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An In Vivo Evaluation of Fit of Zirconium-Oxide Based Ceramic Single Crowns, Generated with Two CAD/CAM Systems, in Comparison to Metal Ceramic Single Crowns

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Zirconia single crowns; precision; marginal gaps.

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Abstract

Purpose: The purpose of this study was to assess in vivo the marginal fit of single crowns produced using two CAD/CAM all-ceramic systems, in comparison to more traditional metal ceramic crowns.
Materials and Methods: Thirty vital, caries-free, and previously untreated teeth were chosen in five patients who needed extraction for implant placement and therefore were included in this study. In the control group (C), 10 regular metal ceramic crowns with porcelain occlusal surfaces were fabricated. In the other two groups (Z and E), CAD/CAM technology was used for the fabrication of 20 zirconium-oxide-based ceramic single crowns with two systems. All zirconia crowns were cemented with glass-ionomer cement, always following the manufacturer's instructions. The same dentist carried out all clinical phases. The teeth were extracted 1 month later. Marginal gaps along vertical planes were measured for each crown, using a total of four landmarks for each tooth by means of a microscope at a magnification of 50×. On completion of microscopic evaluation, representative specimens from each group were prepared for ESEM evaluation. Mean and standard deviations of the four landmarks (mesial, distal, buccal, palatal) at each single crown were calculated for each group. Multivariate analysis of variance (MANOVA) was performed to determine whether the four landmarks, taken into consideration together, differed between groups. Two-way ANOVA was performed to study in detail, for each landmark, how the three systems used to produce the FPDs affected the gap measurements. Differences were considered to be significant at $p < 0.05$.
Results: MANOVA revealed no quantitative differences of the four landmarks, when taken into consideration together, between the three groups ($p < 0.0001$). Two-way ANOVA, performed at each landmark, revealed no quantitative differences between the three groups ($p < 0.0001$ for each landmark).
Conclusions: Within the limitations of this study, it was concluded that the two zirconium-oxide-based ceramic CAD/CAM systems demonstrated a similar and acceptable marginal fit when compared to more traditional metal ceramic crowns.

With a growing awareness of esthetics and biocompatibility, patients increasingly request metal-free solutions.[1] Due to the successful use of all-ceramic crowns in both anterior and posterior segments,[2-6] and with the introduction of advanced dental technology and high-strength ceramic materials, all-ceramic systems may well become a viable treatment option for crowns. Such restorative all-ceramic systems must fulfill biomechanical requirements and provide longevity similar to metal ceramic crowns,[7-9] while providing enhanced esthetics.[10] Zirconia, a polycrystalline material without a glassy matrix and partly stabilized by yttrium oxide (approximately 3 mol%), is an option for metal-free solutions. The use of zirconia ceramics for crowns has been facilitated by the advent of computer aided design/computer aided manufacturing (CAD/CAM) systems.[11-14] If the material is provided in a presintered porous status (green blank), it can easily be machined in a CAM unit.[15]

After machining, the coping has to be densely sintered for 7.5 hours at 1500°C.[15] Upon sintering, the relocation of material via bulk diffusion, surface diffusion, or gas phase affects changes in volume. This may lead to a linear shrinkage of up to 15% to 30% and a subsequent increase in density.[15]

For practical use, the obvious efficiency of the CAD/CAM method has to be weighed against possible inaccuracies resulting from the scanning process, software design, milling, and shrinkage effects.[1] These inaccuracies are likely to lead to poor restoration fit.[16] Several authors have attempted to determine what constitutes clinically acceptable marginal openings not visible to the naked eye and undetectable with a sharp explorer. Christensen[17] evaluated the fit of subgingival and supragingival margins with a group of dentists and stated that the least acceptable marginal discrepancy in visually accessible surfaces was 39 μm, according to the linear regression prediction formula. In an in vivo study, Lofstrom and Barakat[18] used a scanning electron microscope to measure the supragingival margins of the crowns considered a suitable clinical fit by several dentists and reported marginal discrepancy values in a range of 7 to 65 μm. Marginal and internal accuracy of fit is considered to be one of the most important criteria for the clinical quality and success of all-ceramic crowns.[19-21] Increased marginal discrepancy of a crown is supposed to promote the rate of cement dissolution and of microleakage.[22] Microleakage from the oral cavity was considered a cause of inflammation of the vital pulp.[23] Increased plaque retention[24,25] was blamed for poor marginal adaptation of crowns and also a change in composition of the subgingival microflora,[26] indicating the onset of periodontal disease. Marginal discrepancies were said to favor the recurrence of caries.[27] Any misfit in the axial wall area and occlusal plateau is likely to lower resistance to fracture of all-ceramic crowns.[28]

In vitro studies revealed mean marginal gaps of 64 to 83 μm in CAD/CAM-generated all-ceramic single crowns.[29-26] Similar values between 64 and 74 μm have been reported for the zirconia multiunit frameworks produced by the DCS CAD/CAM system (DCS, Allschwil, Switzerland).[31] In vitro results on the fit of all-ceramic CAD/CAM-generated crowns are promising.[31-34] In an in vivo study, Reich et al[1] tested the marginal and internal fit of CAD/CAM fabricated all-ceramic three-unit fixed partial dentures (FPDs). Twenty-four all-ceramic three-unit FPDs were fabricated and randomly subdivided into three equally sized groups. Eight frameworks were fabricated using the Digident CAD/CAM system (Digident, Piscataway, NJ), and another eight frameworks using the Cerec Inlab system (Sirona Dental GmbH, Salzburg, Austria). Vita In-Ceram Zirkonia (VITA Zahnfabrik, Bad Sackingen, Germany) blanks were used for both groups. In a third group, frameworks were milled from yttrium-stabilized zirconium blanks, using the Lava system (3M ESPE, St. Paul, MN). All frameworks were layered with ceramic veneering material. In addition, six three-unit metal ceramic FPDs served as the control group. All FPDs were evaluated using a replica technique with a light body silicone stabilized with a heavy body material. The replica specimens were examined microscopically. The results of this study indicated that gaps were similar to those of metal ceramic restorations, particularly for the Lava and the Cerec Inlab systems. In a previous study, Balkaya et al[35] examined the effect of porcelain and glaze firing cycles on the fit of three types of single all-ceramic crowns (conventional In-Ceram, copy-milled In-Ceram, and copy-milled feldspathic crowns). They concluded that the three all-ceramic crown systems demonstrated a comparable and acceptable marginal fit. The porcelain firing cycle affected the marginal fit of the all-ceramic crowns; however, the glaze firing cycle had no significant effect on fit.

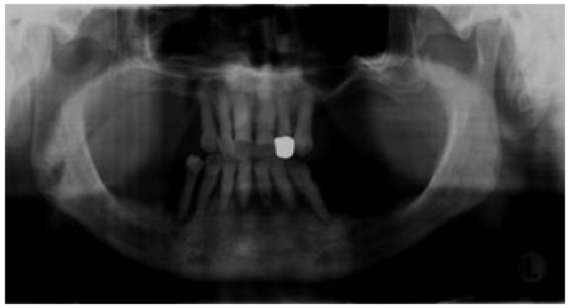

Figure 1 Pretreatment radiograph of a patient.

The aim of this investigation was to evaluate in vivo the marginal fit of single-unit zirconia crowns produced using two CAD/CAM all-ceramic systems, in comparison to more traditional single metal ceramic crowns.

Materials and methods

Thirty teeth were chosen in five patients needing extraction for implant placement and were included in this study: all 30 teeth were vital, caries-free, and had never been treated before. In Figure 1, the pretreatment radiograph of a patient is shown: all teeth were considered hopeless for periodontal reasons, and the two maxillary canines, the two maxillary central incisors, and the right maxillary lateral incisor were included in the study. None of the patients dropped out or were dismissed. The Clinical Medical Ethical Committee of the University of Padova, Institute of Clinical Dentistry, approved the study. Patient consent was obtained before tooth preparation. One operator, constantly following the same techniques, carried out all clinical procedures.

Dental substrate preparation and impression

All teeth were prepared in a standardized manner as described in previous studies:[14] occlusal reduction of 1.5 mm; axial reduction of 1 to 1.5 mm; 1.0-mm wide, 360° rounded shoulder located 0.5 mm subgingivally on the facial aspect for esthetic reasons and supragingivally on the lingual aspect on a sound tooth structure. The internal angles were rounded, and the axial walls were slightly tapered to 10° convergence. Preparations for the traditional metal ceramic single crowns and for both CAD/CAM systems' all-ceramic single crowns were the same. New diamond burs (#6855 314 025, Komet, Gebr. Brasseler Gmbh & Co.Kg, Lemgo, Germany) were mounted in a high-speed handpiece under abundant water irrigation at the initial preparation phase. [Correction added to online publication 23 October 2012: #6862 314 012 corrected to 6855 314 025.] Finishing diamond burs (#8855 314 025, Komet), mounted in a slow-speed handpiece under abundant water irrigation, were used to refine the preparations. [Correction added to online publication 23 October 2012: #8862 314 012 corrected to 8855 314 025.]

A single gingival retraction cord (Gingi-Aid Z-Twist, Gingi-Pak, Belport Co., Inc, Camarillo, CA) was packed and removed before the impression procedures. For the impression phase, 2-mm-thick custom impression trays were fabricated with Palatray LC resin (Heraeus Kulzer, Wehrheim, Germany), mixed in accordance with the manufacturer's instructions. The impression material (Impregum Penta; 3M ESPE, Seefeld, Germany) was machine-mixed (Pentamix; 3M ESPE), and part of it was meticulously syringed all around the tooth to ensure complete coverage of the tooth itself. Five minutes were allowed for setting of the impression material. The impression was then removed from the patient's mouth and poured with an American Dental Association (ADA) type IV artificial stone (New Fujirock; GC Corporation, Tokyo, Japan), following the manufacturer's instructions. Irreversible hydrocolloid impressions (Xantalgin Select fast set; Heraeus Kulzer GmbH & Co, Hanau, Germany) were made of the opposing dentitions, and impressions were poured with an ADA type IV stone (New Fujirock). The definitive and opposing casts were mounted in a semi-adjustable articulator (Whip Mix Corp, Louisville, KY). Provisional crowns were fabricated with polymethyl methacrylate (Jet; Lang Dental Mfg Co, Wheeling, IL) and cemented using eugenol-free provisional cement (Temp Bond NE; Kerr Italia, Scafati, Salerno, Italy), allowing time for fabrication of the definitive crowns.

Single crown preparation

According to a list of randomization,[36] the 30 teeth were divided into three groups:

Group C: in the control group, 10 regular metal ceramic crowns were fabricated. A noble alloy (Valcambi, Balerna, Switzerland) was used for the metal copings, and porcelain (Noritake EX-3; Noritake, Nagoya, Japan) was applied in layers to them, leaving 360° metal margins.

In the other two groups CAD/CAM technology was used for the fabrication of the zirconium-oxide copings:

Group E: 10 single crowns with zirconia copings were generated with the Echo system (Sweden & Martina SPA, Due Carrare, Italy). The layering ceramic was IPS e.max ZirPress (Ivoclar Vivadent AG, Schaan, Liechtenstein) leaving 360° zirconium-oxide margins.

Group Z: 10 single crowns with zirconia copings were generated with the Zirite system (Keramo S.p.A., Tavernerio, Italy). The layering ceramic was Triceram ceramic (Dentaurum GmbH & Co. KG, Ispringen, Germany) leaving 360° zirconium-oxide margins.

Table 1 lists all 30 teeth included in the study and their distribution among the three groups. All copings from groups C, E, and Z were 0.5-mm thick. One week after preparation and impressions, the temporary crowns were removed, and the teeth were cleaned with pumice powder and rinsed. The definitive crowns were evaluated radiographically and visually, and the marginal fit of all of the crowns considered clinically adequate. All crowns from the three groups were cemented with glass-ionomer cement (Ketac-Cem, 3M ESPE), following manufacturer's instructions.

Table 1 The 30 teeth included in the study and their distribution in the three groups

	Groups		
	C Metal ceramic	E Echo system	Z Zirite system
Maxillary central incisors	2	2	2
Maxillary lateral incisors	1	2	1
Maxillary canines	1	1	1
Maxillary first premolars	1	1	1
Maxillary second premolars	1	1	1
Mandibular canines	1	1	2
Mandibular first premolars	1	1	1
Mandibular second premolars	2	1	1

Tooth extraction and specimen preparation

All five patients in this study followed appropriate hygiene procedures. One month after cementation of the crowns, the 30 teeth were extracted, using great care to avoid any damage to the restorative material. All five patients were restored with overdentures on implants.

Microscopic evaluation

For marginal gap measurements along vertical planes, four landmarks (mesial, distal, buccal, palatal) at each tooth were defined. Marginal fit was measured at the external point where the metal or the zirconia coping met the dental structure. Measurements were performed using a microscope (Axioskop; Zeiss, Oberkochen, Germany) at a magnification of 50×. The Axioskop was connected to a digital camera (DC 200; Leica, Bensheim, Germany), and the QWINLITE program (Leica) was used for measurement. The vertical openings were recorded in microns. The marginal fits of each single crown of three groups were measured. On completion of microscopic evaluation, representative specimens from each group were prepared for environmental scanning electron microscope (ESEM) evaluation (FEI Quanta 200, Hillsboro, OR), to evaluate the marginal gaps of different groups (Figs 2–4) qualitatively. All procedures were performed by two investigators: the first prepared the specimens, while the second was blind to the treatment and performed the data analysis.

Statistical analysis

Means and standard deviations of the four landmarks (mesial, distal, buccal, palatal) at each single crown were calculated for each group. Multivariate analysis of variance (MANOVA) was performed to determine whether the four landmarks, taken into consideration together, differed between groups. Two-way ANOVA was performed to carry out a detailed study for each landmark and to determine how the three systems used to produce the crowns affected the gap measurements. Differences were considered to be significant at $p < 0.05$.

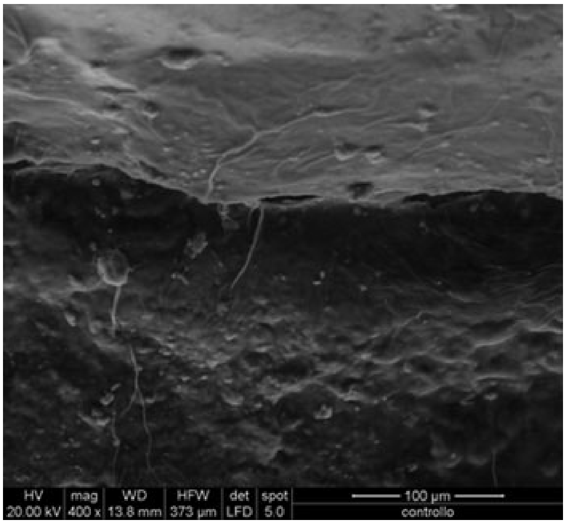

Figure 2 ESEM analysis at 400× of a group C (metal ceramic) specimen.

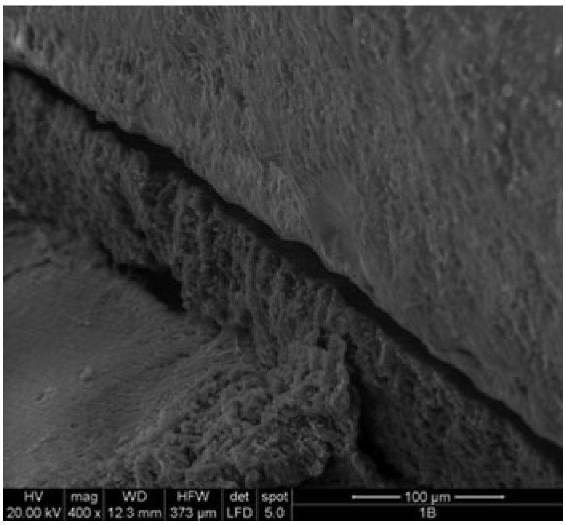

Figure 3 ESEM analysis at 400× of a group E (Echo System) specimen.

Results

Table 2 shows mean (μm) and standard deviation (μm) of the four landmarks at each crown (mesial, distal, buccal, palatal) for each group (C, E, Z). The mean values of all crowns jointly considered for the four landmarks were the following: the mean values of group C crowns were 33.42 μm; the mean values of group E crowns were 35.32 μm; and the mean values of group Z crowns were 34.18 μm.

MANOVA revealed no quantitative differences of the four landmarks, when taken into consideration together, between the three groups ($p < 0.0001$). Two-way ANOVA, performed at each landmark, revealed no quantitative differences between the three groups ($p < 0.0001$ for each landmark).

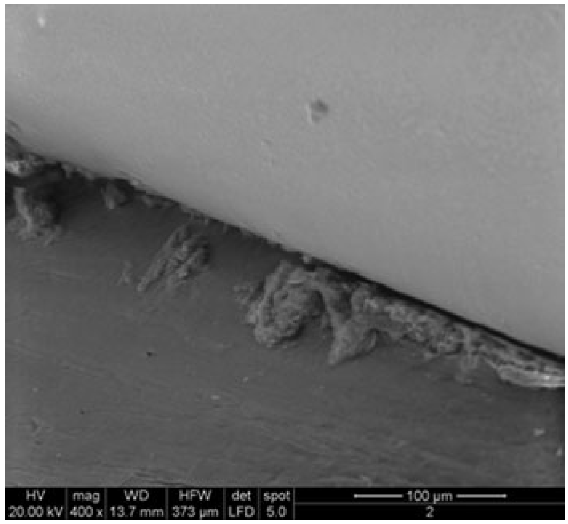

Figure 4 ESEM analysis at 400× of a group Z (Zirite System) specimen.

Table 2 Mean (μm) ± standard deviation (μm) of the four landmarks (mesial, distal, buccal, palatal) at all crowns (mesial, distal, buccal, palatal) for each group (metal ceramic, Echo system, Zirite system definitive crowns)

	Groups		
	C Metal ceramic	E Echo system	Z Zirite system
FPD mesial	33.21 ± 4.6	36.14 ± 3.6	36.62 ± 5.1
FPD distal	34.03 ± 6.0	35.10 ± 4.0	34.76 ± 6.8
FPD buccal	33.34 ± 6.7	36.62 ± 4.8	32.53 ± 6.0
FPD palatal	33.82 ± 5.5	36.54 ± 5.2	32.33 ± 4.8

Discussion

Zirconium-oxide-based ceramic CAD/CAM system crowns are relatively new. Data on fit are indicative of the marginal quality of such crowns. All in vitro studies offer standardized conditions with respect to preparation design, impression technique, or experimental performance and provide valuable information for clinical use; however, clinical evaluation contains a multitude of conditions that deviate from in vitro situations and may lead to assessments that are closer to reality. Within the limitations of this in vivo study, due to the small number of specimens tested, it was concluded that both zirconium-oxide-based ceramic CAD/CAM systems demonstrated a similar and acceptable marginal fit when compared to more traditional metal ceramic crowns, thus confirming the results of previous studies.[1,35] Microscope results were in agreement with observations made from the ESEM.

There were certain limitations to this study. Only two specific zirconium-oxide-based ceramic CAD/CAM systems were evaluated. To estimate the accuracy of the fit of crowns, measurements must be made on both vertical and horizontal planes: in this study only vertical gaps were checked. The teeth with crowns were extracted very early, only 1 month after final cementation. In addition, marginal accuracy is likely to be influenced by the tooth preparation design.[37] Further clinical investigation is necessary to evaluate the effect of different tooth preparation designs on margin distortion.

Within its limits, this study confirmed that it is possible to use CAD/CAM systems to achieve good in vivo marginal fit for single-unit crowns with the advantages of homogeneous standardized materials.[13] However, further research must be carried out, for example, concerning the effect of cementation techniques on the marginal fit of these types of crowns.[14] It is also necessary to carry out additional studies to determine the clinical risk of delamination of the veneering porcelain.

Conclusions

Within the limitations of this study, it was concluded that both zirconium-oxide-based ceramic CAD/CAM systems demonstrated a similar and acceptable marginal fit for single unit crowns when compared to more traditional metal ceramic crowns.

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