Evaluation of the absolute marginal discrepancy of zirconia-based ceramic copings

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Statement of problem. Marginal fit is an important factor for the long-term success of ceramic restorations; however, it is difficult to compare results from studies on marginal accuracy of zirconium oxide-based restorations that used various computer-assisted systems, because different methods were used to obtain the data.

Purpose. The purpose of this study was to analyze the effect of different manufacturing techniques on the marginal adaptation of zirconia ceramic copings.

Material and methods. An extracted mandibular first premolar was prepared for a complete coverage restoration and subsequently duplicated 40 times in a liquid crystal polymer (LCP). Ceramic copings (n=10) were fabricated on the LCP models using the following systems: glass-infiltrated zirconia-toughened alumina (In-Ceram Zirconia) and yttrium cation-doped tetragonal zirconia polycrystals (In-Ceram YZ, Cercon, and Procera Zirconia). The absolute marginal discrepancy of the cores was assessed by using an image analysis system. The data were analyzed using 1-way ANOVA and Scheffé's test (α=.05).

Results. The mean marginal openings were 29.98 ±3.97 μm for the In-Ceram Zirconia group, 12.24 ±3.08 μm for the In-Ceram YZ group, 13.15 ±3.01 μm for the Cercon group, and 8.67 ±3.96 μm for the Procera group. Significant differences were found among the 4 systems (P<.05).

Conclusions. The marginal accuracy achieved for the 4 zirconia-based ceramic crown systems analyzed was within the range of clinical acceptance (120 μm). (J Prosthet Dent 2011;105:108-114)

Clinical Implications

This in vitro study demonstrated that computer-aided technology can produce zirconium oxide-based ceramic copings with a clinically acceptable marginal fit. Of the systems tested, the highest marginal accuracy was achieved with the Procera system.

Ceramic restorations are a metal-free alternative due to their excellent esthetic and biocompatibility properties.[1] One of the most significant advances in the field of restorative dentistry has been the introduction of zirconia-based ceramic materials. These systems use the concept of computer-aided design/computer-aided manufacturing (CAD/CAM) for the fabrication of ceramic crowns and fixed dental prostheses (FDPs) composed of a zirconium oxide ceramic framework combined with a compatible veneering feldspathic porcelain.[2]

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The zirconia-based ceramics most recently developed contain yttrium cation-doped tetragonal zirconia polycrystals (Y-TZP). This material can efficiently arrest crack propagation.[3,4] Tensile stresses acting at the crack tip induce a transformation of the metastable tetragonal zirconium oxide phase into the thermodynamically more favorable monoclinic form. This transformation is associated with a local increase of 3% to 5% in volume. The increased volume results in localized compressive stresses being generated around and at the crack tip, which counteract the external tensile stresses acting on the fracture tip.[5] This phenomenon, known as transformation toughening, results in excellent mechanical properties that are advantageous in prosthetic dentistry.[6]

In addition to fracture resistance and esthetics, marginal fit is one of the most important criteria for the long-term success of ceramic restorations. It is necessary to minimize the marginal gap, since a significant space between the tooth and the restoration exposes the luting material to the oral environment, thus resulting in a more aggressive rate of cement dissolution caused by oral fluids and chemomechanical forces.[7] The consequent microleakage may result in inflammation of the periodontal tissues, secondary caries, and subsequent failure of the prosthesis.[8,9]

Despite the fact that marginal adaptation is a fundamental factor in fixed prostheses, there are limitations relating to the study of this characteristic. There is no consensus on what constitutes a clinically acceptable maximum marginal gap width. The values reported in the literature range from 50 to 200 μm, suggesting the absence of an objective limit based on scientific evidence.[10-12] Most investigators continue to use the criteria established by McLean and von Fraunhofer,[13] who, after examining more than 1000 crowns, concluded that 120 μm was the maximum tolerable marginal opening.[14-16] Another aspect to consider in studies on marginal adaptation is the absence of standardization in the methodology used, which makes data comparison difficult.[17-21]

Several authors have demonstrated that the marginal discrepancy of ceramic crowns is influenced by several factors. While some investigations have assessed clinical variables such as tooth preparation geometry or type of cement, in others, factors related to dental laboratory fabrication techniques have been evaluated.[22-24] Marginal gaps of 1-161 μm have been reported in the literature for conventionally fabricated ceramic crowns.[25-27] In contrast, marginal gaps of 17-118 μm have been reported for CAD/CAM-fabricated ceramic crowns.[15,21,22,27-37] Various investigators have also examined the marginal adaptation of CAD/CAM ceramic FDPs.[38-46] Currently, it is known that these systems produce higher quality restorations by using industrially prepared ceramic materials and a standardized manufacturing process which reduces production time.[47-50] Nevertheless, although one of the objectives of computer-aided technology is to increase the accuracy of the manufacturing process, there are few publications that exclusively analyze the influence of CAD/CAM systems on the marginal adaptation of zirconia crowns. There is no clear evidence that one method of fabrication provides a consistently superior marginal fit.

The purpose of this study was to evaluate the marginal adaptation of 4 different zirconium oxide-based ceramic crown systems. The null hypothesis was that no differences would be found in marginal discrepancy among the restorations fabricated by the various techniques.

MATERIAL AND METHODS

Experimental model

One extracted mandibular right first premolar without caries was cleaned and prepared for ceramic crown fabrication with a 1.2-mm-deep circular chamfer and an occlusal reduction of 2 mm. The angle of convergence of the axial walls was 6 degrees, obtained by using a parallel milling machine (Paraskop M; Bego, Bremen, Germany). The tooth was prepared with the use of a silicone index (Express Impression Material; 3M ESPE, St. Paul, Minn) and a digital slide gauge (Absolute Digimatic Caliper 500; Mitutoyo Corp, Kawasaki, Japan). All surface transitions were smooth and well rounded. The prepared tooth was invested in a silicone investment material (Silastic T-2; Dow Corning Corp, Midland, Mich) and replicated 40 times in wax using an injection process (Digital Vacuum Wax Injector D-VWI; Yasui & Co, Tokyo, Japan). From the wax patterns, 40 artificial teeth were fabricated with liquid crystal polymer (LCP) (Vectra B950; Ticona GmbH, Frankfurt, Germany) using an injection molding machine (J-100 Evolution; Pressing Dental Srl, Dogana, San Marino). To avoid any possible variations during the impression and casting stages, the LCP models were used as definitive dies to fabricate the restorations. The artificial teeth were divided into 4 groups of 10 specimens (Table I). Each group of copings was fabricated by an experienced dental technician who was accustomed to the specific system.

Fabrication of ceramic copings

The In-Ceram Zirconia restorations were produced with the Cerec inLab system (Sirona Dental Systems GmbH, Bensheim, Germany) using the unit's internal laser scanner to digitize the dies. The data were then transmitted to a software program (Cerec inLab 3D, v. 2.7; Sirona Dental Systems GmbH) in which the copings were designed. Once the milling paths were computed, the frameworks were milled from industrially sintered zirconia-toughened alumina blocks (VITA In-Ceram Zirconia blocks for inLab; VITA Zahnfabrik) under water spray. The cores were subsequently infiltrated with a low-viscosity infiltration

TABLE I. Materials tested

Group Code	Ceramic	Batch Number	Manufacturer
IZ	In-Ceram Zirconia	6232	VITA Zahnfabrik, Bad Säckingen, Germany
IY	In-Ceram YZ	7430	VITA Zahnfabrik
CC	Cercon	20016117	Dentsply Intl, York, Pa
PZ	Procera Zirconia	Not available	Nobel Biocare AB, Göteborg, Sweden

glass (In-Ceram Zirconia Glass Powder Z21; VITA Zahnfabrik). The completed copings were placed on their dies.

The manufacture of In-Ceram YZ restorations was similar to that of the previous group, except that the substructures were milled from partially sintered Y-TZP blanks (VITA In-Ceram YZ blocks for inLab; VITA Zahnfabrik). As a result, the computer-designed frameworks were oversized by 20% to 25% to compensate for shrinkage, which occurs during the definitive sintering. The enlarged copings were sintered using a high-temperature furnace (VITA ZYrcomat T; VITA Zahnfabrik) for 8 hours at 1530°C. The fully sintered cores were then returned to their respective abutments.

The Cercon (Dentsply Intl, York, Pa) frameworks were alternatively designed using a conventional waxing technique. These wax patterns were digitized using the optical scanner of the Cercon Brain unit (Dentsply Intl), in which the presintered zirconia copings were milled with a magnification factor of 25% to 30% to compensate for sintering shrinkage. Following shaping, the oversized cores were sintered to full density in a high-temperature furnace (Cercon Heat; Dentsply Intl) for 6 hours at 1350°C. The sintered substructures were placed on their dies.

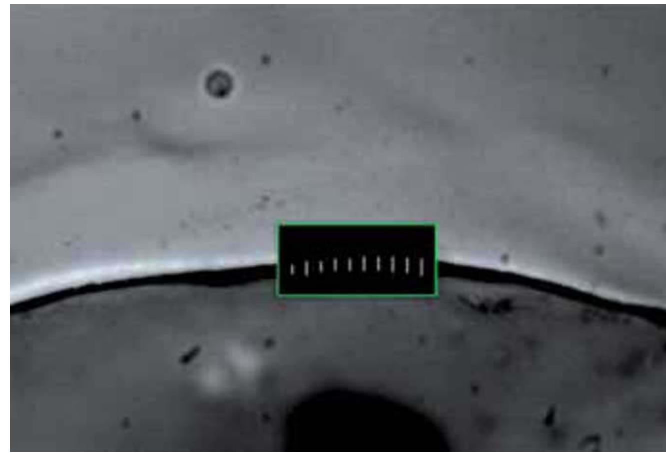
The Procera Zirconia (Nobel Biocare AB, Göteborg, Sweden) restorations were fabricated using the Procera system (Nobel Biocare AB), which was developed for the industrial manufacturing of frameworks in a remote production center. The artificial teeth were initially digitized by a tactile scanner (M50; Nobel Biocare AB). After scanning, the cores were designed using a software program (Procera CAD Design C3D, v. 1.1.0; Nobel Biocare AB). This information was forwarded electronically to the production facility (Procera Sandvik AB, Stockholm, Sweden), where refractory die replicas were milled 25% larger in size to compensate for the sintering shrinkage of the ceramic material. Copings were manufactured by dry pressing high-purity zirconium oxide powder against the enlarged dies. These densely packed substructures were then milled to the desired outer shape and sintered at 1540°C to achieve full density and strength. During this firing, the frameworks shrank to the dimensions of the original dies. After receipt from the Procera production center, the cores were returned to their respective abutments.

Marginal analysis

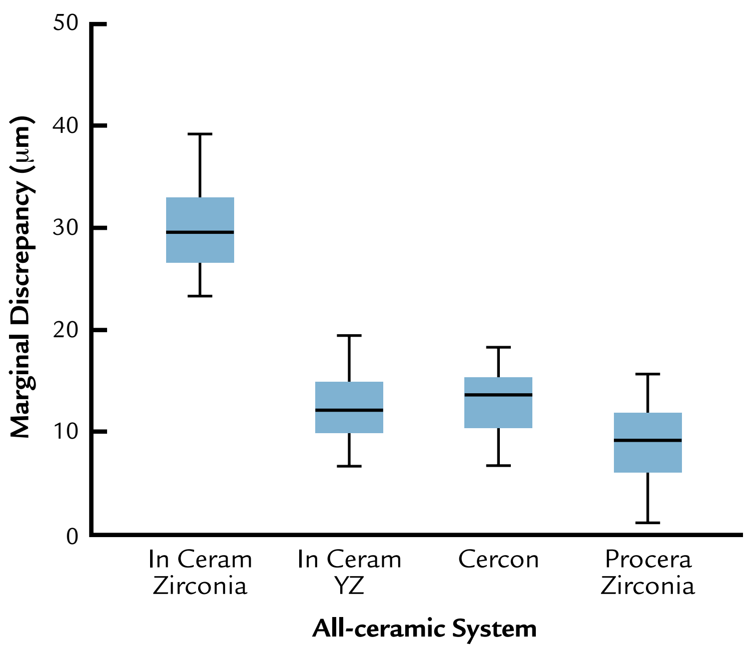
Marginal accuracy was assessed by measuring the absolute marginal discrepancy of the copings on the LCP dies without cementation, using an image analysis system. This method consisted of image analysis software (Optimas 6.1; Media Cybernetics, Inc, Bethesda, Md) in combination with a stereomicroscope (Olympus SZ40; Olympus Corp, Tokyo, Japan) with a magnification factor of ×40 and a charge-coupled device camera (Hitachi CCTV HV-720E (F); Hitachi Ltd, Tokyo, Japan) that captured the zone to be analyzed. For all measurements, the specimens were placed on a metal device to secure the cores at the same position on the dies, applying a uniform load of 10 N with the help of a torque wrench (no. 24075; Astra Tech AB, Mölndal, Sweden) in a plane angled between 90 and 120 degrees. This was to ensure that the maximal distance between the outer restoration margin and the cavosurface angle of the preparation was perpendicular to the optical axis of the microscope (Fig. 1). The measuring areas were previously marked with an indelible marking pen (Lumocolor permanent; Staedtler Mars GmbH, Nürnberg, Germany) in the middle of the buccal, mesial, lingual, and distal surfaces.

An automated image-processing program was designed using the Optimas software (Media Cybernetics, Inc) to measure the marginal discrepancy at 10 points spaced 70 µm apart in each selected area. This macro program, which was linked to a spreadsheet (Microsoft Excel 2007; Microsoft Corp, Redmond, Wash), consisted of the following steps: calibration, transformation into a grayscale image, binarization by adap-

1 Metal device used to secure cores on dies and measure marginal gap width in plane angled at 90-120 degrees to optical axis of microscope.



2 Demonstration of computer-aided measurement of marginal fit (distal aspect of Procera Zirconia coping). Marginal gap analysis was made using stereomicroscope at ×40 magnification.



3 Box plot diagram for marginal gap dimension. Comparison of 4 all-ceramic systems: − represents median, ⊥ represents minimum, ┬ represents maximum. Boxes: 25th and 75th percentiles.

tive thresholding, and morphometric analysis (Fig. 2). Using this technique, a total of 40 single measurements were made around each specimen.

Statistical analysis was performed using software (SPSS 14.0; SPSS, Inc, Chicago, Ill). The Kolgoromov-Smirnov test was used to confirm that the marginal gap data were normally distributed. The mean values and the standard deviations per group were calculated. One-way ANOVA was used to assess the influence of the ceramic system on the marginal discrepancy. In addition, a Scheffé's multiple range test was applied for post hoc comparisons. The level of significance was established at .05.

RESULTS

The results are shown in Figure 3. The overall mean gap was 16.01 ±8.97 μm. The mean values of the marginal opening were 29.98 ±3.97 μm for the In-Ceram Zirconia group, 12.24 ±3.08 μm for the In-Ceram YZ group, 13.15 ±3.01 μm for the Cercon group, and 8.67 ±3.96 μm for the Procera group. The ANOVA test indicated that marginal adaptation was significantly different among the 4 systems (df=3, F=289, P<.001). The results of the Scheffé test showed that the Procera restorations had significantly better marginal fit than the In-Ceram Zirconia, In-Ceram YZ, and Cercon specimens (P<.001). The greatest marginal discrepancies were recorded for In-

Ceram Zirconia specimens, revealing significant differences with respect to the other systems ($P<.001$). Marginal gaps of the In-Ceram YZ and Cercon crowns were not significantly different ($P=.723$).

DISCUSSION

This in vitro study evaluated the marginal adaptation of 4 different zirconium oxide-based ceramic crown systems. The data support rejection of the null hypothesis that no differences would be found in marginal discrepancy among the restorations fabricated by the various techniques.

The mean marginal gap widths of CAD/CAM-fabricated zirconia copings in this study were slightly lower than the range reported in the literature.[15,21,22,27-37] This might be due to recent developments with respect to scanning technology (contact probe, laser line, white light, and conoscopic holography), software (the latest software updates improved the detection of the margin), and milling strategy (closer milling tracks at the inner surface), which may have improved the marginal accuracy.[42] Nevertheless, statistically significant differences were found among the 4 systems investigated.

Procera Zirconia copings presented the lowest mean marginal openings when compared to the other 3 systems. Fewer laboratory steps and the precision of both the digitizing method and the industrial fabrication process for the Procera system might explain these results. In vitro results reported for Procera AllCeram crowns varied from 17 to 83 µm, depending on the methodology used.[27,28,30,33,37] Limited data concerning the fit of Procera Zirconia restorations are available. Gonzalo et al[40,46] and Beuer et al[42] evaluated the marginal gaps of Procera Zirconia 3-unit FDPs, which were between 9 and 26 µm. These results were in agreement with the present study. Conversely, Att et al[41] found that the marginal discrepancy of Procera Bridge Zirconia specimens ranged from 74 to 97 µm. However, in the present investigation, the marginal opening was assessed using different methods and without a cement layer.

Manufacturing of both In-Ceram YZ and In-Ceram Zirconia copings involved the use of the Cerec inLab system. This unit uses a laser line scanner for digitizing the surface topography of dies. Problems regarding the digitization of edge-shaped surfaces and angled areas of tooth preparations have been described when using optical scanners.[39,49,50] This could partly explain the differences between the Procera group and the rest of the groups. The mean marginal discrepancy of In-Ceram YZ copings in this study was not in agreement with the values reported in the literature of 48-183 µm.[20,41,45] However, it has to be considered that comparable in vitro investigations used FDPs as experimental restorations and used different techniques to obtain the data.

In-Ceram Zirconia copings showed the greatest mean marginal discrepancies. This could be explained by technique sensitivity and the number of laboratory steps. Following milling, these cores require a glass-infiltration process. During the infiltration firing, the glass mixture tends to gravitate, creating an excess at the margin of the framework that must be trimmed using a rotary cutting instrument. This procedure must be performed carefully to maintain marginal integrity.[27] Bindl et al[28] reported that In-Ceram Zirconia single crown copings fabricated with the Cerec inLab system had a mean marginal gap width of 43 µm. This value is similar to the mean marginal fit of 57 µm detected for 3-unit FDPs.[43] These results were in agreement with those of the present study.

There are 2 primary factors to consider with respect to the fit of restorations produced by the Cercon CAM system: the skill of the technician and the accuracy of the scanning process. Although this technique excludes some of the steps and errors in a standard production line, a number of handling procedures (definitive die preparation with spacer, waxing, and wax pattern removal from the die) still have the potential to result in discrepancies in the definitive product. Additionally, the optical scanner must digitize the internal aspects of the wax pattern, which is much more difficult to scan than the die. The mean marginal opening of Cercon copings in the present study was lower than the range of values reported in the literature of 80-189 µm.[43-45] These contradictory results may be due to variation in the methods used to assess marginal accuracy.

In the present study, marginal adaptation was evaluated by direct viewing with external measurements. This technique has the advantage of being noninvasive and is, therefore, useful to determine the precision of fit of the whole specimen. However, it is difficult to repeat the measurements from an identical angle and to distinguish the real marginal gap from its projection.[19] Nevertheless, these aspects could be minimized by 2 factors: the use of experimental restorations, which have a better defined and more regular margin and are thus easier to align with the focal plane of the microscope, and the positioning of the restorations in relation to a base to ensure that measurements are always made at the same points.[20] Some investigators[21,23,24,26,27] have shown that the differences in marginal fit of ceramic systems are due to the coping fabrication, because the various phases of porcelain firing do not significantly affect gap dimension, thus validating the use of ceramic copings in this investigation.

There were some limitations in the present study. All copings were produced and tested under ideal conditions, which may not reflect conditions in daily clinical practice. The measurements were performed without cementing the crowns, so the increase in marginal gap width caused by cementation was not included. However, the purpose of this study was to evaluate the production results of certain zirconia restoration systems, without the influence of external factors, to compare the capability of the CAD/CAM technology. Luting procedures make it difficult to obtain information about primary precision that results from the individual manufacturing techniques.[21] Another limitation of the study was that each group of copings was fabricated by a different technician. Further investigations are needed to evaluate the influence of cement spacer thickness and cementation technique on the marginal fit of CAD/CAM restorations as well as the clinical outcome of zirconia restorations.

CONCLUSIONS

Within the conditions and limitations of this study, it was concluded that the absolute marginal discrepancies observed were all within the clinically acceptable limit (120 μm). The Procera Zirconia system presented the best mean marginal adaptation (8.67 ±3.96 μm). The In-Ceram Zirconia system produced the greatest mean marginal gap (29.98 ±3.97 μm), which was 3.5 times larger than that of the Procera system.

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NOTEWORTHY ABSTRACTS OF THE CURRENT LITERATURE

Prospective evaluation of zirconia posterior fixed partial dentures: Four-year clinical results

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Purpose. In this prospective clinical study, the performance of three- and four-unit fixed partial dentures (FPDs) with frameworks fabricated of yttria partially stabilized zirconia was determined after a mean observation period of 50 months. The study focused on the survival of the restoration (in situ criterion) and the success of the ceramic veneers (no defect).

Materials and Methods. Seventy-five patients with a maximum of two missing teeth and an antagonistic dentition were treated at the Department of Prosthodontics, University of Goettigen, with 99 posterior FPDs. Fifty-one specimens (experimental group) were veneered with an experimental ceramic suitable for titanium and zirconia frameworks (thermal expansion coefficient [TEC]: 8.5 μm/m*K); 48 restorations (Ceram-S group) were veneered with a commercially available low-fusing ceramic optimized for zirconia frameworks (TEC: 9.5 μm/m*K). All restorations were luted with zinc-phosphate cement. Statistical analysis was performed according to the Kaplan-Meier method; time-dependent success rates of the different types of ceramic veneers were analyzed using the log-rank test.

Results. Seven restorations were lost: 4 due to technical complications and 3 due to biologic complications. The overall survival rate after 48 months was 94% (Kaplan-Meier analysis). Twenty-three events required clinical intervention for restoration maintenance: 13 ceramic veneer chippings (polishing), 6 losses of retention (recementation), 3 caries lesions (filling therapy), and 1 loss of vitality (endodontic treatment). Between the two groups of veneering materials, no significant difference in the probability for success was determined (log-rank test, $P = .81$).

Conclusions. Within a mean observation period of 4 years, sufficient survival rates for zirconia-based posterior FPDs could be verified. The main complications included fracture of the ceramic veneering material and decementation, which occurred mainly in the mandible.