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ORIGINAL ARTICLE

Precision of fit: zirconia three-unit fixed dental prostheses

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Abstract The purpose of this in vitro study was to compare the precision of fit of substructures milled from semi-sintered zirconia blocks fabricated with two different computer-assisted design (CAD)/computer-assisted manufacturing (CAM) systems. Three-unit posterior fixed dental prostheses (FDP) were fabricated for standardized dies (n=10) with the Lava CAD/CAM system (Lava) and the Procera-bridge-zirconia CAD/CAM system (Procera). After cementation to the dies, the FDP were embedded and sectioned. Four cross-sections were made of each abutment tooth, and marginal and internal fit were evaluated under an optical microscope. A one-way analysis of variance was used to compare data (α=0.05). Mean gap dimensions at the marginal opening for Lava and Procera were 15 (±7) µm and 9 (±5) µm, respectively. Mean marginal openings (P=0.012) and internal adaptation at two out of three measurement locations were significantly different. Within the limitations of this study, the results suggest that the accuracy of both investigated systems is satisfactory for clinical use.

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Introduction

Metal-free all-ceramic restorations have become more widely distributed due to their high aesthetic potential and their excellent biocompatibility properties [1, 4, 6, 10–13, 28, 29, 33, 35, 44, 46]. In attempts to improve strength and fracture toughness, several new ceramic materials and techniques have been developed during the last decades. All-ceramic fixed dental prosthesis (FDP) substructures can be made from various high-strength ceramic materials [40]. Yttria-stabilized zirconia has proven its clinical suitability for posterior FDP [33, 38, 40].

Similar to metal ceramics, the fabrication of zirconia-based FDP uses a high-strength ceramic material for the framework to provide resistance against cyclic loading [5, 33, 38, 40].

Computer-aided manufacturing (CAM) of zirconia substructures currently utilizes two different strategies for the type of milling blocks used. The hardness of the zirconia blocks and hence the difficulty in milling the substructures is determined by the degree of sintering of the blocks. Originally, blocks were fully sintered by a process known as hot isostatic pressing [4]. Milling the actual size of the substructure is associated with disadvantages, such as high wear rates of the milling burs in the CAM machines and prolonged milling time due to slower feed [39, 44]. Since there is no further sintering necessary and therefore no sintering shrinkage, the marginal fit of these substructures is excellent [39, 44]. The demonstrated marginal values for this technique are 60.4 and 74.0 µm [39]. Another study showed that high precision can be achieved using milling devices for densely sintered zirconia [9]. A second method of milling block fabrication utilizes a semi-sintered zirconia material. The semi-sintered block has a chalk-like consistency, making it easily machine-able in the CAM unit. After milling, the substructure is sintered to full density. The post-milling sintering results in a linear shrinkage in the range of 15% to 30% and subsequent increase in density [30, 33]. The increased milling efficiency of the softer semi-sintered block has the trade-off of a potential poorer fit from a 20% sintering shrinkage, the scanning process, compensatory software design, and milling. Apart from the mechanical properties and aesthetics, the long-term clinical success of all-ceramic fixed prosthodontics can be influenced significantly by marginal discrepancies. Poor marginal adaptation increases plaque retention and changes the distribution of the microflora, which can induce the onset of periodontal disease [7, 18, 30, 33, 34]. Microleakage from the oral cavity can cause endodontic inflammation [7]. A clinical study on a CAM only system (DCM prototype of Cercon, DeguDent, Hanau, Germany) reported poor marginal fit and a 22% rate of secondary caries after 5 years [33].

Marginal gaps of 64–83 μm were reported using zirconia as framework material for all-ceramic crowns [7, 37]. A computer-assisted design (CAD)/CAM-system for zirconia substructures (Lava, 3M ESPE, Seefeld, Germany) showed a mean marginal gap of 80 μm in a study investigating the clinical fit of three-unit FDP [30]. Currently chipping of the veneering porcelain appears to be one of the major drawbacks of zirconia-based restorations [24, 33, 41, 44]. There is evidence demonstrating the influence of excessive cement space on veneering porcelain failures [31]. This thick cement layer complicates the challenge to minimize stress concentrations on the tensile surface of the restoration caused by the viscoplastic deformation of the adhesive material under cyclic loading. It was reported that currently recommended cements flow under load [14, 17, 43]. This flow increases the stress in the system dramatically [31]. The increased stress propagates damage and may cause failure of the veneering porcelain [31].

There is consensus between various authors that marginal openings below 120 μm are clinically acceptable [2, 20, 23, 37]. Numerous studies have examined the marginal fit of porcelain crowns [3, 7, 9, 15, 16, 19, 21, 36, 39, 42, 45]; however, in vitro measurement data for the marginal fit of Procera bridge zirconia and Lava have not been reported. Therefore, the purpose of this investigation was to measure the marginal opening and internal adaptation of two manufacturing systems for zirconia-based restorations to the working dies. The working hypothesis states that (1) both systems produce marginal openings below 120 μm and that (2) there is no difference in the marginal opening and internal adaptation of both systems tested.

Materials and methods

A typodont model (Frasaco, Tettnang, Germany) with a missing mandibular right first molar was used. A 1.2-mm, 360° chamfer preparation was made on the second premolar and second molar. To control axial reduction, a silicone impression (Optosil, Heraeus Kulzer, Hanau, Germany) was made prior to tooth preparation. Additionally, the provisional crown (Protemp 3 Garant, 3M ESPE) was used to verify the thickness, so the circumferential and occlusal reduction could be quantified (Dial Caliper, Kori Seiki, Tokyo, Japan). The preparation was completed with a surveyor (F1, DeguDent) using a carbide bur (Komet H 356 RGE 103.031, Brasseler GmbH, Lemgo, Germany) to ensure that the preparation had a total taper of 8°. Twenty polyether impressions (Impregum, 3M ESPE) were made with metal impression trays (U3 #141163 Orbilock, Orbis Dental, Münster, Germany) and poured in a class IV resin-reinforced (ISO type IV) die stone (ResinRock, Whip Mix Europe, Dortmund, Germany). After the dies set, pins (Pindex System, Coltene Whaledent, Altstätten, Switzerland) were placed in the appropriate locations, and the base of the cast was poured in the same dental stone. Dies were removed from cast base and trimmed to the preparation margins. The same investigator made all impressions, and all dies were fabricated by the same experienced technician. Twenty definitive casts with removable dies were fabricated and divided into two groups. The precision of fit of the substructure was measured without veneering [7, 8]. The definitive dies were sent to a dental laboratory.

Ten retainers were fabricated by the Procera CAD/CAM technology. Ten definitive dies were digitized by a mechanical scanning instrument (Forte, Procera, Nobel Biocare), and a dental technician designed the substructures using a CAD software (Procera Software version 1.6). The data were transmitted electronically to the manufacturing centre (Procera Manufacturing, Nobel Biocare, Stockholm, Sweden) where the zirconia retainers were fabricated. A framework thickness of 0.6 mm was chosen, while the manufacturer provides a cement spacer thickness of 40 μm, which cannot be changed by the operator. The definitive dies were returned to the research facility after the scanning process to avoid adjustment prior to measuring. The volume data were used to calculate the anticipated shrinkage, and the substructures were milled from semi-sintered zirconia. All retainers were sintered to full density in a special furnace (further information was not provided by Nobel Biocare). After receiving the retainers from the laboratory, they were returned to their respective dies.

Ten retainers were fabricated by the Lava system. Ten dies were digitized by an optical scanning instrument (Lava Scan), the frameworks were designed (Lava CAD), and the data were electronically transmitted to the milling center

(3M ESPE, Seefeld, Germany). The standard settings were employed (cement spacer 20 µm starting 1.5 mm above the margin; cement gap expansion 50 µm starting 1.8 mm above the margin) and a framework thickness of 0.6 mm was chosen. The substructures were milled from semi-sintered zirconia by a three-axis milling machine (Lava Form, 3M ESPE) in a dry milling process. After the milling, all frameworks were sintered to full density in a special sintering furnace (Lava Therm, 3M ESPE) at a temperature of 1773°K (1,500°C) over 8 h. The definitive dies were returned to the research facility after the scanning process to avoid adjustment at the dental laboratory. After receiving the retainers from the laboratory, they were returned to their respective dies.

All frameworks were examined for deformity and debris and steam-cleaned (Triton SLA, Bego, Bremen, Germany). Additionally, all retainers were cemented on the definitive dies by glass ionomer (KetacCem Aplicap, 3M ESPE) [25, 26]. The capsule of glass ionomer cement was activated for 2 s (Aplicap Activator, 3M ESPE) and mixed automatically (Rotomix, 3M ESPE) for 10 s. The abutments of the retainers were filled (Aplicap Applier, 3M ESPE) with cement, and the cement was spaced out by a disposable brush until the complete surface was coated. The retainer was placed onto the definitive die with finger pressure, and the excess cement was removed. A special cementing device was used to ensure that the pontic was loaded centrally at a force of 50 N for 10 min [27]. The same team of an experienced dentist, who placed the retainer onto the dies, and a dental assistant, who activated the capsule of cement and started the mixing procedure, cemented all substructures. The middles of both abutment teeth were marked on the die in order to have standardized sectioning. Twenty-four hours after cementation, every framework was embedded into gypsum (ResinRock, Whip Mix) to prevent raptures and disruptions during the cross-sectioning process (Accutom 2, Struers, Willich, Germany). The pontic was discarded, and the abutment teeth were sectioned centrally from buccal to lingual and from mesial to distal according to the pencil lines at the middles of both abutment teeth, thus resulting in eight specimens to be evaluated for each framework (Fig. 1).

The frameworks were examined at 50× magnification (internal adaptation) and 200× magnification (marginal fit) with a microscope (Axioskop 2, Zeiss, Oberkochen, Germany). The resolution of the microscope was 0.45 µm. Three digital images were made of each cross-sectional specimen at 50× magnification. One image of a calibration slide was made at the same magnification and used as a reference for calibration at each imaging session. In addition, one image of the marginal area was made at 200× magnification along with a calibration slide at the same magnification. Photographs were made with a digital camera (S1 Pro, Fuji, Tokyo, Japan), and the images were transferred to the imaging data program (Optimas 6.5, Media Cybernetics, Silver Spring, MD, USA).

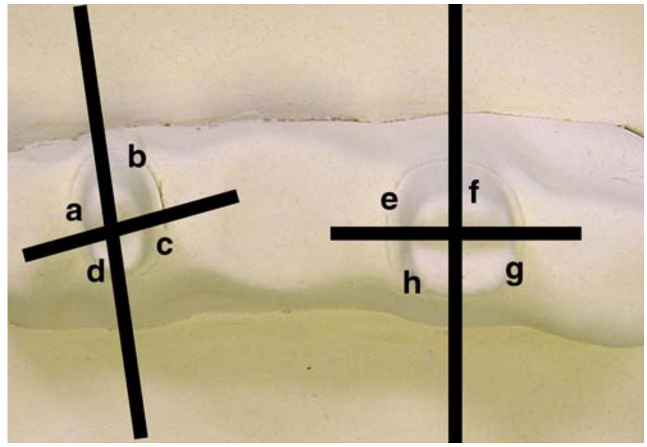

Fig. 1 Occlusal view on a solid FDP model; *Lines* indicate the cross-sections; Letters *a* to *h* indicate the measured specimens

A measurement was made every 50 µm starting at the marginal opening, resulting in 180 measured points per cross-sectional specimen. The measurement was performed using the following method (Fig. 2). A series of points was placed on the die and the internal surface of the restoration. The points were placed automatically by the computer program while the operator was controlling the procedure. The computer program connected two points from one side, and a perpendicular was dropped from a point on the opposite border (Fig. 2).

The length of the perpendicular represented the measured cement gap in micrometers (µm).

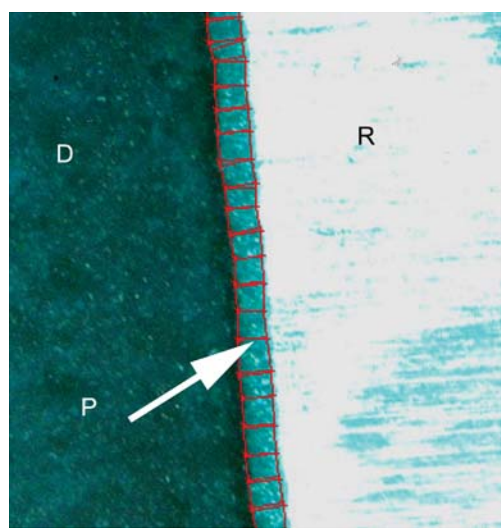

Fig. 2 Internal adaptation at axial wall (*D* die, *R* zirconia retainer, *P* perpendicular/measured cement gap in µm). Points connected and perpendiculars dropped from the opposite border. Length of the perpendiculars represents the measured cement gap in micrometers

For each substructure, the following four measurement locations were used to determine the precision of fit between the retainers and the dies:

1. Marginal opening (MO): The marginal opening at the point of closest approximation between the die and ceramic margin of the retainer.
2. Chamfer area (CA): The internal adaptation of the retainer at the point of the biggest diameter.
3. Axial wall (AW): The internal adaptation of the crown walls at the midpoint of the axial wall (2 mm occlusal to the margin of the die).
4. Occlusal adaptation (OA): The internal adaptation of the surface of the crown to the die at the midpoint from the facial and proximal.

The fit of the substructures was evaluated using the scan line schema (Fig. 3) planned for the investigation; measurements were taken from the database at MO, CA, AW, and OA measurement locations to evaluate the fit of all retainers. Data recorded at the different cross-sections of one specimen were averaged by the different measurement locations.

Data were imported in a statistical program (SPSS 15.0, SPSS Germany, Munich, Germany). Mean data were calculated and analyzed with descriptive statistics. A one-way analysis of variance (ANOVA) was carried out to detect statistical difference between both investigated systems in terms of marginal fit and internal fit at the different measurement locations. To show the difference between the measurement locations, a one-way ANOVA and a post hoc test (Student–Newman–Keuls) were used. The level of significance was set at 5%.

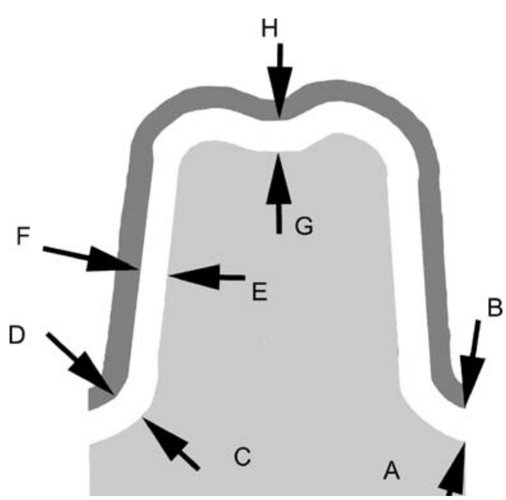

Fig. 3 Crown to die diagram showing measurement locations to determine marginal opening (*MO*; distance between *A* and *B*), chamfer area (*CA*; distance between *C* and *D*), axial wall (*AW*; distance between *F* and *E*), and occlusal adaptation (*OA*; distance between *G* and *H*)

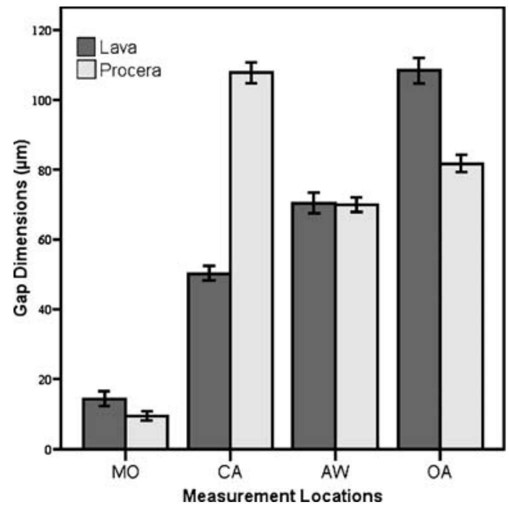

Fig. 4 Mean gap dimension and standard deviation at marginal opening (*MO*), chamfer area (*CA*), axial wall (*AW*), and occlusal adaptation (*OA*) measurement locations for both investigated systems

Results

The mean MO gap dimension for Lava and Procera were 15 (±7) µm and 9 (±5) µm, respectively. The mean internal adaptation gap dimensions for Lava were 50 (±7) µm (CA), 71 (±10) µm (AW), and 108 (±12) µm (OA). Procera showed mean internal adaptation gap dimensions of 108 (±13) µm (CA), 70 (±9) µm (AW), and 82 (±11) µm (OA; Fig. 4).

Table 1 presents the one-way ANOVA on the system groups by MO, CA, AW, and OA measurement locations. Mean gap dimensions between the system groups were significantly different at MO, CA, and OA. The measurement location AW did not demonstrate any significant

Table 1 One-way ANOVAs of between-system factor by measurement locations (MO, CA, AW, and OA)

Source	*df*	Sum of squares	Mean squares	*F* value	*P* value
MO	1	262.365	262.365	6.860	0.012*
CA	1	34,672.557	34,672.557	329.931	0.000*
AW	1	2.987	2.987	0.034	0.855
OA	1	7,399.304	7,399.304	56.293	0.000*

df degrees of freedom

*P=0.05

differences between both systems. The measurement locations showed significantly different values, while three homogeneous groups were detected (Tables 2 and 3).

Discussion

An acceptable MO for full crowns, as reported by Hung et al. [19], is 50 to 75 µm, whereas Weaver et al. [45] suggested 70 (±10) µm. The mean marginal openings for both investigated systems were 15 µm (Lava) and 9 µm (Procera), respectively. The Procera system performed significantly better than the Lava system in terms of marginal fit, so the working hypothesis in terms of equal marginal fit has to be rejected. A possible reason might be different milling strategies, as system Procera showed a significant wider cement gap at CA compared to system Lava. A wider gap width CA allows a complete seating of the retainer and results in a better fit at MO. Some systems propagate this kind of milling strategy described as "radius cutter" adjustment in adding a cement space in the range of 50 µm at critical edges. However, both systems showed lower MO than other investigated all-ceramic systems [3, 7, 9, 15, 22, 30, 34], which means that the part of the working hypothesis concerning marginal fit that would be acceptable in a clinical situation can be supported. This might be due to recent developments concerning scanning technology (Lava Scan ST replaced Lava Scan), software (the latest software updates improved the detection of the margin), and milling strategy (closer milling tracks at the inner surface), which improved the accuracy significantly.

It also has to be taken into account that in vitro studies offer standardized and optimized conditions in terms of the preparation design, impression technique, or experimental performance. Therefore, the results of the present study show the precision of CAD/CAM systems under ideal conditions. A clinical evaluation of the Lava system reported a mean MO of 80 (±50) µm, which included inaccuracies caused by the CAD/CAM system and the clinical procedure [30]. Measurements on Procera crowns in vivo exhibited gap widths that were 61 to 70 µm wider in bucco-lingual direction and 58 to 73 µm wider in proximal locations than gap widths measured in vitro [21]. According to May et al., the MO was defined as the closest distance between retainer and preparation to avoid that overextension or underextension of the retainer crown could affect the result [18, 22]. As the retainers were cemented as received from the dental laboratory in case of overextensions, the retainer margins would have been adapted if they were used clinically. The cement space or internal adaptation is considered to be a uniform space that facilitates seating without compromising retention and resistance forms. This is of paramount importance because all-ceramic restorations are more fragile compared to metal ceramics, as ceramic is a brittle material and sensitive against tension. The precision of fit can influence the clinical prognosis. Tuntiprawon and Wilson [42] reported that all-ceramic crowns displayed greater compressive strength when the mean AW was at a gap dimension of 73 µm. Their study also showed that if the mean AW was increased to 122 µm, lower fracture strength occurred without any significant improvement in seating [42]. Both investigated CAD/CAM systems could fulfill this requirement. The obtained data did not indicate that there were incidences of axial wall contact between dies and the retainers, which would have been visible in the cross-sections.

As reported in a clinical investigation, widest gap dimensions were found in OA [30]. Thin cement layers (80 µm) at measurement location OA have been reported to be more favorable for the mechanical stability of zirconia-based restorations [32]. There is also evidence that a lack of precision in internal fit can promote higher risks for veneering fracture [31]. Apart from mechanical properties of the material used, this also has a clinical aspect. If too much space is lost as a result of large interocclusal discrepancies, the intercuspal clearance available for veneering is reduced. Despite this aspect, the result of the present study indicates that gaps were similar or better to those of metal ceramic restorations [16, 36].

The limitations of the present study were: (1) the gap dimensions were measured using the cross-section technique. As a result, the precision was just measured at eight

Table 2 One-way ANOVA on the measurement location factor (MO, CA, AW, and OA)

Source	*df*	Sum of squares	Mean squares	*F* value	*P* value
Complete data	3	165,098.6	55,032.872	158.716	0.000*

*P=0.05
df degrees of freedom

Table 3 Student–Newman–Keuls post hoc test on different measurement locations

Measurement location	Number	Subgroup 1	Subgroup 2	Subgroup 3
MO	20	11 µm		
AW			70 µm	
CA				87 µm
OA				91 µm
P value		1.0	1.0	0.121

defined areas per retainer, which might not represent the complete fit. Cross-sectioning might also cause damage to the specimens. Therefore, all specimens were embedded in gypsum, cross-sectioned under water spray and low feed rates to avoid possible inaccuracies through damaged specimens. (2) All retainers were cemented onto their respective dies. Therefore, the marginal fit could have been influenced by this procedure. However, as the used cement requires a space of 20 µm, it is theorized that the luting space measured and represented by the cement width did not prevent the accurate seating of the retainers as a result of hydraulic pressure. (3) All retainers were produced and tested under ideal conditions, which might not reflect the precision in daily clinical use. (4) Only the standard settings of the CAD/CAM concerning die spacer thickness have been evaluated. Different settings might influence the accuracy but Procera does not give the opportunity to change the settings. Further research should be carried out testing different spans of FDP and more available systems (CAM technology, hand copying technology).

Conclusions

According to the results of this study, the following conclusions can be drawn:

1. Both CAD/CAM systems tested demonstrated in vitro acceptable marginal openings.
2. The Procera bridge zirconia system showed significantly lower marginal openings.
3. The differences of fit between both investigated systems depended on the region of the retainer being evaluated.

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Conflict of interest The authors declare that they have no conflict of interest.

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