Clinical and laboratory evaluation of CAD/CAM All-ceramic crowns
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CHAPTER 3

One-year Clinical Evaluation of an All-Ceramic CAD/CAM Crown System

Catherine C. Begazo, Jef M. van der Zel, Albert J. Feilzer, Marinus A.J. van Waas. One-year clinical evaluation of an all-ceramic CAD/CAM crown system. Submitted for publication.
Abstract

Purpose: In this retrospective study the clinical performance of all-ceramic crowns made with CICERO CAD/CAM copings was evaluated.

Materials and Methods: 70 all-ceramic crowns were fabricated for 55 patients (47 women and 8 men). Crowns were made for the anterior and posterior regions. A general dental practitioner treated all patients and the CAD/CAM copings were veneered with aesthetic porcelain by one dental technician. A clinician not involved in the crown treatment procedure evaluated all crowns one year after the insertion. Crowns were evaluated using the modified California Dental Association's quality assessment system. For color evaluation the crowns were divided in 3 areas (occlusal, buccal and cervical).

Results: 2 crowns showed chipping of the veneering porcelain and were replaced. With respect to marginal integrity, 5% of the sample presented a disto-lingual gap. The anatomic form was scored excellent (alpha) in all cases; no evidence of attrition was found. For the occlusion criteria, the results show acceptable contacts in the different jaw movements evaluated. No caries contiguous to the crowns was found. The color was considered excellent (alpha) for occlusal and buccal areas. At the cervical area, shining through of the core could be observed in 70% of the crowns due to too high transparency of the veneering porcelain.

Conclusion: The clinical evaluation supported the hypothesis that the quality of all-ceramic crowns based on CICERO CAD/CAM aluminum oxide copings are applicable to all areas of the mouth during the first year of use.
Introduction

Over the years complete crown restorative systems with aesthetic properties have made an enormous evolution. In the late 19th century the ceramic crown was introduced, which exhibited good aesthetic properties. The ceramic materials used at that time showed, however, too low fracture resistance especially when used for posterior restorations. In the middle of the last century the metal-ceramic crown system was introduced. The high strength metal substructure improves the fracture resistance but does not duplicate the inherent translucency of natural teeth. Not just for aesthetic reasons an effort was made to develop alternatives for the opaque metal substructure.

Precious dental metal alloys are costly, while low-priced non-precious metal alloys show a high biocompatibility risk. When metal alloys are not exactly treated in accordance with the manufacturer’s instructions, the phases of the alloy may separate during cooling after casting, resulting in a lower corrosion resistance and therefore a decreased biocompatibility. Ceramics are highly biocompatible and show advantageous characteristics with regard to color, stability and thermal conductivity. Unfortunately, most ceramics are brittle and show low fracture toughness. Where the metal substructure can be worked out thin, high strength ceramic cores need a relative high minimal thickness. Even for high strength alumina systems, failures induced by fracture are often mentioned in literature. As a consequence all-ceramic systems with improved material properties are developed considering the need of greater strength.

The production process of a ceramic crown, however, consists of complicated procedures consisting of many steps. As a result the risk of introducing voids is relatively high, making them prone to fracture. Replacing manually executed procedures by automated procedures, as happens in CAD/CAM systems, may have a beneficial effect on the material properties. The automated fabrication procedures may increase the homogeneity of ceramic restorations and therefore increase the chance of clinical success.

In 1989 Nobel Biocare brought the Procera CAD/CAM system on the market for the fabrication of aluminum oxide copings as base for all-ceramic crowns. For this system relatively good clinical results are reported.
platform for Computer-Integrated Ceramic Reconstruction (CICERO) for the fabrication of all-ceramic restorations with consecutive layers of a shaded high-strength aluminum oxide core material. The method offers the advantage of transferring parts of restorations without using waxing-up, investing and casting. It claims to produce restorations with high precision and superior mechanical properties and has the potential to create an occlusal surface by CAD/CAM that fits into occlusion as well as into articulation.¹⁴ ¹⁵

As a first step in the commercial introduction of the whole system, aluminum oxide copings made by CAD/CAM in a central laboratory and veneered with aesthetic ceramic were introduced. However, no clinical trials on this system were carried out to evaluate longevity of restorations made with CAD/CAM technology of Elephant Dental BV, for this reason a study was started to evaluate the clinical performance over a one-year period producing crowns with copings made by this CAD/CAM system. It was hypothesized that the quality of all-ceramic crowns based on aluminum oxide copings produced by an automated fabrication process (CAD/CAM) are applicable to all areas of the mouth.

Materials and Methods

A general dental practitioner was solicited to use the new CICERO technology for crowns restorations on his patients. Fifty-five patients (47 women and 8 men) with a mean age of 38 years (range 19 years to 66 years) received 1 or 2 artificial crowns. All of them were informed about the ongoing research and signed a consent letter. In total seventy crowns were made in both arches. The distribution of restored teeth is presented in Table 1.

Table 1. Distribution of CAD/CAM crowns involved on this clinical evaluation.

<table>
<thead>
<tr>
<th></th>
<th>Maxilla</th>
<th>Mandible</th>
<th>Total number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisors</td>
<td>38</td>
<td>32</td>
<td>70</td>
</tr>
<tr>
<td>Canines</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Premolars</td>
<td>16</td>
<td>7</td>
<td>23</td>
</tr>
<tr>
<td>Molars</td>
<td>16</td>
<td>25</td>
<td>41</td>
</tr>
</tbody>
</table>
The general dental practitioner made the preparations according to the preparation guidelines recommended by the manufacturer.\textsuperscript{16} CICERO preparation guidelines prescribe a shoulder angle between 90 - 130 degrees, a shoulder width between 0.7 - 1.2 mm and an occlusal reduction between 1.5 - 2.0 mm with encompassing rounded inner edges. The outline must be clearly recognizable, which makes it possible automatically to define the margins of the preparation using the software of the system. A standard set of burs was recommended (for separation: Komet 850314014 (Brasseler GmbH, BRD); for palatal contouring: Komet 899314027 (rough) and 8899314027 (fine); for undeeep chamfer preparation: Komet 881314010 (rough, r=0.5 mm) and 8881314012 (fine, r=0.6 mm); for deep chamfer preparation: Komet 881314014 (rough, r=0.7 mm) and 8881314016 (fine, r=0.8 mm)). Once the tooth preparation was completed, impressions were made, using Impregum (3M-Espe, Seefeld, Germany) and poured in stone (Fuji Rock, GC Japan). All crowns were fabricated in accordance with the standard procedure for CICERO all-ceramic crowns.

The CAD/CAM procedure is extensively described by Van der Zel et al\textsuperscript{14} for this reason it will only be summarized in this article: Before the scanning procedure starts, the area of the laboratory model that is not suited for the restoration design and does not represent the preparation itself is blackened to create a high contrast for unambiguous scanning of the preparation. Subsequently the laboratory model of the preparation is scanned with a laser scanner (Micromeasure GmbH, Wetzlar, Germany). In this way an image of the 3-dimensional geometry of the die was obtained. In the CAD module of the system, an aluminum oxide coping was designed with a thickness of approximately 0.6 to 0.7 mm throughout to provide a substructure with optimal support for the veneering porcelain. Factory-standardized preformed refractory blocks (ECO Ceramics B.V., Beverwijk, the Netherlands) were fixed in a high-precision device in the milling machine. A copy of the preparation, which includes a non-homogenous designed cement space, was milled of the preformed refractory blocks using standard diamond preparation tools. The following cutting tools are used: a diamond cylinder of 5.3 mm diameter, a diamond rounded disk of 9.3 mm diameter, and a diamond pointed tool of 0.9 mm. On this die, slurry of aluminum oxide reinforced glass ceramic (Synthoceram, Elephant Dental B.V., the Netherlands) was placed. After the slurry had dried replacing the refractory block again in the milling device created the shape of the coping. Hereafter the coping was fired on the refractory block. After firing and cooling down, the refractory material was
removed by sandblasting. Checking the fit on the laboratory model and measuring the thickness was part of a final check of the copings. The dental technician retrieved the coping by mail to execute the veneering procedure using special porcelain (Sintagon, Elephant Dental B.V., the Netherlands) according to the color selection made by the general practitioner. After checking the crowns in the mouth, they were cemented (Poly F, Dentsply, USA).

After a one-year period, a dentist not involved in the patient's treatment, evaluated the crowns by means of a clinical evaluation form, a radiographic evaluation, a subjective questionnaire and the patient's files. Furthermore, intraoral photographs of the crown in the occlusal and buccal views were taken and alginate impressions were made to fabricate stone models of the dentition with the crown in place. The photographs and stone models were used as documentation.

The clinical evaluation involved the California Dental Association (CDA) criteria with one modification: In order to provide information about color of the crowns in detail each crown was divided in three areas: buccal, cervical and occlusal areas. Each area was evaluated separately.

The radiographic evaluation was based on the periapical x-rays taken from the restored tooth. Two evaluators, working independently, compared and assessed each x-ray. When the ratings differed, the evaluators resolved their disagreement by joint examination. The items of the evaluation were: tooth endodontically treated 'yes' or 'no', tooth reconstructed by endodontic post 'yes' or 'no'. The periapical condition was assessed using ridit success/failure analysis (Bross 1958).

At last every patient was requested to fill in a questionnaire to reveal his/her opinion about the crowns. The questionnaire involved questions about general satisfaction, color, shape and comfort. These items were scored 1 to 5. Questions about sensibility to cold and warm and about pain were asked too. These items were scored 1 to 4.

Results

All patients were seen after 12 months: all inserted crowns were in function. The clinical evaluation shows the following results according to the CDA criteria: Anatomic shape was considered 'excellent' (alpha) in 98% of the cases. Two crowns showed chipping of the porcelain, for which reason they were asked to be replaced.
Marginal adaptation assessment showed 3 (5%) crowns with a gap at the disto-lingual area. Margin discoloration was scored 100% 'excellent' (alpha). No caries contiguous to the crown was found. Color of the crowns was 100% 'excellent' (alpha) at buccal and occlusal areas. The cervical margin was assessed too bright in 70% of the crowns.

All crowns, except two, were radiologically evaluated (Table 2). Two female patients were pregnant at the moment of the evaluation, for this reason an x-ray was not taken. Before the cementation of the CAD/CAM crowns involved in this study, 34 (50%) teeth were endodontically treated and 28 (41%) teeth were reconstructed by endodontic post. 59 (87%) teeth were considered with optimal periapical conditions. 9 teeth were found not in optimal periapical conditions, 6 of them presented a round periapical radiolucency with less than 2 mm diameter, 2 of them with a periapical radiolucency larger than 2 mm diameter. One molar case was considered not optimal because the mesial root was not completely filled.

Table 3 shows the results of the evaluation of the questionnaire. All the patients reported to be satisfied or very satisfied with the crowns. Color was also considered (very) satisfactory in general, 4 did not have an opinion and 3 were dissatisfied. The shape of the crown was considered satisfactory for most of the patients, 8 did not have an opinion and one patient was unsatisfied. Also comfort was considered (very) satisfactory; one patient was unsatisfied. The patient's opinion about sensibility to cold and warm coming from the teeth involved is shown in Table 4. In general the patients reported no sensibility to cold and warmth and no pain, one patient reported a very sensible tooth.

**Table 2.** Radiographic evaluation. *Two women were pregnant at the date of the evaluation, for that reason x-rays were not made.*

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>*Total number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth endodontically treated</td>
<td>34</td>
<td>34</td>
<td>68</td>
</tr>
<tr>
<td>Tooth reconstructed by endodontic post</td>
<td>28</td>
<td>40</td>
<td>68</td>
</tr>
<tr>
<td>Tooth with optimal periapical condition</td>
<td>59</td>
<td>9</td>
<td>68</td>
</tr>
</tbody>
</table>
Table 3. Patient’s opinion about satisfaction, color, form and comfort (N=70). 1 = very satisfied, 2 = satisfied, 3 = no opinion, 4 = no satisfied, 5 = very unsatisfied.

<table>
<thead>
<tr>
<th>General Satisfaction</th>
<th>Color</th>
<th>Form</th>
<th>Comfort</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>43</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>40</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4. Patient’s opinion of tooth sensitivity (N = 70) 1 = no sensitivity/pain, 2 = a bit of sensitivity/pain, 3 = no opinion, 4 = tooth sensible/painful.

<table>
<thead>
<tr>
<th>Sensibility to cold and/or warm</th>
<th>Painful</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Discussion

The one-year survival rate of the aluminum oxide copings made with the CICERO CAD/CAM system was 100%. Two crowns however showed chipping on the veneering porcelain. As the copings were still intact these crowns were not registered as total failures. Chipping can occur for different reasons, i.e. strong occlusal contacts (bruxism), wrong manipulation of the porcelain in the laboratory by the dental technician, composition of the porcelain itself, etc. It was not possible to detect the reason of chipping for both cases. However, in the long-term these crowns may be more prone to fracture. Therefore extended research is necessary to reveal the effect of strong CAD/CAM copings on manually finalized all-ceramic crowns. As the CAD/CAM system used in this study is aimed at the fabrication of a whole layered all-ceramic crown, in the near future the veneering layers may be fabricated automatically too. In that case, the veneering ceramic will be more homogeneous and less prone to manipulation errors increasing the chance for clinical success.

The CAD/CAM procedure used in this study to make aluminum oxide copings proved to give aesthetically acceptable restorations using the CDA criteria. The CDA
criteri however, prescribe to evaluate color of a restoration at a distance of 18 inches from the mouth, mentioned 'conversation distance'. If the evaluation has been done within this criterion, 100 % of the crowns would be evaluated as 'excellent' (alpha) and the results do not differ from other clinical studies under the same conditions.\textsuperscript{13,21} Using that way of evaluation, it would be impossible to find out that in general the crowns were too bright in the cervical area (70% mismatch). This incidence justifies the decision to evaluate the color of the crowns more in detail, dividing them in three areas: occlusal, buccal and cervical. This brightness occurs due to the shining of the bright aluminum oxide coping through the porcelain. This can be attributed to a lack of experience with the shading of the coping, a lack of space available for the porcelain due to tooth preparation errors etc. It is recommended to prepare a large space for the ceramic material at the margin and/or to use a thin layer of opaque dentine to mask out the bright color of the underlying coping. A change of the copings' design may be an alternative solution to improve the marginal aesthetic of the crowns. Considering the high strength of the coping it may not be necessary to extend the margin to the shoulder. A design where the coping margin ends for instance 0.5 mm above the shoulder may result in a sufficiently strong construction. However, the addition of the veneering porcelain on the shoulder in a manual way will be difficult. In the case that the whole crown is made automatically, which is the case of CICERO, it will not create any problem.

The results obtained in this study justify further clinical studies of crowns produced with CICERO CAD/CAM system.

Conclusio

One-year clinical evaluation supported the hypothesis that the quality of all-ceramic crowns based on CAD/CAM aluminum oxide copings are applicable to all areas of the mouth. To overcome the aesthetic shortcomings at the margin, an alternative coping design has to be evaluated further.
References


