An in vitro evaluation of fit of the crowns fabricated by zirconium oxide-based ceramic CAD/CAM systems, before and after porcelain firing cycles and after glaze cycles

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ABSTRACT
Background: The objective of this in vitro study was to evaluate the vertical marginal fit of crowns fabricated with zirconium oxide based ceramic CAD/CAM systems, before and after porcelain firing cycles and after glaze cycles.

Materials and Methods: An acrylic resin model of a left maxillary first molar was prepared and duplicated to have a master die. Ten die stone dies were sent to the CAD/CAM (Amann Girrbach) for crowns fabrication. Marginal gaps along vertical planes were measured at four indentations at the mid mesial, mid distal, mid buccal, and mid palatal before (Time 0) and after porcelain firing cycles (Time 1) and after glaze cycles (Time 2) using a light microscope at a magnification of ×100. One way ANOVA LSD tests were performed to determine whether the mean and standard deviation of sub group Time 2.

Results: The mean values of the ZrO2 CAD/CAM Time 0 were (6.77 μm), Time 1 (8.75 μm) and Time 2 (10.62 μm). One way ANOVA test revealed a highly statistically significant difference between time (0) and time (1), while there is no any significant difference between time (0) and time (2), and between time (1) and time (2).

Conclusions: Within the limitations of this study, it was concluded that the ZrO2 CAD/CAM demonstrated acceptable marginal fit. The porcelain firing and the glaze firing cycles affected the marginal gap.

Key words: Vertical marginal fit, CAD/CAM, and Zirconium oxide. (J Bagh Coll Dentistry 2013; 25(1):43-48).

INTRODUCTION
With a growing awareness of esthetics and biocompatibility, patients increasingly request metal-free solutions(3). Due to the successful use of all-ceramic crowns both in the anterior and posterior segments (3), and with the introduction of advanced dental technology and high-strength ceramic materials, all-ceramic systems may become a viable treatment option even for extended fixed partial dentures (FPDs). Such restorative all-ceramic systems must fulfill biomechanical requirements and provide longevity similar to metal-ceramic restorations (3) while providing enhanced esthetics (4).

Zirconia, which is a polycrystalline material without a glassy matrix and is partly stabilized by yttrium oxide (approximately 3 mol%), is an alternative for multiunit frameworks.

The use of zirconia ceramics for multiunit FPDs has been facilitated by the advent of computer-aided design/computer aided manufacturing (CAD/CAM) systems(5). These all-ceramic restorations must meet requirements for strength, color stability, and precision of fit for clinical success(6).

Due to the solubility of luting agents(7), minimizing marginal opening is paramount in decreasing prosthetic failure resulting from caries, plaque and food accumulation, and inflammation of the periodontal tissues (8).

McLean and Von Fraunhofer in 1971(9) examined more than 1000 crowns after a 5-year period and concluded that a marginal opening of ≤120 μm was clinically acceptable.

Copy milling and CAD-CAM systems have gained popularity due to their ease of fabrication, good mechanical properties, and decreased porosity(10).

The CAD-CAM technologies introduced to the dental profession in 1971(11). The most common method to fabricate a zirconia substructure is by CAD/CAM milling from a solid block. The fully sintered zirconia is milled at a 1:1 ratio, while the partially sintered zirconia is milled 20% to 25% larger than the desired final size due to shrinkage caused by the sintering process. The development of CAD/CAM technology has focused on precise and consistent manufacturing of zirconia ceramics. CAD/CAM technology relies on exact dimensional predictions to compensate for sintering shrinkage, is an economical and reproducible method and in addition, has demonstrated improved marginal fit(12).

MATERIALS AND METHODS
Preparation of Master Die:
A dentoform left maxillary first molar was prepared to receive all ceramic crown using a high speed hand piece with air-water coolant, that was adapted to the suspending arm of the modified surveyor in such a way so that the long axis of the bur was paralleled to the long axis of the ivorine tooth, the horizontal arm of the surveyor.
permitted vertical as well as rotational movement around the tooth.

The left maxillary first molar was prepared to receive a complete ceramic crown, with the following preparation features: a 90° radial shoulder finish line all around the tooth with (1 mm) depth determined by a digital vernier, a total circumferential axial reduction was about 1.5 mm, and axial taper of 6° using a diamond bur No.(G846R). This bur was selected because it provides a shoulder finishing line; occlusal reduction of about 2mm was performed using a diamond disk bur No.(G818).13 The prepared dentoform tooth was used as a pattern for construction of the metal master die. The dentoform tooth was then sprued, invested, burned out and casted using Nickel-Chromium alloy (Figure 1).

![Figure 1: Finished master die with its acrylic base having seating groove at each corner](image1)

A block of acrylic resin was then constructed to hold the master die in such a way so that the long axis of the master die lied vertical to the horizontal plane of the acrylic block, and a dental surveyor was used for this purpose. Four seating grooves (5mm depth and 3mm base) at each corner of the upper surface of the block were made to be used later as a guide and stopper for the special tray during Impression making. A surveyor was used to construct the special tray for the master die.

**Impression procedures:**

A surveyor was used during the process of Impression taking, the master die was fixed to the horizontal table of the surveyor in such a way so that the long axis of the tooth was kept parallel to the long axis of the analyzing rod of the surveyor; the special tray was fixed to the suspending arm of the surveyor through the analyzing rod (previously attached to the tray during its construction) so that a standardized path of insertion and removal of the special tray was obtained. The special tray was coated with poly (vinyl siloxane) adhesive for one hour prior to Impression making. The Impression was done using heavy and light viscosity poly vinyl siloxane. The special tray was used to obtain 30 Impressions. Both the heavy and light body Impression materials and catalysts were mixed using auto mixing gun. Type IV die stone was mixed in a vacuum auto mixer, the Impression was poured on the vibrator in accordance with the manufacturer’s instructions, Thirty die stones were constructed from thirty Impressions. All laboratory procedures were performed by the same operator.

**Zirconia core manufacturing by CAD/CAM system (Group III):**

Ten zirconia crowns were constructed in the following manner:

**Scanning of the die:**

Scannable liquid (compatible with the scanning device of Ceramill InLab), was applied to the die stone to obtain precise scanning picture (Figure 2).

![Figure 2: The scanning machine (Ceramill,AmanGirbach,Germany)。(Figure 2)](image2)

The optical scanner scanned the die models with the help of the Ceramill 3D InLab Software; Three-dimensional images were displayed on the computer monitor, so that all the surfaces and finishing lines were shown clearly (Figure 3).
Core design:
Core designing procedure through the software was done with the following features, a minimum wall thickness of the core (1mm), and cement gap should have 0.05 mm thickness, starting at 0.25mm from the margin14 (Figure 4).

The copy seen in the final design in the monitor (Figure 5).

After applying the information for the design to the milling centre in software (Figure 6), a suitable blank (height and size) was selected from the blank loaded library of the CAD-CAM system.

The Y-TZP blank (zirconium block) was placed in the blank holder and fixed with the screws by the screw key, and the milling process was then started. All those steps were done following the manufacturer instructions of Ceramill InLab CAD/CAM system (AmannGirrbach Dental Systems, Germany) (Figure 7).

After the milling procedure had ended the blank was removed from the milling machine and the copy frame separated from the blank by a labrotary hand peice with a fissure bur (Figure 8).
Colouring and Sintering:
The copy was given its individual colour by immersing it in the dye solution. Sintering was carried out in the Ceramill Therm high-temperature furnace 1500°C for 9 hours to complete sintering.

Porcelain veneering cycling:
For all three groups, the closing margins were made with a core structure. The veneer started (0.5 mm) thickness at the margin, occlusally 1 mm and at middle third about 0.75 mm.

Measurement of the marginal gap:
Marginal gaps along vertical planes were measured at four indentations on the margin at the midpoint of mesial, distal, buccal and palatal surfaces of the die using a light microscope. The measurements were done at three interval times:
1- (Time 0): Before porcelain firing.
2- (Time 1): After porcelain firing.
3- (Time 2): After glazing cycle.

A screw loaded holding device following Thiab and Zakaria, 2007 was used during measurements in order to maintain a seating pressure of (13.4N) between the all-ceramic crown and the master metal die during measurements calculation for this purpose.

The microscope was calibrated to 0.001 mm (1 μm) at magnification 100x, and the measurements were done by placing the sample on the microscope stage, which was adjusted until the image of the marginal area was displayed clearly on the computer monitor, and the digital image of the gaps were then captured. The image was treated with program (Image J) which was used to measure the vertical marginal gap between the copy and master die. The program (Image J) was used to measure the value in a pixels mark by drawing a line between the finishing line on the die and the copy margin line (Figure 9). All digital readings were recorded and converted to (μm) by a magnification factor.

RESULTS
A total of 480 measurements from CAD/CAM were recorded at three intervals, Time 0 (before) and Time 1 (after) porcelain firing cycles and Time 2 (after glaze cycles) with 16 measurements per crown at each interval time. On the other hand comparing the results recorded in table (1) showed that the lowest mean value was recorded 6.775 μm in (time 0) subgroup followed by 8.750 μm (time 1) and with height vertical marginal gap value recorded 10.625 μm(time 2).

Table 1: Descriptive statistics of the three groups or three times.

<table>
<thead>
<tr>
<th>Sub group</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (0)</td>
<td>10</td>
<td>4.25</td>
<td>10.75</td>
<td>6.775</td>
<td>1.8388</td>
</tr>
<tr>
<td>Time (1)</td>
<td>10</td>
<td>6.25</td>
<td>11.75</td>
<td>8.750</td>
<td>1.9257</td>
</tr>
<tr>
<td>Time (2)</td>
<td>10</td>
<td>7.25</td>
<td>14.25</td>
<td>10.625</td>
<td>2.6621</td>
</tr>
</tbody>
</table>

The ANOVA test results showed highly significant differences among the different time subgroups (as shown in Table 3).

Table 2: One way- ANOVA for CAD-CAM group (Time 0, Time 1 and Time 2)

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>74.129</td>
<td>37.065</td>
<td>7.844</td>
<td>0.002</td>
</tr>
<tr>
<td>Within Groups</td>
<td>127.588</td>
<td>4.725</td>
<td>H.S.</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>201.717</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The LSD test of results showed that there is highly significant difference between time (0) and time (2), while there is no any significant difference between time (0) and time (1), and between time (1) and time (2) (as shown in Table 3).

Table 3: LSD test between the time subgroups of the CAD-CAM.

<table>
<thead>
<tr>
<th>(I) VAR00000</th>
<th>(J) VAR00000</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (0)</td>
<td>Time (1)</td>
<td>-1.90000</td>
<td>.97032</td>
<td>.061</td>
</tr>
<tr>
<td>Time (0)</td>
<td>Time (2)</td>
<td>-3.82500</td>
<td>.97032</td>
<td>.001</td>
</tr>
<tr>
<td>Time (1)</td>
<td>Time (2)</td>
<td>-1.92500</td>
<td>.97032</td>
<td>.058</td>
</tr>
</tbody>
</table>

DISCUSSION
In this in vitro study, the zirconium oxide-based ceramic CAD/CAM systems mean marginal gap (10.62μm) was demonstrated acceptable marginal gaps according to Christensen and McLean and von Fraunhofer; Suarez et al; Wolfart et al; Quintas et al; Bindl and
Mörmann (21), Sailer et al (22), Iwai et al (23) who suggested that 120 μm should be the highest limit for clinically acceptable marginal discrepancies.

The results showed that glazing produced greater marginal gap differences that are statistically highly significant. These results are in agreement with the results of Balkaya et al (24) and Pak et al (25).

Marginal gap values reported in the present study also in agreement with those of Gonzalo et al (14) who reported that the CAD-CAM Zirconia restoration showed the lowest marginal gap (9-12 μm).

However, these results disagree with the results of Pera et al (26), Probster et al (27), Shearer et al (28), Song et al (29), Vigolo and Fonzi (30) which could be attributed to:

- The increase in the marginal gap in veneered coping after the body porcelain firing cycles may also be a result of porcelain contamination on the inner surfaces of copings, and reduction in the resilience of the core material and rigidity of the porcelain (31).

The difference in thermal expansion coefficient (TEC) of the veneering ceramic and the core material leads to pressure tensions during cooling at room temperature which lead to stress effect on the marginal fit (32).

Another explanation of the difference in marginal gap may be explained by the fact that during the porcelain veneering procedure, particles of porcelain melt and gather to fill up voids and the resulting contraction of the porcelain mass causes a compressive force on the coping (33).

The deformation of the coping under the stress of contracting porcelain is spread around the whole circumference of the margin. So the literature has suggested certain causes that may be responsible for the distortion such as: porcelain contraction, design and thickness of the core substructure and inadequate support of the core framework during firing (34).

The small value of vertical marginal gap attributed to:

- The creating of an enlarged during designing of the framework before sintering Y-TZP blank and milling, to compensate the account shrinkage that associated with sintering to achieve the definitive fit of restoration with its final strength (35).

The presintered Y-TZP blank have a number that was set in the software during designing of the core that represent the volume of sintering shrinkage, so that the balance between the enlarged machining of the pre sintered Y-TZP block and the shrinkage occurring during the sintering process is highly precise, thus creating frameworks with an overall improved marginal gap and high significantly smaller than other system.

The CAD-CAM Ceramill system is the supra fine milling of the inner surface that will improve the seating of the coping to the die.

Effect of die spacer:

Some authors (Grajower, Lewinstein (36), Hunter, Hunter (37), and Adriana et al (38)) stated that “adequate die spacing is a more important factor than margin configuration for the accuracy of crown margins”. The greater the internal relief, the less time interval is required for definitive seating, leading to less force required and potentially less strain to all-ceramic margins (39).

The other causes of lowest marginal gap of the CAD-CAM Ceramill system was attributed to fewer laboratory steps and predetermined die spacer designed in the software (50 μm thickness).

According to some studies, if die spacer was applied to the entire prepared surface except a region of 0.25 μm above the finish line might cause improved marginal fitting of the core (38,40,41).

REFERENCES

41- Campbell SD. Comparison of conventional paint-on die spacers and those used with the all-ceramic restorations. J Prosthodont Dent 1990;63:151-5.