statistically significant differences between the master metal die and epoxy-working die for top, middle and bottom values. For Cicero, the cement space at the middle and base were higher \((t=2.97, df=18, p=0.008\) and \(t=2.31, df=18, p=0.033\) respectively) for the master metal die \((M=135.0\mu m, SD=26.0\) and \(M=126.0\mu m, SD=26.9\) than for the epoxy-working die \((M=106.2\mu m, SD=16.4\) and \(M=99.4\mu m, SD=24.6\).

The cement space thickness of the Procera copings at time 1 were all higher than the design specification of 60 \(\mu m\) \((p\) varies from 0.022-0.000). At time 2, they were higher than 60 \(\mu m\) for the master metal die \((p=0.001)\), and also in the middle part for the epoxy-working die \((p=0.007)\). For Cicero, the cement space thickness for the master
metal die did not differ from the specification of the manufacturer (140 µm). However, for the epoxy-working die, the cement space at the middle and base were lower than 140 µm (p=0.001). For both systems the average cement space thickness was in the range of 120 - 130 µm.

Discussion

Based on the computerization of laboratory procedures, one of the often claimed advantages of CAD/CAM systems is a high precision and reproducibility of production results. The different dental systems available in the market at the moment emphasize their capability to produce copings with a shape and size comparable to their CAD design. Nevertheless, the different phases of the CAD/CAM production process may have an influence on the accuracy of the final product. In spite of the fact that in some cases the deficiencies of the different phases of the CAD/CAM process can be compensated with proper software design, it may be expected that the weakest part in the process chain will be the limiting factor of the final product quality. This study was designed to assess how precise these two CAD/CAM systems are and to evaluate whether the scan, the design or the manufacturing phase is the weakest chain in the process. In other words, ‘Is what you designed what you get?’ and if not; ‘which part of the CAD/CAM process is the most critical?’ The results show that in reality it is difficult to meet the preset design parameters. Moreover, it may be advisable to define the ‘quality’ of a CAD/CAM system by specifying the design parameters by ranges instead of by exact values.

It was surprising to find differences in coping thickness between Procera copings fabricated for the pilot study and the copings fabricated one year later. It may be explained by the fact that during the Procera process the scanning procedure was carried out in another place as the design and manufacturing procedures, so it took place under the supervision of different dental technicians.

Another finding concerning the Procera system was that the resulting copings had a significantly bigger cement space. This may be explained by two possible factors: First, the use of an enlargement of the coping model ‘between 12 and 20%’. It seems that this interval does not give the guarantee of control technology. Secondly, also remarked by Boening et al.\textsuperscript{17}, with the use of a sapphire ball of 2.5 mm of diameter, it was theoretically unable to locate irregularities or grooves with radii smaller than 1.25 mm in the scanning process. However it is also possible that
the information received by the dental lab that made the Scanning and CAD procedures were not the valid data.

However, it should be mentioned that the marginal gap dimension was not part of this study. The large cement space found in this study does not mean that the marginal gap might not be satisfactory as the relatively loose fit copings can easily fit into place, which may result in small marginal cement spaces.

CICERO copings showed to be within the limits of acceptance in both parameters evaluated; but they showed significant differences between the Scanning procedures. Therefore, it might be concluded that with this system the design and scanning can be easily reproduced with comparable results. Both systems showed a poorer behavior on the top part of the preparation. However this incident was not unexpected; the fit of three different all-ceramic crowns has been reported to have a good gap of 35 to 63\(\mu\)m, but the gap at the incisal edge was more than 100\(\mu\)m in all three types. This suggests that the adaptation at the incisal edge is inferior to that at the marginal area\(^{22-24}\). Even when this study was done under standardized conditions, cutting the first slice precisely at 2 mm from the upper border of the coping was a challenging procedure.

Other studies showed different internal fit. May et al.\(^{13}\) found that Procera copings have an internal fit between 49 to 63 \(\mu\)m for premolar and molars. The internal gap for a Cerec 2 anterior crown has been reported as 141 ± 21 \(\mu\)m\(^{25}\). Also Mou et al.\(^{26}\) and Sjögren\(^{27}\) found that the average internal gap of Cerec crowns was approximately 100 to 200 \(\mu\)m, with the widest gap located at the distal surface. Thus, internal fit remains the weak point of Cerec restorations because the internal configurations of these restorations are based on images scanned with the optical Cerec camera based system, and the distal shadow problem seems unavoidable. Leinfelder et al.\(^{28}\) suggested that the interfacial gap for resinous cement should not exceed 100 \(\mu\)m since poorly fitting restorations are supported mainly by the luting cement and their longevity might be jeopardized. Grey et al.\(^{29}\) found the mean cement space thickness of In-Ceram crowns to be 123 \(\mu\)m. Nevertheless, these different results are in contrast with the American Dental Associations (ADA) Specification No. 8\(^{30}\), which states that the luting cement film thickness for a crown restoration should be no more than 25 \(\mu\)m when using a Type I luting agent, or 40 \(\mu\)m with a Type II luting agent. However, this requirement might be outdated as it was defined in an era where dentists were using the soluble zinc oxyphosphate cements. Thin cement spaces increased the longevity of the cements as it decreased the loss
of cement by dissolution. Nowadays, adhesive cements are available that show a low dissolution behavior which makes thicker cement layers for the perspective of solubility acceptable. Tuntiprawon and Wilson\textsuperscript{31} found that all-ceramic crowns with smaller gap dimensions at the axial wall and marginal openings demonstrated the best compressive strengths of luted crowns. However, the preparation shape could also be an influential factor in the internal fit. It is currently unknown what type of preparation design is necessary to fabricate crowns that provide good fit on both the inner surface and at the margin\textsuperscript{8}. Finally the probability of bond failure due to uneven cement space remains unknown and deserves further investigation.

Conclusions

Forty all-ceramic CAD/CAM copings were fabricated according to manufacturer conditions and following two scanning procedures; the cement space and the coping thickness were measured. Within the conditions and limitations of this study, the following conclusions may be drawn:

- CICERO system manufactured copings with a coping thickness and cement space as designed.
- Procera system manufactured copings with a coping thickness as designed but with too large cement space.
- The Scanning procedure was a factor of influence for Cicero system.

References


