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ORIGINAL ARTICLE

Influence of framework configuration on the marginal adaptation of zirconium dioxide ceramic anterior four-unit frameworks

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Abstract

Objective. To evaluate the influence of the framework configuration on the marginal adaptation of four-unit anterior fixed partial denture (FPD) frameworks made of partially sintered zirconium dioxide (ZrO_2) ceramics. ***Material and methods.*** Forty-eight standardized partially sintered ZrO_2 ceramic four-unit FPD frameworks were fabricated using three different CAD/CAM systems: Cercon Smart Ceramics (group CE), Vita YZ/Cerec In-Lab (group YZ/CL), and Xawex (group XA). Two different framework configurations (straight and curved) were manufactured for each group. The marginal adaptation of the frameworks was measured at 60 different points across the entire circumferential margin using a stereomicroscope. Marginal discrepancy values were compared between the two framework designs and between the three test groups using the *t*-test. The overall level of statistical significance was 5% after correcting the *p*-values using the Bonferroni–Holm method. ***Results.*** The following geometrical means of the marginal discrepancies were obtained for the curved/straight design: group CE, 120.0 μm/88.0 μm; group YZ/CL, 96.8 μm/86.5 μm; and group XA, 147.3 μm/113.4 μm. Significant differences were detected between the straight and curved designs for groups CE ($p = 0.001$) and XA ($p = 0.003$), but not for group YZ/CL ($p = 0.225$). For both designs, the marginal discrepancies were significantly smaller in group YZ/CL than in group XA. For the curved design, the marginal discrepancies in group YZ/CL were also significantly smaller than those in group CE. ***Conclusions.*** Within the limitations of this study, the framework configuration influences the marginal adaptation of anterior four-unit FPD frameworks that are manufactured from partially sintered ZrO_2 ceramics independently of CAD/CAM system.

Key Words: *CAD/CAM*, *distortion*, *shrinkage*, *zirconia*

Introduction

Several treatment modalities are available for the replacement of two missing maxillary incisors. These include a partial or full-coverage fixed partial denture (FPD), a removable partial denture or fixed implant-supported crowns. Four-unit porcelain-fused-to-metal (PFM) FPDs can restore function, comfort and esthetics in a highly satisfactory manner [1] with a good long-term prognosis [2–5]. Generally, FPDs are more effective than removable partial dentures in terms of patient comfort and acceptance [6,7]. Successful single-tooth replacement with osseo-integrated implants has been well documented in the dental literature [8–10]. However, deficiencies in the quality and/or quantity of the hard and soft tissues mean that simultaneously placed paired implant-supported restorations in the anterior maxilla cannot always meet the esthetic and biomechanical requirements [11,12].

The PFM technique, which was introduced in the late 1950s, is the most commonly used procedure in fixed prosthodontics. PFM restorations have several disadvantages, however, including gingival discoloration [13], opacity [14,15], and a slight risk of gingivostomatitis caused by metal allergy [16,17]. In recent years, the increasing demand for esthetic restorations has led to greater use of all-ceramic materials owing to their high biocompatibility and superior esthetics compared with PFM restorations [18–20]. In addition, the development of computer-aided design/computer-aided manufacturing (CAD/CAM) systems for the fabrication of all-ceramic FPDs has promoted their use in daily private practice. Data on the clinical reliability

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Table I. Used ceramics, CAD/CAM systems and manufacturers

Group	Ceramic systems	Manufacturer	CAD/CAM systems	Manufacturer
CE	Cercon Smart Ceramics	DeguDent, Hanau, Germany	Cercon Smart Ceramics	DeguDent, Hanau, Germany
YZ/CL	Vita YZ	Vita, Bad Säckingen, Germany	Cerec inLab	Sirona, Bensheim, Germany
XA	Xawex	Xawex AG, Fällanden, Switzerland	Xawex	Xawex AG, Fällanden, Switzerland

of In-Ceram® FPDs have recently been published and the long-term prognosis is promising [21,22]. However, only short-term data are available for zirconium dioxide (ZrO_2) ceramic four-unit FPDs [23,24]. ZrO_2 ceramics exhibit a significantly higher flexural strength and toughness than other commercially available dental ceramics [24]. Generally, ZrO_2 ceramics can be milled at three different stages: green, pre-sintered, and fully sintered [25]. The original framework milled from green stage and pre-sintered ZrO_2 blocks is enlarged to compensate for the prospective material shrinkage (20–25%) that occurs during the final sintering stage [23,24]. Fully sintered ZrO_2 blocks can be milled using diamond burs under cooling liquids. The milling of green stage and pre-sintered ZrO_2 blocks is faster and causes less wear and tear on the hardware compared with the milling of fully sintered blocks.

From an anatomical point of view, dental arches show great variation and no two arches are identical. The curved configuration of the anterior dental arch is markedly different from the linear posterior region. These facts must be taken into account when designing the enlarged framework for ZrO_2 ceramics [23,24]. Distortion of the framework is likely to occur after the final sintering and will have a negative impact on the marginal adaptation. The quality of the marginal adaptation has been shown to influence the long-term success of restorations [26–28]. In terms of longevity, the clinically acceptable range of marginal discrepancies is between 100 and 150 μm [29–31]. Information about the marginal adaptation of all-ceramic FPDs is limited [32–34]. Tinschert et al. reported that the mean marginal discrepancies ranged from 61 μm to 74 μm for the ZrO_2 ceramic FPD frameworks fabricated with the Precident DCS system (DCS, Allschwil, Switzerland) [32]. The marginal fit values of experimental all-ceramic FPDs ranged between 89 and 130 μm in an in vivo study [33]. In an in vitro study, the mean marginal gap values of Empress® 2 (Ivoclar-Vivadent, Schaan, Liechtenstein) FPDs were between 58 and 68 μm [34]. However, no scientific data are available on the influence of the framework configuration on the marginal adaptation of ZrO_2 ceramic four-unit FPDs in the partially sintered state. The purpose of this study was to evaluate the influence of the framework configuration on the marginal adaptation of four-unit anterior ZrO_2 ceramic frameworks. In addition, the performance of the marginal adaptation for three different CAD/CAM systems was evaluated.

Material and methods

The maxilla of a dummy model (KaVo, Leutkirch, Germany) was used to reproduce a clinical case in which an anterior four-unit FPD was employed to replace a missing central and lateral incisor. The plastic left central incisor and right canine were prepared to receive all-ceramic full-coverage crowns with an accentuated chamfer. An incisal reduction of 1.8 to 2.0 mm was made using a diamond bur (80 μm grit) followed by a circular 1.2-mm-wide chamfer. The preparation was finished using a diamond (30–40 μm grit) and all of the sharp angles were rounded. The conical angle of the prepared teeth was confirmed using a parallel meter. The prepared teeth were placed in their corresponding anatomical positions in the maxillary dummy model and an impression of the abutments was made using a vinyl polysiloxane-impression material (Monopren; Kettenbach, Eschenburg, Germany). Acrylic resin (Pattern resin; GC, Tokyo, Japan) was poured into the impression to reproduce the abutments. Subsequently, the resin pattern was invested, burned out, and cast. Master dies were made from nickel-chromium alloy (Wiron 99; Bego, Bremen, Germany) in order to achieve stable and uniform shapes. The master dies were used for fabrication of the FPD frameworks and measurement of the marginal adaptation. A one-stage impression was made for fabrication of the master model using Monopren and a custom-made impression tray. Afterwards, the dies were fabricated using dental stone (Fujirock II; GC Europe, Leuven, Germany) in accordance with the specific requirements of each CAD/CAM system. A total of 48 four-unit frameworks were fabricated using three different CAD/CAM systems (16 specimens per group): the Cercon Smart Ceramics system (DeguDent, Hanau, Germany) (group CE); the Vita YZ (Vita, Bad Säckingen, Germany)/Cerec inLab system (Sirona, Bensheim, Germany) (group YZ/CL); and the Xawex system (Xawex AG, Fällanden, Switzerland) (group XA) (Table I). All the tested ZrO_2 frameworks were fabricated by milling in the green (group CE and XA) or pre-sintered stage (group YZ/CL) in accordance with the manufacturer's recommendations. Afterwards, the frameworks were post-sintered in special furnaces. Two different framework configurations were manufactured for each group: the straight (ST) and the curved design (CU) (Figure 1). In the ST design, the two abutments and the pontics were arranged linearly. In the CU design, the pontics were located in a

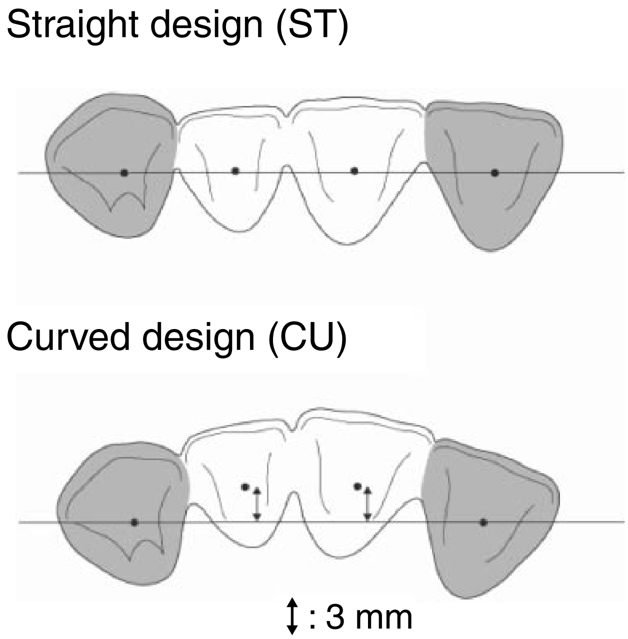

Figure 1. The two different framework designs (straight and curved designs).

perpendicular position 3 mm from the straight line. Each subgroup consisted of eight specimens. The two different framework designs were fabricated with identical dimensions using a silicone index. The frameworks were constructed from a core material with a uniform thickness of 0.8 mm. The connectors were modeled with an occluso-gingival height of 3.5 mm and a bucco-lingual width of 2.5 mm.

The marginal adaptation of the frameworks was measured in the absence of veneering porcelain [32,35]. The frameworks were seated on their respective abutments and held in place using finger pressure. Impressions of the marginal areas were made using a vinyl polysiloxane impression material (Dimension Garant L; 3M ESPE, Seefeld, Germany) and epoxy resin replicas were poured (Polyurock; Metalor, Neuchatel, Switzerland). These were used to measure the marginal adaptation.

A stereomicroscope (Zeiss, Oberkochen, Germany), 3CCD camera (Sony, Köln, Germany), and personal computer (IBM Compatible Personal Computer with Microsoft NT Operating System 4.0) were used to record the marginal adaptation. The camera reproduced ×40 magnification images on a high-resolution (800 × 600 pixel) computer monitor so that a video image of the marginal discrepancy could be examined using a special software program (Analysis 3.0; Soft-Imaging Software GmbH, Münster, Germany). Measurements of the marginal discrepancies around the circumference of the abutments were made directly on screen. The marginal area of the replicas was oriented perpendicularly and orthoradially to the 3CCD camera in order to measure the distance parallel to the abutment axis from the framework margin to the preparation line. After scanning the selected area, the specimens were moved to the adjacent area visible on the monitor. In four areas of each replica (mesial, distal, labial, and palatal), 15 measurements were evenly distributed and carried out for each replica. Using this technique, a total of 60 single measurements [36] were made around the circumference of each abutment. The geometrical mean value of each replica was used as the data point for one specimen.

For each framework, 10 measurements were made on each surface (buccal, distal, mesial, and palatal) of the two abutments (canine and central incisor). A mean of the 80 marginal discrepancy measurements was used for the statistical analysis. Box plots were drawn to illustrate the results. After logarithmic transformation, the marginal discrepancy values appeared to be normally distributed, so the geometric mean was used rather than the arithmetic mean. For each group and design, the geometric mean and 95% confidence limits were determined. Pairwise t-tests were carried out on the logarithm of the gap values in order to compare the three groups for both designs. The p-values were corrected for multiple testing using the Bonferroni–Holm method. The overall level of statistical significance was 5%. The central hypothesis for the present in vitro study was that the shrinkage of partially sintered ZrO_2 ceramics during the sintering process affects the marginal adaptation of anterior four-unit frameworks.

Results

The descriptive statistics of the marginal discrepancy values of the different four-unit ZrO_2 frameworks are presented in Table II. The geometrical means, standard errors, and 95% confidence intervals for the marginal discrepancy values are displayed in Table III. Significant differences in the marginal discrepancies were identified between the straight and curved framework designs for groups CE ($p = 0.0013$) and XA ($p = 0.0033$), but not for group YZ/CL ($p = 0.22$). For the curved design, the marginal discrepancies were significantly smaller in group XY/CL than in groups XA ($p = 0.00014$) and CE ($p = 0.037$); these values were also significantly smaller for group CE compared with group XA ($p = 0.042$). For the straight design, the marginal discrepancies were significantly smaller in group XY/CL compared with group XA ($p = 0.0003$), and in group CE compared with group XA ($p = 0.0008$). No significant difference was detected between groups XY/CL and CE ($p = 0.7$).

Discussion

The influence of the framework configuration on the marginal adaptation of partially sintered ZrO_2 ceramic anterior four-unit FPD frameworks using three different CAD/CAM systems was investigated in this in vitro study. The hypothesis that the shrinkage

Table II. Descriptive statistics of the marginal discrepancy values of the different four-unit ZrO_2 frameworks

Group	Design	No. of samples (*n*)	Minimum	Maximum	Median	IQR*
CE	Curved	8	97.3	147.0	121.5	[110.402; 129.046]
YZ/CL	Curved	8	75.4	112.2	96.4	[92.245; 106.55]
XA	Curved	8	115.6	172.6	153.6	[139.996; 157.284]
CE	Straight	8	80.7	105.8	85.8	[83.418; 89.769]
YZ/CL	Straight	8	77.6	97.2	87.6	[81.668; 91.012]
XA	Straight	8	97.2	128.9	113.4	[108.105; 121.817]

* Interquartile range.
CE: Cercon Smart Ceramic.
YZ/CL: Vita YZ/Cerec inLab.
XA: Xawex.

Table III. Geometric means, standard errors and 95% confidence intervals of the marginal discrepancy values of the different four-unit ZrO_2 frameworks

Group	Design	No. of samples (*n*)	Means*	SE†	CI 95%‡
CE	Curved	8	119.946	1.049	107.235–134.163
YZ/CL	Curved	8	86.761	1.046	87.049–107.556
XA	Curved	8	147.335	1.046	132.538–163.784
CE	Straight	8	88.050	1.032	81.672–94.926
YZ/CL	Straight	8	88.533	1.028	80.982–92.464
XA	Straight	8	113.406	1.033	104.954–122.539

* Geometric mean.
† Standard errors.
‡ 95% confidence interval.
CE: Cercon Smart Ceramic.
YZ/CL: Vita YZ/Cerec inLab.
XA: Xawex.

of partially sintered ZrO_2 ceramics during the sintering process affects the deformation of the FPD framework was accepted. The results showed that the framework configuration had a significant influence on the marginal adaptation of the partially sintered ZrO_2 four-unit frameworks tested.

The green and pre-sintered ZrO_2 ceramic four-unit FPD frameworks of ST design exhibited significantly better marginal adaptation compared to the CU design. These results can be attributed largely to the distortion of the framework due to the shrinkage of the ceramics during the final sintering stage. The findings of this study are consistent with a previous report. For partially sintered ZrO_2 ceramics, Besimo et al. [37] stated that the influence of shrinkage during sintering on marginal adaptation is not clear. In order to define reasonable clinical guidelines, it can be assumed that when FPDs are fabricated using partially sintered ZrO_2 ceramics, a relatively straight configuration can be expected. In the present study, the marginal discrepancies of the four-unit FPD frameworks were measured with no veneering porcelain. There is a lack of information on the effect of the application of veneering porcelain on the marginal adaptation for the ZrO_2 ceramic crowns and FPDs. The influence of veneering porcelain applications on the distortion is not clear from the present results and further studies will be needed to clarify this issue.

The adaptation of restorations made out of ZrO_2 ceramics may be affected by the preparation design, milling process, size of milling burs, and material conditions during the milling procedure. In the current study, group YZ/CL exhibited lower marginal discrepancy values compared to the other two groups. ZrO_2 material of group YZ/CL belongs to the pre-sintered stage, which is milled with carbide burs under dry condition. Samples of groups CE and XA belong to the green stage ZrO_2 ceramics and they are milled with diamond burs under cooling liquids. It is possible that the different types of material used during the milling procedure attributes those results. Pre-sintered ZrO_2 ceramic exhibits a better marginal adaptation of four-unit frameworks than that of green stage ZrO_2 ceramics. However, further studies with different experimental designs are required to validate these findings.

Several authors have reported that marginal discrepancies between 100 and 150 μm are clinically acceptable in regard to longevity of the restorations [30,31]. Only a few studies have investigated the quality of the marginal adaptation of ZrO_2 ceramic restorations, with results ranging between 0 and 115 μm [38,39]. In these reports, the single crowns were manufactured from a fully sintered high-isostatic-pressed (HIP) ZrO_2 ceramic. In the present study, the marginal discrepancies of four-unit FPD frameworks (with geometric means between 86 and 154 μm) showed slightly larger values compared to those reported in investigations on single crowns. This might be related to the more complex geometric form of the FPDs compared with single crowns. Nonetheless, the marginal discrepancy values of the four-unit FPD frameworks in the current study were within the clinically acceptable limits. To our knowledge, the present study is the first in which partially sintered ZrO_2 ceramics are used in analysis of the relationship between marginal adaptation and configuration of the frameworks.

There were some limitations in the experimental design of the current study which made it difficult to relate the results to clinical reality. The marginal adaptation was evaluated only by checking the external fit of ZrO_2 ceramic frameworks using the replica technique. For evaluation of the internal fit of restorations, it is necessary to use the cross-section technique described above. However, it was not possible to measure these parameters because of the experimental design of this study. Moreover, in the present study, only two configurations of the four-unit frameworks were evaluated, and these varied greatly owing to differences in the position of the abutment teeth, the pontics, and the relationship of the occlusion. Therefore, further investigations will be necessary to evaluate the relationship between marginal adaptation and framework configurations under different experimental designs.

Within the limitations of this study, it can be concluded that: the framework configuration influences the marginal adaptation of anterior four-unit partially sintered ZrO_2 ceramic frameworks regardless of the type of CAD/CAM system. Moreover, the marginal discrepancy values reported in this study were within the clinically acceptable range.

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