Clinical and laboratory evaluation of CAD/CAM All-ceramic crowns
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CHAPTER 2

Effectiveness of Preparation Guidelines for an All-Ceramic Restorative System

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Abstract

Purpose: The aim of this study was to evaluate in a clinical field-test the ability of the implementation of manufacturer’s preparation guidelines for the all-ceramic CICERO system.

Materials and Methods: General dental practitioners from the northwest region of the Netherlands were asked to make complete crowns preparations in accordance with the specific guidelines of the CICERO system. A sample of 3446 tooth preparations was evaluated with regard to shoulder angle, shoulder width and top angle. They were quantified using a special software program. The results were compared with criteria defined in the manufacturer’s preparation guidelines.

Results: On a multivariate level all (main and interaction) effects were significant (P<0.05) excluding the interaction effect of the location of measurement on the tooth by the upper or lower jaw. The value of the shoulder angle showed a strong relation with the tooth position in the mouth as well as with the location of measurement on the tooth. The shoulder width in the lower jaw was significantly smaller when compared to the width in the upper jaw. The shoulder width of the lower incisors was the smallest and also showed the largest variance per tooth. On group level (incisor, cuspid, premolar, molar), except for the shoulder width of the lower incisors, the average values of all preparation parameter showed to be within the borders as defined in the preparation guidelines of the manufacturer. However, on an individual tooth level nearly all preparations showed to have one or more locations with imperfections.

Conclusion: General dental practitioners are able to follow recommended guidelines for the shoulder preparation. Deviation from the guidelines are mainly caused by anatomical and accessibility restrictions.
Introduction

Increasing patient expectations regarding the appearance of restorations test the ingenuity and skill of the dental team. Due to the aesthetic limitations of metal-ceramic restorations, caused by the non-translucent metal base, the desire to use metal-free restorative materials has increased the demand for all-ceramic restorations for anterior and posterior regions.\textsuperscript{1,2,3,4} In spite of the fact that all-ceramic materials have advantageous characteristics such as biocompatibility, color stability and low thermal conductivity, the popularity of all-ceramic restorations is impeded by their lack of fracture resistance. In contrast to metal ceramic crowns, all-ceramic crowns are prone to cracking due to local stresses, since a ductile stress relief mechanism is absent.

To overcome the lack of fracture resistance several high-strength all-ceramic systems have been introduced in the market during the last decades. Nevertheless, this often resulted in disappointing experiences. A recent clinical long-term study confirmed that there is a significant risk of failure when placing restorations completely made of Dicor\textsuperscript{®} (Dentsply, York, Pennsylvania, USA).\textsuperscript{5,6,7} Cerestore\textsuperscript{®} (Johnson & Johnson, New Brunswick, NJ, USA) and Hi-Ceram\textsuperscript{®} (Vita Zahnfabrik, Bad Säckingen, Germany) showed a high incidence of molar fractures in the first 2 years after placement as well.\textsuperscript{8} Newer systems like In-Ceram\textsuperscript{®} (Vita Zahnfabrik, Bad Sackingen, Germany) may still fracture when applied in stress-bearing regions. A prospective clinical study conducted in a private practice showed that failure tended to be more common for premolar and molar In-Ceram\textsuperscript{®} crowns than for anterior crowns.\textsuperscript{9} One has to realize that it is not only the fracture resistance of the material selected that determines the longevity of all-ceramic restorations. All-ceramic restorations should have a minimum thickness and an appropriate shape to facilitate a favorable stress distribution and a stress-transfer to the supporting teeth.\textsuperscript{10}

It has been proven that the preparation design dictates the shape and bulk of the restoration; consequently it has a considerable influence on the clinical behavior and longevity of the fixed prosthodontic restoration.\textsuperscript{11,12,13} However, not only the material but also many other factors such as aesthetics, pulp vitality and access influence the decision of the dentist to choose a particular preparation design. Therefore the dentist is a significant factor in the final result of the tooth preparation.\textsuperscript{14}
Nevertheless, manufacturers of all-ceramic systems require from the dentist to follow valid principles of design according to the needs of the system selected.

Manufacturers of all-ceramic systems have developed different preparation guidelines according to their necessities. Since 1988 a research group in the Netherlands has been working on the development of a new dental CAD/CAM platform for Computer-Integrated Ceramic Reconstruction (CICERO) for the fabrication of all-ceramic restorations with consecutive layers of a shaded high-strength aluminum-based core material. This system includes specific tooth preparation guidelines for the dentist who decides to make use of it. However, it is questionable whether the dentist can follow preparation guidelines in all cases. It was hypothesized that, under clinical circumstances, the final preparation frequently does not match in shape and size with the preparation requested by the manufacturer as the dentist has to give priority to other parameters of influence.

The use of CAD/CAM systems for producing restorations has the advantage of having the final preparation as well as the restoration design digitally available. This technology enhances research on the dentist’s ability to create the advised tooth preparation, introduces a new way of failure analysis for the near future and also gives the possibility that the data obtained may be used as input for a Finite Elemental Analysis. In this way the weakest part of the restoration may be found, allowing the prediction of the longevity of the restorations.

As a first step to revise the failure analysis of all-ceramic CAD/CAM restorations, a study was carried out to investigate the variations between tooth preparations made in general practice and the tooth preparation prescribed by the manufacturer for the application of the CICERO system.

**Materials and Methods**

General dental practitioners from the northwest region of the Netherlands cooperating with CICERO during the introduction phase of this system were requested to participate in this study. An informative meeting was offered to them to be educated on the different aspects of the tooth preparation defined by the manufacturer. All dentists received written guidelines with the manufacturer’s specifications. In the guidelines a shoulder angle (SA) between 90 – 130 degrees and a shoulder width (SW) between 0.7 – 1.2 mm encompassing rounded inner edges are prescribed (Figure 1). A standard set of burs was recommended (for
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For palatal contouring: Komet 899314027 (rough) and 8899314027 (fine); for undepth 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)).

Figure 1. CICERO preparation guideline: 1. Shoulder Angle between 90 and 130 degrees; 2. Reduction of the axial wall should be between 0.7 and 1.2 mm, 3. Incisal reduction should be between 1.5 and 2 mm (anatomic), 4. Avoid sharp incisal angles and line angles, deep cavities and undercuts. Slightly conical preparations, 5. A clear and recognizable outline; 6. Optimum restorative dimension in the outline area for increased aesthetics.

(Left) Appropriate
- Chamfer preparation
- Shoulder preparation

(Right) Not appropriate
- Feather margin preparation
- Knife-edge preparation

Within the CICERO system, the dentist made the preparation and took an impression, while the local dental technician made the gypsum model (Fuji Rock, GC Japan). The laboratory models were sent to CICERO Central Lab for the fabrication of an all-ceramic CAD/CAM coping of a reinforced aluminum oxide glass (Synthoceram, Elephant Dental B.V., the Netherlands). The participating local dental laboratories added the veneering porcelain (Sintagon, Elephant Dental B.V., the Netherlands) manually.

A sample of 3446 laboratory models containing the respective tooth preparation for all-ceramic restoration were received and divided in 4 groups: 1376 incisors, 199 cuspids, 819 premolars and 1052 molars, respectively.
Scanning procedure

The CICERO system employs a fast laser stripe scanning method (Micromeasure GmbH, Wetzlar, Germany) to measure the 3-dimensional geometry of the preparation, its immediate surroundings and the opposing teeth. 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. This later on enables the automatic identification of the preparation margin by the computer. Subsequently the model is placed in the scanner-clamping device, which is fitted with a ball and socket table that can be tilted and locked in any direction allowing the path of insertion of the restoration to be approximately parallel to the vertical z-axis of the scanner. Within this standard set up, the dies are fine-scanned using steps of 0.05 mm between consecutive scan lines, with high definition. A straight laser stripe, which is projected onto the cast, is deformed by the 3-dimensional occlusal geometry of the tissues, a charged coupled device (CCD) camera scans the projected line. Finally the computer calculates the actual 3-dimensional position of the tissue surfaces using this deformation. With the data obtained by this method, a computer-generated surface of the prepared tooth is extracted, creating a virtual model, which is a precise image of the tooth preparation. The accuracy of the scanning method lies within 0.01 mm.\(^\text{15}\)

Determination of preparation properties

The digital image of the preparation was used to measure the shoulder angle (SA), the shoulder width (SW) and the top angle (TA) at different locations on the tooth (Figure 2). For this goal, a special software was developed. In an ideal situation the SA should be determined as the angle of the shoulder to the tooth-axis. As in this investigation only the laser scan image of the tooth preparation obtained from the laboratory model was used, information of the real tooth-axis was not available. Therefore the tooth-axis direction was assessed as follows: for the scanning procedure the laboratory model has to be placed in the laser scanner by a dental technician without undercuts seen from the direction of the scanner eye. This direction is taken as the preliminary tooth-axis. After scanning the preparation, the image obtained is automatically divided in 250 cross-sections. From all cross-sections the TA of the cavity wall with the preliminary tooth-axis can be calculated and the bisector direction is defined. The vector direction, which is the average of all
the bisector directions, is considered as the ‘tooth-axis’. As a consequence the TA is twice the preparation angle (PA). The SA is defined as the angle of the shoulder tangential with the line of the ‘tooth-axis’. To establish the SW in each cross-section, three auxiliary lines are drawn: the first one is a tangent line to the pulp preparation wall, the second line is parallel to the tooth-axis through the crossing point of the tangent of the shoulder with the tangent to the pulp preparation wall and the third line is parallel to the tooth axis through the shoulder border. The SW is defined as the distance between the last two parallel lines. The SA and the SW in this study were measured in four of the 250 cross-sections: the mesio-distal, the bucco-lingual and the two sections in between (Figure 3). In this way, the SA and SW were obtained on eight sides of each preparation (mesial, mesio-buccal, buccal, disto-buccal, distal, disto-lingual, lingual and mesio-lingual).

Figure 2. Schematic representation of the determination of preparation properties. Shoulder Angle (SA) is the resultant angle between an imaginary line tangential to the shoulder wall that crosses the Tooth Axis. Top Angle (TA) is obtained from the 250 cross-sections of the tooth preparation. Shoulder Width (SW) is the distance between two parallel lines to the Tooth Axis. One line is tangential to the intersection between the shoulder line and the pulp preparation wall line; the second line is tangential to the shoulder border.
Figure 3. Four cross-sections from 250 were selected for the digital evaluation, Mesio-Distal, Bucco-Lingual and the two sections in between.

Statistical analysis

A MANOVA (a multivariate analysis of variance) was performed to evaluate statistically significant differences between the measured SA, SW and TA. It used SA, SW and TA as the dependent variables. Jaw ('Jaw': upper/lower) and element type ('Element type': incisor/cuspid/premolar/molar) were used as between subjects factors. The location of measurement on the tooth ('Location': (mesial / mesio-buccal/buccal / disto-buccal / distal/ disto-lingual / lingual / mesio-lingual) was entered as a within subjects factor. To evaluate the deviation of the realized preparation parameters with the advised manufacturer's guidelines on an individual tooth level, the incidence of preparations that deviated on one or more variable values from the preparation guidelines was calculated. Therefore for each tooth the number of deviations with the required value on all eight locations was counted.

A preparation was defined as 'perfect' when it fulfills both requirements, SA and SW, requested by the manufacturer in the eight locations evaluated. Considering that deviations from the guidelines in SA smaller than 90 degrees and in SW larger than 1.2 mm will not influence the longevity of all-ceramic crowns, it was assumed that the preparations that fulfilled these requirements were 'acceptable'.

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1 mm
Results

The data was analyzed in two levels, per group (incisor, canines, premolar and molar) and per individual tooth. For the group analysis the average preparation characteristics were considered; for reasons of clarity it was decided to present the results of two instead of four cross-sections per tooth as the statistic analysis showed no influence on the final conclusion when decreasing the amount of 'locations' on the tooth. The analysis of the sample per group is shown in Table 1. On an individual tooth level each realized preparation was compared with the preparation design as advised by the manufacturer. The results of this evaluation are shown in Table 2.

Measured preparation characteristics

On a multivariate level all (main and interaction) effects were significant (p<0.001) except for the 'Location' by 'Jaw' interaction effect, which was not significant (p=0.06). Univariately the jaw main effect was significant for the SA (p=0.041) and the SW (p<0.001) but not for the TA (p=0.888). All other (main and interaction) effects were significant (p<0.001).

Shoulder Angle

The value of the SA showed a strong relation with the 'Element type' as well as with the 'Location' on the tooth (Figure 4A and 4C).

Shoulder Width

The SW was the smallest at the incisor position in the lower jaw. In general the SW in the lower jaw is significantly smaller when compared to the same position in the upper jaw. This effect diminishes when the position of the tooth in the mouth is more distant from the front teeth. The 'Element type' incisor from the lower jaw showed to have the biggest variance in SW per 'Location' on the tooth (Figure 4B and 4D).
Figure 4. Graphical presentation of the results: (A) Shoulder Angle (SA) by ‘element type’ on different ‘locations’ for the upper jaw. (B) Shoulder Width (SW) by ‘element type’ on different ‘locations’ for the upper jaw. (C) SA by ‘element type’ on different ‘locations’ for the lower jaw. (D) SW by ‘element type’ on different ‘locations’ for the lower jaw.

Figure 5. Graphical presentation of the top angle by ‘element type’ on the upper and lower jaw.
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Top Angle

The results of the TA determinations are presented in Figure 5. As the bisector angle was taken to determine the 'tooth axis', twice the PA equals the TA. From this figure it can clearly be seen that the TA and thus the PA increase going from incisors to molars.

Table 1. The analysis of the sample per group level. The average results of the different variables measured for 'element type' and 'location on the tooth' separately: the shoulder angle (SA) in degrees, the shoulder width (SW) in mm and the top angle (TA) in degrees. In parenthesis the standard deviation is presented.

<table>
<thead>
<tr>
<th>Element</th>
<th>Mesial</th>
<th>Buccal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SA</td>
<td>SW</td>
</tr>
<tr>
<td>Upper Incisor</td>
<td>115.6(19.6)</td>
<td>0.9(0.3)</td>
</tr>
<tr>
<td>Lower Incisor</td>
<td>128.0(20.5)</td>
<td>0.6(0.3)</td>
</tr>
<tr>
<td>Upper Cuspid</td>
<td>120.5(19.9)</td>
<td>0.8(0.3)</td>
</tr>
<tr>
<td>Lower Cuspid</td>
<td>124.8(16.3)</td>
<td>0.7(0.3)</td>
</tr>
<tr>
<td>Upper Premolar</td>
<td>119.2(17.6)</td>
<td>0.8(0.3)</td>
</tr>
<tr>
<td>Lower Premolar</td>
<td>118.9(18.8)</td>
<td>0.8(0.3)</td>
</tr>
<tr>
<td>Upper Molar</td>
<td>118.5(17.6)</td>
<td>0.8(0.3)</td>
</tr>
<tr>
<td>Lower Molar</td>
<td>113.6(17.8)</td>
<td>1.0(0.3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>Distal</th>
<th>Lingual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SA</td>
<td>SW</td>
</tr>
<tr>
<td>Upper Incisor</td>
<td>117.0(18.8)</td>
<td>0.9(0.3)</td>
</tr>
<tr>
<td>Lower Incisor</td>
<td>129.1(19.6)</td>
<td>0.7(0.2)</td>
</tr>
<tr>
<td>Upper Cuspid</td>
<td>119.6(19.7)</td>
<td>0.9(0.3)</td>
</tr>
<tr>
<td>Lower Cuspid</td>
<td>122.0(16.2)</td>
<td>0.8(0.3)</td>
</tr>
<tr>
<td>Upper Premolar</td>
<td>119.7(18.2)</td>
<td>0.9(0.3)</td>
</tr>
<tr>
<td>Lower Premolar</td>
<td>117.0(18.0)</td>
<td>0.8(0.3)</td>
</tr>
<tr>
<td>Upper Molar</td>
<td>118.6(16.1)</td>
<td>1.0(0.3)</td>
</tr>
<tr>
<td>Lower Molar</td>
<td>112.8(18.4)</td>
<td>0.9(0.3)</td>
</tr>
</tbody>
</table>

Preparation guidelines versus realized preparation design

Except for the SW average of the lower incisors, which mean value was significantly smaller at labial, mesial and distal locations than the required width, all other average preparation parameter values showed to be within the borders as defined in the preparation guidelines of the manufacturer. However, the incidence of realized preparations that deviate on one or more locations or variables (SA and SW)
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the required value was significantly higher. The TA parameter was not described in the CICERO preparation guidelines therefore the results of this study cannot be compared, but they are still of interest for further research and reveal the average taper of these type of preparations.

Table 2. The analysis of the sample on tooth level. The incidence of the tooth preparations within the parameters of the manufacturer’s preparation guidelines (‘perfect’ = SA between 90 and 130 degrees and SW between 0.7 and 1.2 mm) and the tooth preparations that slightly deviate from ‘perfect’ (‘acceptable’ = SA also smaller than 90 degrees and SW larger that 1.2 mm). U = upper jaw, L = lower jaw.

<table>
<thead>
<tr>
<th>Jaw</th>
<th>Incisor</th>
<th>Cusp</th>
<th>Premolar</th>
<th>Molar</th>
<th>Over-all</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-acceptable</td>
<td>18.5%</td>
<td>12.4%</td>
<td>13.6%</td>
<td>22.4%</td>
<td>17.8%</td>
</tr>
<tr>
<td>U-perfect</td>
<td>8.0%</td>
<td>2.3%</td>
<td>3.1%</td>
<td>3.7%</td>
<td>5.5%</td>
</tr>
<tr>
<td>L-acceptable</td>
<td>1.7%</td>
<td>0.0%</td>
<td>10.6%</td>
<td>58.1%</td>
<td>16.8%</td>
</tr>
<tr>
<td>L-perfect</td>
<td>0.0%</td>
<td>0.0%</td>
<td>1.1%</td>
<td>1.5%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

Discussion

An adequate tooth preparation is important from many perspectives. Firstly it is necessary to minimize potential failures due to functional loading of the restoration by creating possibilities for an adequate restoration design. Secondly it is necessary for optimal aesthetics to make adequate space for the porcelain veneer at one side and sufficient core material for strength at the other side. Moreover tooth preparations must be accomplished without compromising the pulp and/or the supporting structures. All these requirements should be in balance leading to an aesthetic and durable all-ceramic restoration.12

Considering the results from this study, one can conclude that the recommendations made by the CICERO system, with respect to SA (between 90 – 130 degrees) and SW (between 0.7 – 1.2 mm) do not give problems for the general practitioner. However, it is valuable to recognize that the dentist has some problems to create preparations in the molar region that are in line with the manufacturer’s guidelines. This may be explained by the limited space available for handling the preparation equipment due to a limited mouth opening. From time to time, it will be impossible to keep the bur in the direction needed for the creation of a preparation as described in the guidelines. Such a preparation may have a negative influence on the
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Clinical results of all-ceramic restorations. Precisely where the stresses are the highest, the preparation deviates the most from the guidelines. Our results show clearly this strong correlation, the Top Angle increases from the front to the backsides in both arcades.

Longevity in fixed prosthodontics is not only dependent upon the precision and skill with which the work is carried out, but also to a large degree upon a proper assessment, diagnosis, utilization and finally implementation of valid principles of preparation design. The multifactorial cause of failure of fixed prosthodontics makes failure analysis quite difficult. The aim of the majority of the research to improve the longevity of all-ceramic restorations by materials strength improvement is questionable. Moreover most research is looking for stronger core materials, which will be combined with the still relatively weak veneering porcelains.

Different methods to measure the shoulder preparation for crowns are described in the literature. Seymour et al.\textsuperscript{17} in an in vitro study made use of a coordinate measuring machine with a non-contact 830 nm wavelength laser triangulation probe (Renishaw OP2), at 50 µm intervals, recording x, y and z surface coordinates. From the digital data obtained, it would appear that there are deficiencies in shoulder preparations, particularly in width. The same methodology was used in their next study in 1999\textsuperscript{18}; the results showed that there is a tendency for the academic and general practitioners who took part of their in vitro and in vivo study to under-prepare and over-angle labial shoulder preparations.

Another way to assess tooth preparation design was described by Etemadi et al.\textsuperscript{19} who evaluated stoned dies for individual posterior resin-bonded porcelain onlays and complete crowns placed in a specialist practice. Measurements were recorded to the nearest 0.1 mm using a dial micrometer, and to the nearest degree for taper using a protractor. Recently Sutton and McCord\textsuperscript{2} reported the variations in tooth preparations for resin-bonded all-ceramic crowns in general dental practices in the United Kingdom and Ireland. The total amount of tooth reduction in the mesio-distal and bucco-lingual planes of the preparation was only possible to be measured if the corresponding contralateral tooth was present and unrestored. The measurements were made using dial vernier calipers (Mitutoyo, Japan) with thinly machined measuring tips.

With the introduction of CAD/CAM one can analyze tooth preparations as was never before possible. This study introduces a new option to reach this goal. The preparation parameters as well as restoration design parameters become digitally
available making a failure analysis before and/or after the failure occurs possible to predict and/or analyze. In an ideal situation the failure probability can be calculated, for instance by applying Finite Element Analysis, before making the restoration. In that way the design of the restoration could be accommodated or preparation advices generated.

The sample analyzed on a group level shows most of the SA and SW averages within the parameters established by the manufacturer, and then it was considered a 'perfect' tooth preparation (Table 1). However the individual analysis on a tooth level was done in a way that when it appears that SA and/or SW in one 'location' was not within the manufacturer's parameters, the tooth preparation was considered not even 'acceptable' (Table 2).

Dentistry nowadays emphasizes the conservation of a healthy tooth structure. During a tooth preparation the dental practitioner should keep in balance the respect for the natural teeth anatomy and the requirements to make an appropriate preparation for a fixed restoration. It could be considered that the dentists participating in this study tried to reach this balance. This could be the explanation of the results for the analysis per individual tooth; each tooth has a particular dental anatomy and in some cases in order to protect the tooth vitality it was not possible to follow the manufacturer's requirements.

With the method developed in this study it is also possible to reveal more explicit data regarding deviations on specific locations of the preparation guidelines. It is remarkable to notice that on the average nearly all preparations were perfect, while with a specific analysis to each preparation only 1.2% in the lower jaw and 5.5% in the upper jaw were on all aspects perfect. In general it may be concluded that it is very difficult for a dentist to create a preparation that fulfills on all locations the requirements set out by the guidelines. As a consequence an all-ceramic crown made on such a preparation might have from the beginning already a lowered chance of longevity defined by the preparation, while this incident would not have a big influence for metal ceramic crowns. The influence of this factor on the longevity of an all-ceramic restoration is still unknown. For that reason the effect of the shoulder preparation with respect to longevity of the CICERO system will be included in a longitudinal study of complete crown clinical performance, beginning with an assessment of the quality of the preparation and relating this to long-term prognosis.
Conclusions

From this study, it can be concluded that the position in the mouth and the anatomy of the tooth are of main influence on the resulting shape of the preparation. Dental clinicians are able to follow recommended guidelines for shoulder preparation. However, rarely a preparation is created that can be classified as perfect. Deviation from the guidelines is mainly caused by anatomical and accessibility restrictions.

References


