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Marginal Adaptation and Internal Fit of Posterior 3-Unit Zirconia FPDs Fabricated with Different CAD/CAM Systems

Keywords

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ABSTRACT

The purpose of this study was to compare the accuracy of zirconia FPDs fabricated by different laboratory CAD/CAM system. Thirty-six FPD zirconia frameworks were fabricated on corresponding epoxy resin models that were duplicated from a master model of mandibular second premolar and second molar mounted in an acrylic block to simulate missing first mandibular tooth. Frameworks were divided into groups ($n = 12$) of three laboratory CAD/CAM systems: Cercon, Amann Girrbach, and Zirkonzahn. For the two factors, system and abutment type, the absolute marginal discrepancy (AMD) was measured before cementation. Internal fit was also determined at three sites after cementation. The data were analyzed statistically ($\alpha = 0.05$). The effects of system and tooth type were not significant for AMD ($p > 0.05$). Both factors showed influence on the internal fit of FPDs ($p < 0.05$). Molars showed larger gaps in axial and occlusal sites ($p = 0.001$ and $p = 0.003$), and Cercon led in better occlusal adaptation compared with Amann Girrbach ($p = 0.013$). The systems tested did not show differences in AMD, despite different incorporated components. However, internal fit was significantly different between tooth type and system.

INTRODUCTION

Esthetic restorations are in increased demand in dental practice. Because of the low strength of most original dental ceramics, their indications have been limited to the anterior zone and low-stress areas. The advent of zirconia ceramic in combination with CAD/CAM technology has extended the application of all-ceramic restorations, even to load-bearing posterior areas, due to its toughness as well as biocompatibility and esthetic appeal.[1] The strength and durability of zirconia fixed partial dentures are reported to be comparable with those of conventional metal-ceramic FPDs.[2]

The utilization of CAD/CAM techniques has introduced automation to the restoration fabrication process, with the concomitant elimination of manual errors such as can occur during waxing and casting. Although there are certain limitations inherent to CAD/CAM equipment that may impair the accuracy of the final product[3] – for example, in the fabrication of zirconia-based restorations – most modern CAD/CAM systems use semi-sintered blocks of ceramic due to feasibility of the milling process and improved speed. However, the subsequent sintering step can cause a considerable amount of shrinkage, approximately 25%. Therefore, a larger coping has been designed to compensate for sintering shrinkage.

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The accuracy of this step depends on the accuracy of computer software and the homogeneity of the zirconia block [3]. Moreover, the accuracy of scanners, the precision of machining parts, and milling design could also influence the quality of the restorations produced.[4]

Clinically, accuracy has been linked to the internal fit and marginal discrepancies of the restorations. Lack of appropriate marginal adaptation could lead to periodontal disease due to plaque accumulation, and to secondary caries and endodontic inflammation because of bacterial microleakage, also causing restoration loss subsequent to cement layer disintegration.[5] In addition to improved strength, a sufficient internal fit is required for retentive and resistant forms of prostheses. Insufficient internal fit results in a thicker cement layer that could compromise ceramic strength.[5,6]

Investigation of previous clinical trials revealed that the incidence of clinical complications was higher with zirconia compared with conventional metal-ceramic FPDs over up to 5 years of clinical observation.[7] Marginal discrepancy was found to be as high as 56.7% in multi-unit FPDs made by one CAM system over three years.[3] Posterior three-unit zirconia FPDs fabricated with CAD/CAM technology exhibited larger internal gaps than those constructed by conventional metal-ceramic techniques.[8] Several factors have been proposed to affect the marginal fit of zirconia restorations, including the state of the zirconia being used (fully sintered or pre-sintered), marginal design, edentulous span, type of abutment, veneering procedures, and fabrication systems.[9] Nevertheless, controversial results have been reported over the studies.

The marginal gap in a three-unit FPD fabricated with two different CAD/CAM systems (Everest and Lava) was found to be comparable with that in a metal-ceramic FPD and within the clinically acceptable range.[10] However, the marginal discrepancy of CAD/CAM zirconia crowns was higher than that in lithium disilicate CAD/CAM crowns fabricated with the same system.[11] Conversely, in a study by Hamza *et al.*[12], the vertical marginal gap of two CAD/CAM systems, Everest and Cerec InLab, was tested in crowns made of zirconia and lithium disilicate materials. No significant difference between the materials was found. However, the manufacturing systems influenced the vertical marginal discrepancy of the crowns. The authors correlated their findings mainly to the difference in the milling systems.

Therefore, manufacturing companies are encouraged to improve their products to lower the likelihood of inaccuracies.[3] Regardless of the commercial brands, and with the exception of one system (Nobel Biocare's Procera), the scanners can use either a laser beam or a white light for scanning. Although there is no evidence demonstrating the superiority of either, it is claimed that white light presents greater potential for capturing details of the scanned objects.[13] In addition, the milling machinery has been upgraded to devices with multiple axes of motion to mill the curvature required for sculpting a natural contour for restorations.[14] To the knowledge of the authors, the abovementioned systems have been compared in only a limited number of studies.

Therefore, the aim of the present study was to compare the internal fitness and marginal gap of three-unit zirconia FPDs fabricated by three different CAD/CAM systems. Our working hypothesis was that the manufacturing system would have no influence on the internal fitness and marginal gap of those FPDs.

MATERIALS AND METHODS.

A model of mandibular premolar and molar teeth (Typodont) were used to simulate missing first molar. Teeth were mounted in an acrylic block (3.0 × 1.5 × 15 mm) by means of auto-polymerizing acrylic resin (Tray Material). A silicone mold (Putty material) was made to control the reduction. A conventional preparation for a full-ceramic crown, 2 mm reduction of the occlusal surface followed by axial reduction leading to a 1.5 mm circumferential round shoulder, was performed by means of a diamond bur (ISO 856.016). Abutments were prepared by means of a milling device to ensure an axial 6-degree taper. After the model was finished and polished, the occlusal heights of the premolar and molar were 5 mm and mesiodistal widths were 4.5 mm and 7.5 mm, respectively. The model was surveyed for an undercut-free path of insertion. Custom trays were fabricated with an auto-polymerized acrylic resin (Tray Material) with a uniform space of 4 mm. An impression was taken with a polyvinyl silicon material (Light body; Panasil). Thirty-six impressions were made and filled with epoxy resin materials with high dimensional precision (Megatool EPH 5162) to produce 36 epoxy resin models, each divided randomly among three groups based on the CAD/CAM systems. In group CC, resin models were digitized by means of a laboratory scanner (D-700). The scanner uses a laser beam and two cameras to capture the 3D profile of the model's surface with an accuracy of 20 µm. The software (Dental Designer) provided a 3D file of the scanned model. In the digital file, the framework was designed with a uniform thickness of 0.5 mm and a 35-µm cement space thickness. The designed framework was exported to a 4-axis milling unit (Cercon Brain Expert), where the frameworks were milled out of partially sintered zirconia disks (Cercon Zr Disk). In group ZZ, the models were scanned by means of an optical strip-light scanner (S600 ARTI). The scanner was equipped with twin cameras with an accuracy of 7 µm. The digital data for models were used by Zirkonzahn CAD/CAM software to design the frameworks similar to those for the previous groups. The frameworks were milled by the Zirkonzahn milling system (Milling Unit M2), which consisted of 5 axes and used presintered zirconia material (Prettau Zirconia; Zirkonzahn).

In the third group, AG, the models were scanned by means of an optical scanner with two cameras (Ceramill Map 400). The framework designs were completed with Ceramill CAD software (Ceramill Mind), and the frameworks were milled from presintered zirconia disks (Ceramill ZI) with a 5-axis milling device (Ceramill motion 2). All frameworks had the uniform thickness of 0.5 mm with a cement space of 35 microns. The connector dimensions were 3 mm in height and 3 mm in width. Frameworks were heated to reach their final strength in a corresponding sintering oven.

Each framework was examined on its corresponding die *(Figure 1)*. An experienced technician (minimum experience of 10 years) checked the fit of frameworks from each system three times, using a silicone-disclosing material (Fit Checker), and maximum and absolute marginal discrepancy (AMD)[15] was measured mid-buccally, mid-proximally (non-pontic side), and mid-lingually, and at three extra points on each side with a 100-µm interval (total of 21 points per abutment). An average value was regarded as the AMD of that point. All measurements were performed by a stereomicroscope (Leica M205) at a magnification of 75x with the aid of digital software (Dino-lite Digital).

Finally, the frameworks were steam-cleaned and cemented to their corresponding models using a dual-polymerized MDP-containing resin cement (Panavia F2). A 5-kg weight was applied during the initial setting of the cement. The specimens were then light-polymerized with a light unit (D75) for 60 s on each side at 600 mW/cm^2 and at a distance of 1.0 mm. All specimens were stored in distilled water for 24 hours, then cut to yield abutments in halves. Internal fit was then measured at 6 pre-determined sites, on each axial walls, the occlusal surface and at the finish lines *(Figure 2*). At each sites, 6 points with 100-µm interval were measured using a stereomicroscope (Leica m205) ((total of 18 points per abutment) at a magnification of 75x with the aid of digital software (Dino-lite Digital) *(Figure 3*). An average of measurements has been recorded. The mean differences of AMD and internal fit of the abutments and the three systems were statistically analyzed by two-way ANOVA and a *post hoc* test.

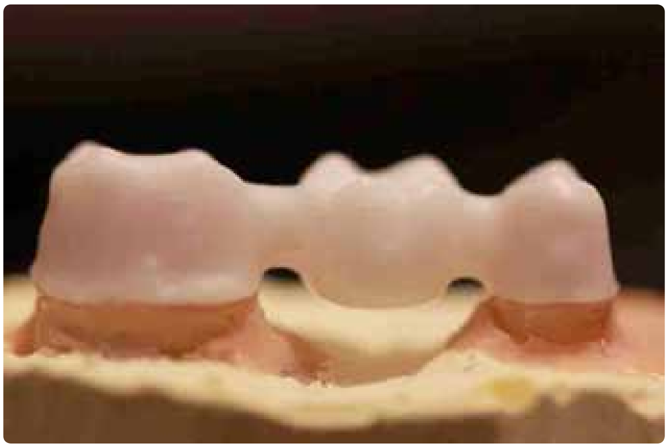

Figure 1: A three-unit FPD on its corresponding epoxy resin dies.

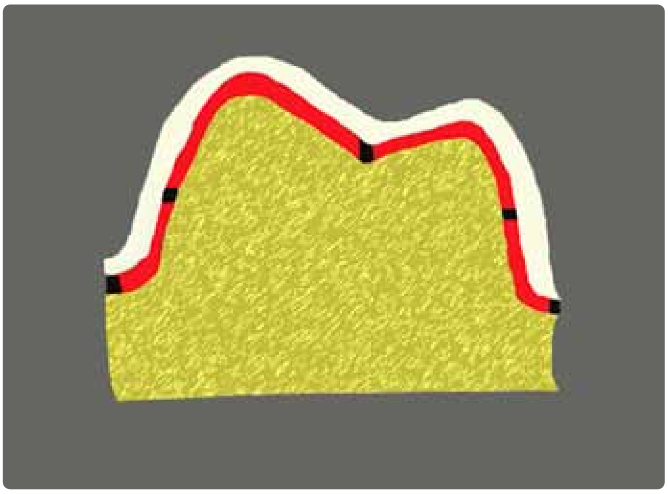

Figure 2: Measurement locations for internal gap.

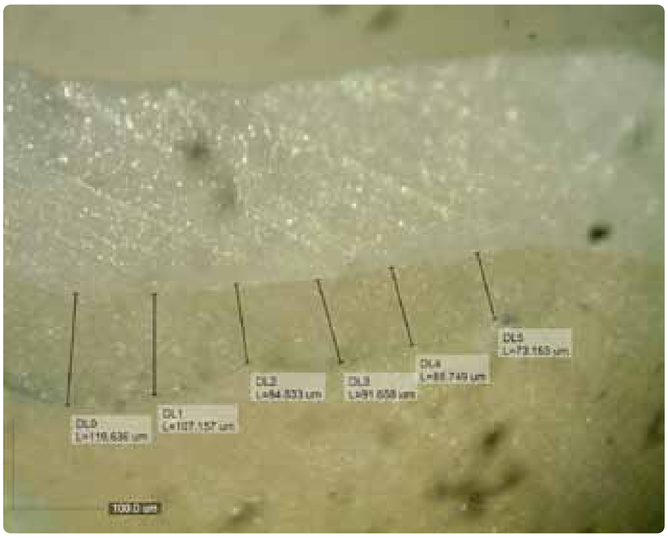

Figure 3: An example of internal gap measurement by stereomicroscope (magnification of ×75).

RESULTS

The AMD and internal fit of frameworks in two abutments and among three systems are summarized in Tables 1 and 2. Before cementation, for AMD, there was no significant difference in any of the groups or between premolars and molars ($p > 0.5$). Furthermore, for all measurements, the interaction of systems and abutment types was not significant ($p > 0.5$). After cementation, regardless of the manufacturers, while abutment types did not affect the marginal gap ($p > 0.05$), the gap in axial and occlusal sites in molars was higher than that in premolars ($p = 0.001$ and $p = 0.003$). Furthermore, at the manufacturer level, occlusal discrepancy was found to be significantly better for Cercon compared with Amann Girrbach ($p = 0.013$) *(Figure 4*).

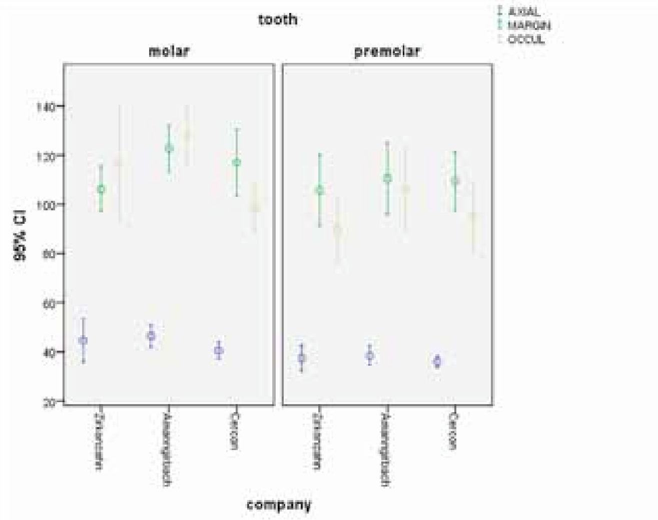

Figure 4: Internal fit of two abutments at different locations.

Table 1. Mean values, standard deviation and statistical grouping of AMD for test groups measured before cementation.

System	Abutment	Number	Minimum (μm)	Maximum (μm)	Mean (μm)	Std. Deviation (μm)
Zirconzahn	Molar	12	64.35	156.95	102.85	26.10
	Premolar	12	80.80	131.25	106.23	16.62
Amann Girbach	Molar	12	46.70	111.40	84.56	19.80
	Premolar	12	86.60	132.80	108.76	15.90
Cercon	Molar	12	67.95	161.20	113.23	34.21
	Premolar	12	25.70	147.30	112.92	35.81

Table 2. Mean values, standard deviation and statistical data of the total internal gap for test groups measured at reference points.

Company	Abutment	Location	Number	Minimum (μm)	Maximum (μm)	Mean (μm)	Std. Deviation (μm)
Zirkonzahn	Molar	Axial	12	31.10	79.94	44.58	13.63
		Margin	12	85.20	135.04	106.15	14.67
		Occlusal	12	92.73	233.00	118.67	37.20
	Premolar	Axial	12	23.45	51.31	37.39	8.33
		Margin	12	67.19	165.61	105.76	22.75
		Occlusal	12	39.38	109.48	89.66	21.09
Amann Girbach	Molar	Axial	12	32.27	55.12	46.38	7.26
		Margin	12	100.06	148.49	122.69	14.87
		Occlusal	12	104.33	161.05	128.13	17.92
	Premolar	Axial	12	29.00	54.08	38.42	6.27
		Margin	12	61.76	144.47	110.44	22.95
		Occlusal	12	79.10	160.02	106.19	26.47
Cercon	Molar	Axial	12	33.01	49.26	40.48	5.42
		Margin	12	91.83	153.78	116.92	21.36
		Occlusal	12	79.51	128.29	98.72	15.14
	Premolar	Axial	12	31.25	40.52	36.90	3.49
		Margin	12	81.02	142.67	109.39	18.70
		Occlusal	12	66.75	138.23	94.61	21.98

DISCUSSION

In the present study, the marginal adaptation of three-unit zirconia FPDs was investigated among three CAD/CAM systems. Although several recent studies have focused on the same subject, only a few investigated multiple-unit FPDs, reporting that the accuracy of a zirconia single coping was better than that of an FPD.[16] Furthermore, the marginal gap could be less accurate when the pontic span is increased.[17,18]

In addition, the accuracy of FPDs fabricated by CAD/CAM technology may differ relative to tooth type.[16,19,20] Therefore, in our study, the accuracy of three-unit FPDs fabricated by three systems and within abutments was compared. Marginal accuracy of four-unit zirconia FPDs has been compared among four systems (Kohorst *et al*.).[17] The mean values of marginal gap were not reported within individual abutment types, and the overall mean AMD values were found to be in the range of 37.6 ±14.8 µm to 109.1±31.1 µm. The lowest gap was found in Everest, whereas the highest belonged to the Cercon group, although the latter was a CAM-only manufacturing process in that a wax-up had to be made first and the digital image was then produced by scanning the wax-up with a laser-beam scanner (Cercon Brain). Song *et al*.[10] studied the AMD of anterior zirconia FPDs fabricated by two CAD/CAM systems, with metal-ceramic FPDs as the control group. The reported values showed significantly better results for FPDs made by the Everest system (60.46 ± 21 µm) than by the Lava system (78.71 ± 29.24 µm) and the metal-ceramic control group (81.32 ± 13.89 µm). Conversely, no difference was found between the AMD at the finish lines of frameworks fabricated with three systems and conventional PFMs in a study by Buchi *et al*.[21] However, the mean values were 107 ± 26 µm in the control group, 140 ± 26 µm in the Cercon CAM-only group, 104 ± 40 µm in the Cerec InLab group (Sirona), and 95 ± 31 µm in the Everest group. Again, the abutment types were not tested individually.

In our study, AMD values were found not to be significant among the systems or between tooth types. The mean values for premolars were 108 ± 18 µm and for molars 102 ± 28 µm in Zirkonzahn, for premolars 108 ± 15 µm and for molars 88 ± 19 µm for Cercon, and for premolars 112 ± 35 µm and for molars 113 ± 34 µm for Amann Girrbach. These values are higher than those reported in similar studies. The contributing parameters are discussed later. In our study, in addition to AMD, internal fit was also examined.

It is believed that mechanical performance of all-ceramic restorations is supported by their internal adaptation. Any internal misfit should be occupied by luting cement. It has been shown that residual stress in a thick cement layer can distribute unfavorable stress in the ceramic that may eventually promote fracture and weaken the strength of the ceramic material.[22]

A range of 49-135 µm of internal gap has been reported as clinically acceptable.[19] However, in a study on the effect of cement thickness on the fracture strength of all-ceramic crowns, it was shown that cement thickness of 70.0 µm performed better than 120.0 µm.[23] In our study, although the internal fit was measured at three sites (occlusal, axial, and marginal), only at the occlusal surface was a significant difference observed. All test groups showed significantly better fit for premolars than for molars. The worst value was identified in molars of the Amann Girrbach group (128.1 ± 17.9 µm), which is beyond the acceptable range. FPDs fabricated by the Cercon system showed better results than the other two groups. For comparison, few studies have been found conducted with similar settings. Beuer *et al*.[20] evaluated the precision of fit of frameworks made with two CAD/CAM systems (Etkon and Cerec InLab) and a CAM/only (Cercon) system. The marginal adaptation was also compared within abutment types (premolar and molar). Their results revealed significant differences between systems and abutment types at the measured sites. The mean marginal fit and internal adaptation were 29.1 ± 14.0 µm and 62.7 ± 18.9 µm for Etkon, 56.6 ± 19.6 µm for Cerec InLab, and 81.4 ± 20.3 µm and 119.2 ± 37.5 µm for the CAM-only system. However, the sites of difference were not similar to those found in our study. In several studies, the Cercon CAM/only system revealed significant misfit.[20,21] However, in our study, the incorporation of the Cercon-3Shape CAD/CAM system showed improvement and no difference in AMD and internal fit when compared with two integrated systems (Zirkonzahn and Amann Girrbach) and obtained even better results with occlusal discrepancy. A larger gap in the occlusal area is expected in CAD/CAM-fabricated FPDs.[17,22,24]

This observation could be explained partially by volume shrinkage of the pre-sintered zirconia blocks during sintering procedures. As such, the ceramic volume is larger for molars than for premolars or incisors. The scanner resolution has been stated as another contributing factor.

Regardless of scanner mechanisms, the captured data are in the form of numerous point clouds that should be converted to a clinically usable 3D image format. The accuracy of the final image depends on multiple factors, among which are the particular scanner's hardware and software. For example, undercuts and sharp edges can lead to missing data during the scanning process. There are several algorithms to compensate for the kinds of errors in data acquisition and to generate a closest-matched 3D image to the captured datapoints.[13,14]

As a result of compensation, some sharp edges may be rounded to some extent, which may cause internal discrepancies. According to the literature, occlusal surface and cavosurface lines of marginal areas of preparation are more prone to such errors, which may explain the higher gap in these areas than in axial walls. Furthermore, marginal gap and/or internal misfit of the anterior bridge is expected to be less than in posterior FPDs due to flatter and simpler topography of anterior abutments.[10] Conversely, it has been argued that dies with smaller sizes could produce more scanner errors.[22] "Small size" refers to a standardized metal die 0.6 mm in diameter and 4.5 mm in height. The hypothesis did not apply to our findings, in that the smaller abutment obtained better marginal accuracy. More research is required for a definitive conclusion to be drawn.

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The occlusal seating and vertical discrepancy of crowns have also been correlated to several other factors such as axial wall taper, marginal design, and cement space.

In general, researches are consistent that more parallel walls are associated with more occlusal discrepancy.[25] Shoulder preparation, which is believed to give rise to a larger marginal opening, facilitates better occlusal seating compared with chamfer.

Finally, thicker cement space provides more freedom for cement outflow and better seating. However, both total occlusal convergence of the preparation and cement space were smaller in the study by Beuer *et al.*[20] than in ours (20-30 μm and 50 μm, respectively). Despite this, the marginal gap and internal fit were found to be lower in their study. In addition to different methods and materials, system-related factors – such as the accuracy and quality of scanners, the design software, and the milling device – could contribute to the dissimilarity of these results. The Everest CAD/CAM system, which was investigated in other studies, and the Zirkonzahn system, in our study, both use an optical scanner and a 5-axis milling device. However, diverse results were found. Even similar systems could provide different results over various studies.[21,24]

The systems tested in our study incorporate different milling devices with different movement ability, a 5-axis milling device in the AG and ZZ groups, and a 4-axis milling machine in the C groups. Generally, with more axis of motion, more detailed milling of surface features of the restorations can be expected. In our study, however, no significant differences were found in marginal gaps among the FPDs in the test groups. In fact, internal fit of Cercon with the 4-axis milling device showed better results. It is argued that unless the size of the milling bur is fine enough to fit into the curves of the surface profile, increasing flexibility in motion does not automatically produce a more precise product. In our study, the bur size was 1 mm in all groups. Thus, a 5-axis milling and/or devices may be further indicated in full-contour monolithic milling and/or inlays and onlays.[14]

However, the results cannot be simply extrapolated to real clinical conditions, in that several common errors may cause the preparations to deviate from standard and may compromise the accuracy of final restorations. Renne *et al.*[26] evaluated the marginal gaps of lithium disilicate ceramic crowns made by a CAD/CAM and concluded that any flaws in preparation could result in poorer marginal gap. Lipped margins, sharp cervico-axial line angles, and beveled and/or spiked finish lines have been cited as the most common errors. Therefore, this may imply that, in 'real' circumstances, the use of a more accurate milling device and/or a finer bur may facilitate better results. However, the duration of the milling period increases accordingly. In addition, the burs should be replaced after shorter service.

Our findings, in accordance with those of the majority of related studies, showed that despite the statistically significant difference in the marginal gaps of test groups, most of the obtained values fit well in the acceptable clinical range (i.e., under 120 μ). However, it is argued that, in clinical situations, the maximum gap size defines the integrity of a restoration. In other words, despite an acceptable mean value, a large gap at one site may compromise marginal integrity and promote cement degradation, recurrent caries, and/or periodontal problems. Therefore, Rinke *et al.*[24] suggested that the maximum marginal gap should also be analyzed. The maximum marginal gap between groups was not statistically analyzed here due to insufficient sample size, which might be regarded as a limitation of the present study. Additionally, it would be more valuable if the result could be examined against a control group or a gold standard method.[22] However, by far CAD/CAM technology is the most common method used for fabrication of zirconia restorations and no gold standard has been established among available systems.[9] Nonetheless, comparison the systems could provide information about their performance and possible rating.[6,12,21,10]

In our study, the combined conditions of each system have been investigated, and the findings could not be related directly to a specific component of each system. For example, with Cercon, a laser beam scanner and a 4-axis milling device were used, whereas an optical strip light scanner and a 5-axis milling device were incorporated by Zirkonzahn, while Amann Girrbach used an optical scanner and a 5-axis milling device. Thus, an understanding of the details of the effect of each part (i.e., scanner, software, and milling device) appears to require further study.

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CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that, in an ideal preparation, an acceptable marginal gap could be reached in three-unit zirconia FPDs fabricated by different manufacturers. However, CAD/CAM systems could influence the internal fit of those FPDs.

CLINICAL SIGNIFICANCE

CAD/CAM manufacturing companies have improved their systems and machinery to achieve better end-products. Investigating the accuracy of restorations made by these systems helps both clinicians and technicians in employing them.

MANUFATURERS' DETAILS

- Typodont; Nissin Dental Product Inc., Kyoto, Japan

- Tray Material; Major, Moncalieri, Italy
- Putty material; Spidex; Coltène/Whaledent GmbH, Langenau, Germany
- Diamond bur; ISO 856.016, D+Z, Lemgo, Germany
- Light body; Panasil, Kettenbach & Co., Eschenburg, Germany
- Megatool EPH 5162; Ghaffari Chemicals Inc., Tehran, Iran
- D-700; 3Shape A/S; Copenhagen, Denmark
- Dental Designer; 3Shape A/S, Copenhagen, Denmark
- Cercon Brain Expert; Dentsply, York, PA, USA
- Cercon Zr Disk; DeguDent, Hanau, Germany
- S600 ARTI; Zirkonzahn, Gais, Italy
- Milling Unit M2; Zirkonzahn, Gais, Italy
- Prettau Zirconia; Zirkonzahn, Gais, Italy).
- Ceramill Map 400; Amann Girrbach GmbH, Pforzheim, Germany
- Ceramill Mind; Amann Girrbach GmbH, Pforzheim, Germany
- Ceramill ZI; Amann Girrbach GmbH, Pforzheim, Germany
- Ceramill motion 2; Amann Girrbach GmbH, Pforzheim, Germany
- Fit Checker; GC Corporation, Tokyo, Japan
- Leica M205; Leica, Vienna, Austria
- Dino-lite Digital, Tokyo, Japan
- Panavia F2; Kuraray, Osaka, Japan
- D75; Coltolux/Whaledent, Cuyahoga Falls. OH, USA

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