An In Vitro Evaluation of Fit of Zirconium-Oxide-Based Ceramic Four-Unit Fixed Partial Dentures, Generated with Three Different CAD/CAM Systems, before and after Porcelain Firing Cycles and after Glaze Cycles

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Abstract

Purpose: The purpose of this study was to assess in vitro the marginal fit of four-unit fixed partial dentures (FPDs) produced using three different computer aided design/computer aided manufacturing (CAD/CAM) all-ceramic systems before and after porcelain firing cycles and after glaze cycles.
Materials and Methods: An acrylic resin model of a maxillary arch was fabricated. Teeth #6 and 9 were prepared; teeth #7 and 8 were absent. Forty-five four-unit zirconium-oxide-based ceramic FPDs were made following conventional impression and master cast techniques: 15 were made with the Everest system, 15 with the Procera system, and 15 with the Lava system. Marginal gaps along vertical planes were measured for each bridge before (Time 0) and after (Time 1) porcelain firing cycles and after glaze cycles (Time 2) using a total of 8 landmarks (4 for tooth #6 and 4 for tooth #9) by means of a microscope at a magnification of ×50. MANOVA was performed to determine whether the 8 landmarks, jointly considered, differed between CAD/CAM systems and time phases. Two-way ANOVA was performed to investigate in detail, for each landmark, how gap measurements were related to CAD/CAM systems and time phases. Differences were considered to be significant at $p < 0.05$.
Results: The mean values of the Everest system (μm) were: 63.37 (Time 0), 65.34 (Time 1), and 65.49 (Time 2); the mean values of the Lava system (μm) were: 46.30 (Time 0), 46.79 (Time 1), and 47.28 (Time 2); the mean values of the Procera system (μm) were: 61.08 (Time 0), 62.46 (Time 1), and 63.46 (Time 2). MANOVA revealed quantitative differences of the 8 landmarks, jointly considered, between the three CAD/CAM systems ($p < 0.0001$), but it did not reveal any quantitative differences among the three time phases ($p > 0.4$). Two-way ANOVA revealed that the Lava system produced gap measurements statistically smaller than the Everest and Procera systems ($p < 0.0001$ for each landmark).
Conclusions: Within the limitations of this study, it was concluded that the three zirconium-oxide-based ceramic CAD/CAM systems demonstrated a comparable and acceptable marginal fit; however, the Lava system produced gap measurements statistically smaller than the Everest and Procera systems. The porcelain firing cycles and the glaze cycles did not affect the marginal fit of the zirconium-oxide-based ceramic CAD/CAM systems.

With a growing awareness of esthetics and biocompatibility, patients increasingly request metal-free solutions.[1] Due to the successful use of all-ceramic crowns both in the anterior and posterior segments,[2-6] 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[7-9] while providing enhanced esthetics.[10] 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.[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 framework has to be densely sintered for 7.5 hours at 1500°C.[15] Upon sintering, volume changes result from the relocation of material via bulk diffusion, surface diffusion, or gas phase. This may lead to a linear shrinkage of up to 15-30% 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 could lead to poor restoration fit.[16] Several authors have attempted to determine what constitutes clinically acceptable marginal openings that are not visible to the naked eye and are 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 that were considered clinically well-fitting by several dentists and reported marginal discrepancy values in a range of 7 to 65 μm. Marginal and internal accuracy of fit is valued as one of the most important criteria for the clinical quality and success of all-ceramic crowns.[19-21] Increased marginal discrepancy of a crown wad can promote the rate of cement dissolution and of microleakage.[22] Microleakage from the oral cavity is considered a cause of inflammation of the vital pulp.[23] Poor marginal adaptation of crowns can cause increased plaque retention[24,25] and change of the composition of the subgingival microflora,[26] indicating the onset of periodontal disease. Marginal discrepancies are said to favor the recurrence of caries.[27] Misfit in the axial wall area and occlusal plateau could reduce resistance to fracture of all-ceramic restorations.[28]

In vitro studies revealed mean marginal gaps of 64 to 83 μm in CAD/CAM-generated all-ceramic single-tooth restorations.[29-31] 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).[32] In vitro results on the fit of all-ceramic CAD/CAM-generated restorations are promising.[32,33] In an in vivo study, Reich et al[34] tested the marginal and internal fit of CAD/CAM fabricated all-ceramic three-unit FPDs. Twenty-four all-ceramic FPDs were fabricated and randomly subdivided into three equally sized groups. Eight frameworks were fabricated using the Digident CAD/CAM system (Girrbach Dental, Pforzheim, Germany); another eight frameworks were fabricated using the Cerec Inlab system (Sirona Dental Company, Bensheim, Germany). Vita Inceram Zirkonia blanks (Vita Zahnfabrik, Bad Säckingen, Germany) were used for both groups. In a third group, frameworks were milled from yttrium-stabilized Zirconium blanks using the Lava system. All frameworks were layered with ceramic veneering material. In addition, six three-unit metal-ceramic FPDs served as a control group. All FPDs were evaluated using a replica technique with a light body silicone stabilized with a heavy body material. The replica samples were examined under microscope. The results of this study indicated that the 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-unit 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. Few data are available concerning the effect of porcelain and glaze firing cycles on the fit of zirconia multiunit frameworks produced by CAD/CAM systems.

The aim of this investigation was to evaluate in vitro the marginal fit of four-unit zirconia FPDs produced using three different CAD/CAM all-ceramic systems before and after porcelain firing cycles and after glaze cycles.

Materials and methods

Manufacturing all-ceramic FPDs

An acrylic resin model (Blue Star type E, Breitschmid, Kriens, Switzerland) of a maxillary arch was fabricated (Fig 1). Teeth #6 and 9 were prepared. Teeth #7 and 8 were absent. The prepared margin for the zirconium-oxide-based ceramic FPDs was clearly defined by a distinct chamfer and was entirely supragingival. The circumferential reduction of tooth substance was between 1.2 and 1.5 mm. Palatal reduction was about 1.5 mm. All internal edges were rounded to an estimated radius of 0.6 mm. The retentive surface of the prepared teeth had to be at least 4-mm high with a convergence angle of about 5°. Forty-five identical 2-mm-thick custom impression trays were made with light-polymerizing composite methacrylate resin (Palatray XL, Heraeus Kulzer, Hanau, Germany), prepared according to the manufacturer's instructions. The teeth in the resin model were covered by two layers of baseplate wax (Tenasyle, Imadent, Torino, Italy) to allow a consistent thickness of impression material, and an irreversible hydrocolloid (Xantalgin Select fast

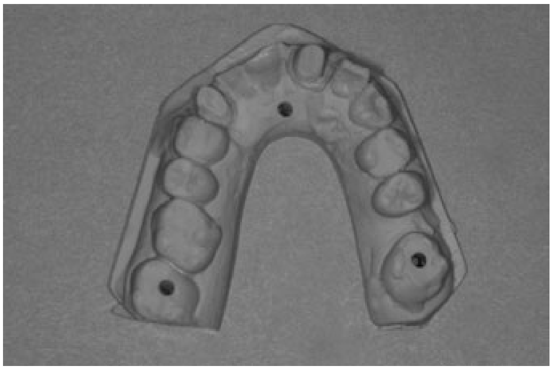

Figure 1 An acrylic resin model of a maxillary arch was fabricated. Teeth #6 and 9 are prepared; teeth #7 and 8 are absent.

set, Heraeus Kulzer) impression was made to obtain a single cast on which all custom trays were molded. Tissue stops were incorporated between teeth #6 and 9. Three location marks (circular depressions 2-mm wide and 1-mm deep) were made on the acrylic resin model (2 posterior marks, 1 anterior mark) and included in the impression trays to standardize tray positioning during impression making. The impression trays were coated with polyether adhesive (Impregum, 3M ESPE, Seefeld, Germany) 1 hour before each impression was made. Forty-five polyether impressions were made according to the manufacturer's directions: a medium-bodied consistency polyether (Impregum Penta; 3M ESPE) was used to load the impression tray, and a light-bodied consistency polyether (Permadyne Penta L, 3M ESPE) was meticulously syringed around the teeth to ensure their complete coverage. Both impression materials were machine-mixed (Pentamix, 3M ESPE). The impression tray was lowered over the reference resin model until the tray was fully seated on the three location marks and maintained in position throughout the polymerization time. Five minutes were allowed for polymerization of the impression material. An American Dental Association (ADA) type IV die stone (New Fujirock, GC Corp., Tokyo, Japan) was used to pour the impressions in accordance with the manufacturer's instructions. The casts were retrieved from the impressions after 24 hours. All clinical and laboratory procedures were performed by the same operator.

According to a list of randomization,[36] the 45 casts were sent to the scanning centers of the randomly assigned CAD/CAM system (Fig 2). Fifteen zirconia four-unit FPDs were manufactured by the use of each tested CAD/CAM system; the frameworks were veneered using appropriate layering ceramics by an experienced ceramist:

1. *Group A:* Fifteen four-unit FPDs were made with the Everest system (KaVo Dental GmbH, Biberach, Germany). The layering ceramic was the Vita D-ceramic (VITA Zahnfabrik, H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) (Fig 3A).
2. *Group B:* fifteen four-unit FPDs were made with the Procera system (Nobel Biocare, Göteborg, Sweden).[37,38] The layering ceramic was the NobelRondo Zirconia (Nobel Biocare) (Fig 3B).
3. *Group C:* Fifteen four-unit FPDs were made with the Lava system (3M ESPE).[39] The layering ceramic was the Lava Ceram (3M ESPE)[40] (Fig 3C).

A silicone mold was fabricated and used to standardize the shape of all 45 bridges. For all three groups the closing margins were made with the zirconia structure.

Measurements

For marginal gap measurement along vertical planes, four landmarks at the canine (mesial, distal, buccal, palatal) and four landmarks at the central incisor (mesial, distal, buccal, palatal) were defined, for a total of eight measurements per FPD. Marginal fit was measured at the external point where the zirconia coping met the acrylic resin model. 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 program QWINLITE (Leica) was used for measurement. The vertical openings were recorded in microns. The marginal fit of four-unit zirconium-oxide-based ceramic FPDs produced using the three CAD/CAM all-ceramic systems were measured before porcelain firing cycles (Time 0), after porcelain firing cycles (Time 1), and after glaze cycles (Time 2).

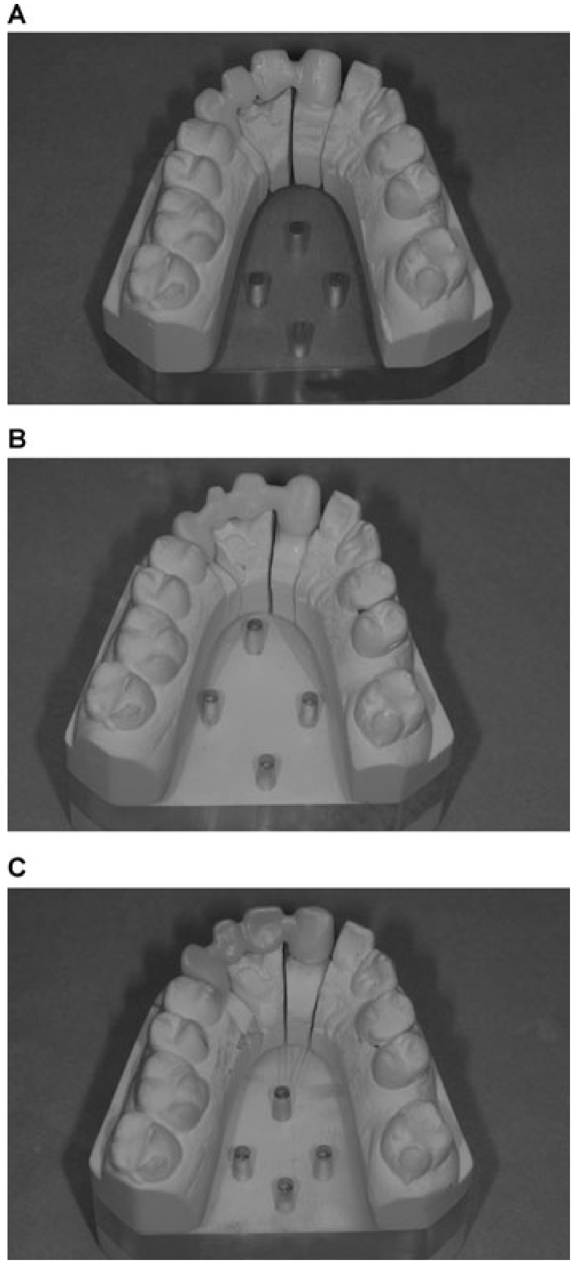

Figure 2 (A) Everest system structure; (B) Procera system structure; (C) Lava system structure.

Statistics

Means and standard deviations of the four landmarks at the canine (mesial, distal, buccal, palatal) and of the four landmarks

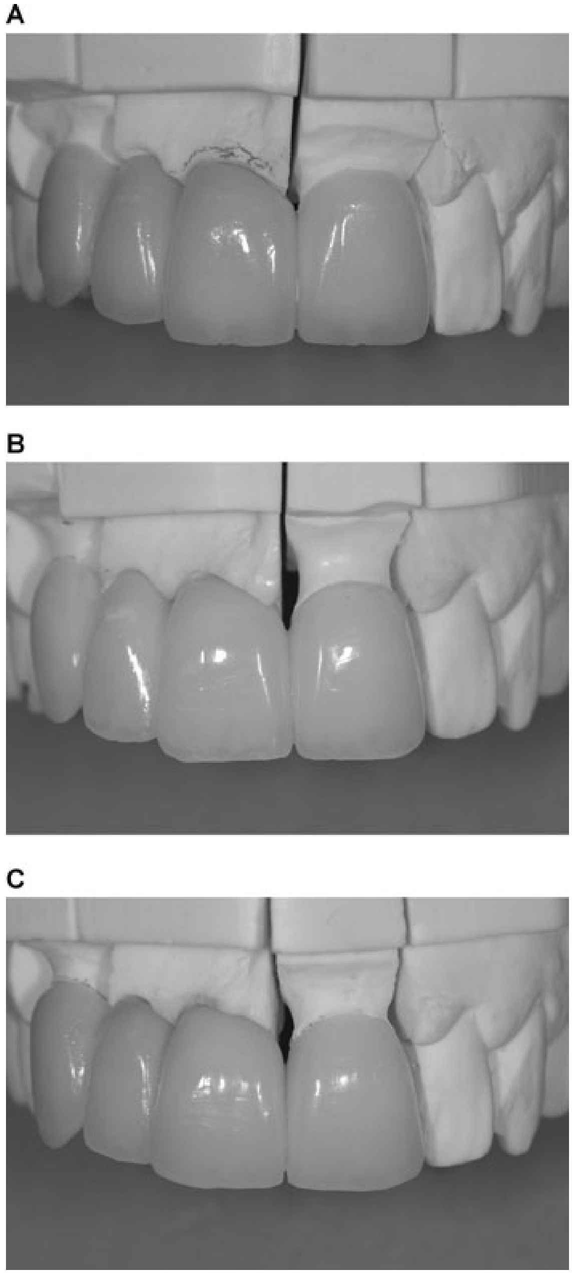

Figure 3 (A) Four-unit FPDs made with the Everest system. The layering ceramic is Vita D-ceramic; (B) four-unit FPDs made with the Procera system. The layering ceramic is the NobelRondo; (C) four-unit FPDs made with the Lava system. The layering ceramic is the Lava Ceram.

at the central incisor (mesial, distal, buccal, palatal) were calculated for each CAD/CAM system (Everest, KaVo Dental GmbH, Biberach, Germany; Procera, Nobel Biocare, Göteborg, Sweden; Lava, 3M ESPE, Seefeld, Germany), and for each time phase (before porcelain firing cycles, after porcelain firing cycles, and after glaze cycles).

Multivariate analysis of variance (MANOVA) was performed to determine whether the eight landmarks, jointly considered, differed between CAD/CAM systems and time phases. Two-way ANOVA was performed to study in detail, for each landmark, how CAD/CAM systems and time phases affected the gap measurements. Differences were considered to be significant at $p < 0.05$.

Results

Table 1 shows the means (μm) and standard deviations (μm) of the four landmarks at the canine (mesial, distal, buccal, palatal) and of the four landmarks at the central incisor (mesial, distal, buccal, palatal) for each CAD/CAM system (Everest, Procera, Lava), before porcelain firing cycles (Time 0), after porcelain firing cycles (Time 1), and after glaze cycles (Time 2). The mean gaps for each CAD/CAM system jointly considered for the four landmarks at the canine (mesial, distal, buccal, palatal) and for the four landmarks at the central incisor (mesial, distal, buccal, palatal) were the following (in μm): for the Everest system, 63.37 (Time 0), 65.34 (Time 1), 65.49 (Time 2); for the Lava system, 46.30 (Time 0), 46.79 (Time 1), 47.28 (Time 2); for the Procera system, 61.08 (Time 0), 62.46 (Time 1), 63.46 (Time 2).

MANOVA revealed quantitative differences of the eight landmarks, jointly considered, among the three CAD/CAM systems

Table 1 Mean (μm) $\pm$ standard deviation (μm) of the four landmarks at the canine (mesial, distal, buccal, palatal) and of the four landmarks at the central incisor (mesial, distal, buccal, palatal), for each CAD/CAM system (Everest, Procera, Lava), before porcelain firing cycles (Time 0), after porcelain firing cycles (Time 1), and after glaze cycles (Time 2)

		CAD/CAM System		
		Everest	Procera	Lava
Canine mesial	Time 0	63.2 ± 8.6	60.6 ± 6.1	46.1 ± 2.6
	Time 1	65.5 ± 7.3	61.1 ± 5.5	46.7 ± 2.7
	Time 2	65.1 ± 7.1	61.1 ± 5.4	47.3 ± 2.3
Canine distal	Time 0	64.0 ± 7.0	62.7 ± 5.8	45.0 ± 3.0
	Time 1	64.9 ± 6.3	64.1 ± 5.1	45.6 ± 3.1
	Time 2	65.7 ± 7.0	65.0 ± 5.4	45.9 ± 2.7
Canine buccal	Time 0	63.2 ± 7.7	62.5 ± 5.0	46.6 ± 3.8
	Time 1	65.0 ± 6.0	63.9 ± 4.6	46.6 ± 3.8
	Time 2	65.5 ± 5.5	64.5 ± 5.2	47.9 ± 3.5
Canine palatal	Time 0	63.9 ± 8.5	60.3 ± 6.8	46.5 ± 5.2
	Time 1	66.5 ± 6.5	61.5 ± 5.5	46.9 ± 4.7
	Time 2	63.7 ± 16.5	63.4 ± 5.6	47.9 ± 3.9
Central incisal mesial	Time 0	62.5 ± 8.9	61.1 ± 6.2	46.6 ± 3.9
	Time 1	65.3 ± 5.7	62.0 ± 6.4	46.8 ± 3.9
	Time 2	65.3 ± 5.7	62.9 ± 6.2	46.7 ± 3.3
Central incisal distal	Time 0	62.6 ± 7.6	60.2 ± 7.0	45.7 ± 3.5
	Time 1	65.2 ± 4.8	62.7 ± 4.5	47.1 ± 3.3
	Time 2	66.1 ± 4.7	63.4 ± 3.9	46.5 ± 3.4
Central incisal buccal	Time 0	65.5 ± 6.8	60.5 ± 5.6	47.2 ± 4.8
	Time 1	66.5 ± 5.0	62.3 ± 6.5	47.3 ± 4.5
	Time 2	67.1 ± 5.3	63.6 ± 7.1	48.5 ± 4.8
Central incisal palatal	Time 0	62.1 ± 9.1	60.7 ± 5.2	46.7 ± 4.6
	Time 1	63.9 ± 6.7	62.3 ± 5.2	47.4 ± 4.4
	Time 2	65.5 ± 6.7	63.8 ± 5.6	47.5 ± 4.4

($p < 0.0001$), but it did not reveal quantitative differences among the three time phases ($p > 0.4$).

Two-way ANOVA, performed at each landmark, revealed quantitative differences between the three CAD/CAM systems ($p < 0.0001$ for each landmark); moreover, Everest and Procera systems were not statistically different for the landmark at the canine distal ($p > 0.40$), buccal ($p > 0.35$), or palatal ($p > 0.05$), or at the central incisal mesial ($p > 0.05$) and palatal ($p > 0.20$). Furthermore, two-way ANOVA revealed that the Lava system produced gap measurements statistically smaller than the Everest and Procera systems ($p < 0.0001$ for each landmark).

Finally, two-way ANOVA did not reveal quantitative differences between the three time phases, except for the landmark at the central incisal distal ($p < 0.05$), in which measurements at Time 0 were statistically different from measurements at Times 1 and 2 ($p < 0.05$).

Discussion

Zirconium-oxide-based ceramic CAD/CAM system FPDs made of three or more units are relatively new. Data on fit are indicative of the marginal quality of such FPDs. All in vitro studies have offered standardized conditions with respect to preparation design, impression technique, or experimental performance and may provide valuable tips for clinical use; however, clinical evaluation includes a multitude of conditions that deviate from in vitro situations and may lead to assessments that are possibly closer to reality. Within the limitations of this in vitro study, due to the small number of specimens tested, it was concluded that all three zirconium-oxide-based ceramic CAD/CAM systems demonstrated a comparable and acceptable marginal fit; however, the Lava system produced gap measurements statistically smaller than the Everest and Procera systems. The porcelain firing cycles and the glaze cycles did not affect the marginal fit of the zirconium-oxide-based ceramic CAD/CAM systems.

There were some limitations to this study. To evaluate the accuracy of the fit of restorations, measurements should be made for both vertical and horizontal planes: in this study, only vertical gaps were checked. The crowns were not subjected to an artificial aging process: thermal cycling and mechanical loading are generally used to simulate oral conditions. Hung et al[41] demonstrated a significant negative effect of thermal cycling on marginal fit of crowns; however, Beschnidt and Strub[42] demonstrated that there was no significant effect of an aging procedure on marginal fit. In addition, marginal accuracy may be influenced by tooth preparation design.[43] Further investigation is necessary to evaluate the effect of tooth preparation designs on the marginal distortion.

Within the examined limits, this study confirmed that it is possible to use CAD/CAM systems to achieve good in vitro marginal fit with the advantages of homogeneous standardized materials;[13] however, further research should be carried out, for example, concerning the effect of cementation techniques on the marginal fit of these types of restorations.[14] Additional studies regarding the clinical risk of delamination of the veneering porcelain or the fracture through the framework at the connector or at the retainers should also be conducted.

Conclusions

Within the limitations of this study, it was concluded that:

1. The three zirconium-oxide-based ceramic CAD/CAM systems demonstrated a comparable and acceptable marginal fit; however, the Lava system produced gap measurements statistically smaller than the Everest and Procera systems.
2. The porcelain firing cycles and the glaze cycles did not affect the marginal fit of the zirconium-oxide-based ceramic CAD/CAM systems.

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