Influence of milling systems and marginal configurations on the fit of yttrium stabilized tetragonal zirconia polycrystals (Y-TZP') copings

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Abstract

Objective: The aim of this study was to evaluate marginal fit of yttrium tetragonal zirconia polycrystals (Y-TZP') copings with different finish line designs fabricated with various digital scanners and milling systems.

Methods: Three model plastic teeth were prepared with three finish line designs: Design-1, continuous chamfer; Design-2, chamfer with shallow depression; Design-3, chamfer with deep depression. The “master models” were replicated using elastomeric polyvinyl siloxane impression material and poured in type IV stone generating 90 dies, 30 dies for each design. Dies were scanned and copings were milled utilizing three digital scanners and computer-aided design/computer-aided manufacturing (CAD/CAM) systems: System-1, InEos Red Scan (Sirona Dental Systems, Germany), Vitablocks® Mark II (VITA, Germany) copings milled by Cerec® inLab (Sirona Dental Systems, Germany); System-2, Cerec® AC Connect with BlueCam (Sirona Dental Systems, Germany), Vitablocks® Mark II (VITA, Germany) copings milled by Cerec® inLab (Sirona Dental Systems, Germany); and System-3, NobleProcera™ Optical Scanner (NobleBiocare™), procera zirconia coping milled by a Noble Procera™ milling machine (NobleBiocare™). Copings were seated on their respective “master models” and secured with uniform force. Eight measurements per coping were performed at pre-established points, with a metallurgical microscope (Zeiss, Germany) connected to a high precision digital video-micrometer (Javelin JV6000, California, USA) at 200 × magnification.

Results: The tested systems demonstrated marginal gaps ranging from 12.4 to 26.6 µm. Results for marginal fit of milled copings fabricated using three systems with different finish line designs differed significantly (p < 0.05). Procera zirconia copings scanned and milled with NobleProcera™ exhibited significantly lower marginal gaps compared to other specimen groups. However, InEos Red Scan/Vitablocks® Mark II/Cerec® inLab showed maximum marginal gaps among the study specimens.

Conclusions: CAD-CAM manufactured Y-TZP' copings exhibited marginal gaps ranging from 12.49 to 26.6 µm. The CAD-CAM fabrication system was a significant factor influencing the marginal misfit of Y-TZP' copings. Margin design

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exhibited system dependent influence on the marginal misfit. Marginal misfit observed for all systems were within clinically acceptable parameters.

Keywords
Marginal misfit, computer-aided design/computer-aided manufacturing, yttrium stabilized tetragonal zirconia polycrystals, copings, chamfer

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Introduction
All-ceramic crown systems are extensively used for restoration of missing teeth as they offer excellent esthetic outcomes and biocompatibility. However, the mechanical behavior and cement interface of all ceramic restorations are considered to be a weak link, potentially compromising their successful clinical performance. Failure at cement interface results in accumulation of plaque and inflammation; however, lack of cement support for ceramics may introduce mechanical compromise and functional failures. Dental cements are employed to maintain the position of restorations; and factors, which influence the restorative cement interface, include, height and convergence of axial walls, preparation diameter, presence of retentive channels, and the type of cement used. These factors explain the complications coupled with cement flow and the oblique seating of crowns. An ideal internal fit has been shown to improve the mechanical behavior of all-ceramic restorations in terms of strength, resistance, and retention. Therefore, an ideal cement–restoration interface is critical for the long-term clinical success of all ceramic restorations.

All-ceramic yttrium stabilized zirconia polycrystals (Y-TZP) based restorations are mechanically strong; however, their fit and adaptation is highly dependent on the digital scanning and milling systems employed. It is suggested that factors including, sensitivity of scanners, accuracy of designing software, depth of scanning field, use of reflective powder coatings, and intra-oral or chamfer scanner critically influence the marginal and internal accuracy of Y-TZP CAD-CAM all-ceramic restorations. In addition, the accuracy of milling machines, including three-axis and five-axis milling and wet versus dry milling are similarly vital to the accuracy of Y-TZP restorations. Gonzalo et al., investigated the marginal accuracy of posterior fixed partial dentures fabricated with LAVA all ceramic and Procera Bridge Zirconia using scanning electron microscopy. Both CAD-CAM systems showed comparable marginal accuracy outcomes. A similar study comparing digital ceramic system (DCS), Procera, and VITA YZ-Cerec CAD-CAM zirconia systems for marginal openings with geometric means, exhibited significant difference in marginal accuracy outcomes. It appears that a controversy exists among the present evidence on the fit and accuracy of Y-TZP restorations using different CAD-CAM systems.

Margins of all ceramic Y-TZP restorations are clinically placed at a sub-gingival location following the scallops of the gingival margins for desired esthetic outcomes. As this augments the potential for extrusion of cements in gingival soft tissues and possible inflammatory processes, alterations in marginal configurations are proposed. Some studies have shown that finish line design can facilitate the escape of cement early in the cementation process. It is suggested that a shoulder finish line exhibits larger mean marginal values and increased microleakage than a chamfer finish line. It is recommended, that for ease of scanning and milling in Y-TZP computer-aided design/computer-aided manufacturing (CAD/CAM) systems, critical guidelines must be followed by clinicians and technicians, including a preparation margin of chamfer or rounded shoulder. Therefore, the influence of marginal configuration with a labial depression replicating the labial gingival scallop and its influence on restorative marginal integrity is a relevant question. To our knowledge from the indexed literature, evidence related to the marginal accuracy and adaptation of Y-TZP restorations based on margin configuration types (including labial margin depression), fabricated with different contemporary CAD-CAM systems is limited. It is hypothesized that the marginal accuracy of these restorations would significantly differ, based on the margin configurations and CAD-CAM system used in their fabrication. Therefore, the aim of this study was to evaluate marginal fit of Y-TZP copings with different finish line designs fabricated with various digital scanners and milling systems.

Methods
The ethics review committee approved the in-vitro experiment protocol and was reported in accordance with checklist for reporting in-vitro studies (Central Registration & Identification Scheme).

Preparation of master models
Three pre-shaped plastic model teeth “master models” were modified to have three different finish line preparation designs (Figure 1). The first design (chamfer) included a bevel on the top surface for ease of seating and orientation of the copings that was made by a smooth round end tapered diamond bur. The second design (chamfer with
shallow depression) included a 1.5 mm shallow depression on one aspect of the finish line. A 3 mm deep depression was created on the third design (chamfer with deep depression) on one aspect of the finish line; both were done with a round end taper green diamond bur on a high-speed hand piece, followed by a smooth round end tapered diamond bur. A carbide-finishing bur was used to smoothen all preparations. Prepared model teeth were cleaned using a steamer.

**Impression and preparation of stone dies**

Each “master model” was replicated by injecting polyvinyl siloxane heavy impression material (Reprosil, Dentsply, MN, USA) regular set in individual stock cylindrical plastic tubes painted with corresponding adhesive, and a light viscosity polyvinyl siloxane impression material was injected on the finish line. The model teeth were removed from the impression at material setting, and the impression was examined for defects or trapped air bubbles. A total of 90 impressions (n = 30 impressions per design) were recorded. All the impressions were carefully boxed with boxing wax (Kerr), and then poured with type IV die stone (Whip mix). At 45 minutes, stone dies were removed from wax and trimmed with a wet model trimmer finishing system, generating 90 stone dies (n = 30 dies per design).

**Scanning of stone models and milling ceramic copings**

Ceramic copings were milled for all dies using three CAD-CAM systems and materials generating a total of 90 copings. Dies were scanned utilizing three digital scanners and milled with three CAD-CAM systems. These systems are the following:

- **System-1**: InEos Red (Sirona) and Vitablocks Mark II (VITA) copings milled by Cerec-inLab (Sirona);
- **System-2**: Cerec BlueCam (Sirona) and Vitablocks Mark II (VITA) copings milled by Cerec-inLab (Sirona);
- **System-3**: NobleProcera Optical Scanner and Procera zirconia copings milled by Noble Procera™ milling machine.

Figure 1. Master model teeth with finish line designs: Design-1, chamfer; Design-2, chamfer with shallow depression in finish line; and Design-3, chamfer with a deep depression in finish line.
System-2: The BlueCam scan followed a similar process to the CEREC® inEos red scanning, including calibrations, dies spray, and biogeneric referencing. However, the BlueCam has a 14 mm vertical scan range, and the height of the die crown preparation must be within this range in order to get a scanned image (Figure 2).

System-3: A stone master die was placed on the “moving object table” (NobleProcera Optical Scanner) that had a stable platform. The axis was centered at a direct alignment to the red laser scanner and parallel. The design was optimized and an appropriate finish line was determined using the NobelProceraTM prosthetic software. It gives the option of automatic cut-back function and has a visual aspect of the design from every possible angle. Zirconia was selected as the milling material (NobelProceraTM Zirconia) for 0.7 mm thickness for copings. Completed designs were digitally sent to the NoblebiocreTM laboratory and milling center, and milled copings were returned within two business days (Figure 3).

Marginal gap measurements
Each milled coping was seated on its respective “master model”, and then secured with uniform force. The metallurgical microscope (Zeiss, Germany) was connected to a high precision digital video-micrometer (Javelin JV6000, California, USA) and measurements were taken under $200 \times$ magnification. The images of the specimens measured were saved as bit-map files on the Windows® based computer attached to the microscope. The specimens were placed flat in a way that the margin was vertical in the computer screen, allowing the vertical lines in the video-micrometer to measure the gap. Eight marginal gap measurements were performed at pre-established points namely, “mesio-buccal, mid-buccal, disto-buccal, mesial, mesio-lingual, mid-lingual, and disto-lingual, distal,” including three measurements at the shallow and deep depression areas in Design-1 and Design-2.

All data were assessed through normality testing using the Kolmogorov–Smirnov test. The means and standard deviations were compared using analysis of variance and a multiple comparisons test (Tukey–Kramer).

Results
Evaluation of the tested systems demonstrated marginal gaps ranging from 12.49 to 26.6 $\mu$m. Specimens in System-1 (Vitablocks® Mark II-InEos Red Scan-Cerec®
inLab) showed a mean of 25.7 ± 6.8 µm marginal opening, while System-2 (Vitablocks® Mark II-Cerec® AC Connect-bluecam-Cerec-inLab) copings exhibited mean marginal misfits of 18.1 ± 4.9 µm. System-3 copings (Zirconia-NobleProcera™ Optical Scanner Noble-Procera™ milling machine) exhibited marginal gaps with a mean of 13.3 ± 3.3 µm, which were lowest among the groups (Table 1 and Figure 4). Marginal misfit among the different fabrication systems was significantly different (p < 0.05). System-1 showed significantly higher misfit compared to System-2 and System-3, respectively (p < 0.05). System-3 specimens showed significantly lower misfit values compared to System-1 and System-2 specimens (p < 0.05).

With regards to finish line types, Design-1 (chamfer) showed a mean marginal misfit of 26.6 ± 7.5 µm, 16 ± 4.7 µm, and 12.49 ± 2.8 µm for System-1, System-2, and System-3 specimens, respectively. Similarly, Design-2 (chamfer with shallow depression) specimens showed marginal openings of 26.4 ± 7.6 µm, 18 ± 4.17 µm, and 13.6 ± 3.34 µm for System-1, System-2, and System-3 specimens, respectively. While Design-3 (chamfer with deep depression) specimens showed mean marginal gaps of 24.3 ± 5 µm, 19.6 ± 5.3 µm, and 14 ± 3.61 µm for System-1, System-2, and System-3 specimens, respectively (Table 1). Among the systems tested there was significant difference between finish line design type 1, type 2 and 3 (p < 0.05).

Among specimens fabricated with System-3, marginal misfit for Design-1' copings were significantly lower than Design-2 and Design-3, respectively (p < 0.05). Among System-2 specimens, Design-1' copings showed significantly lower marginal misfit compared to copings with Design-2 and Design-3, respectively (p < 0.05). However, among System-1' specimens, all preparation designs (Design-1, Design-2, and Design-3) showed comparable marginal misfit (p > 0.05) (Table 1).

**Discussion**

The present study was based on the hypothesis that the marginal accuracy of Y-TZP restorations would significantly differ based on the margin configurations and CAD-CAM system used in their fabrication. Study findings revealed a significant influence of the CAD-CAM system type used and the margin configuration design on the marginal misfit. Therefore, the hypothesis was rejected. Factors including...
Marginal misfit is defined as the discrepancy or the “gap” between a restoration and the prepared tooth margin\textsuperscript{11, 12}. Holmes et al. defined the absolute marginal discrepancy as “angular combination of the horizontal and vertical error which would reflect the total misfit at that point”\textsuperscript{11}. The clinical long-term success of any restorations is dependent on the accurate marginal and internal fit. Accurate fit of restorations is extremely essential to achieve acceptable longevity\textsuperscript{13, 14}. The presence of discrepancies at the crown margin favors the formation of plaque and microleakage, increased dissolution of the cement that can lead to secondary caries, and/or periodontal disease\textsuperscript{13, 15}. According to the literature, marginal fit assessments can be either qualitative (inspection, exploratory probing, and radiographic examination) which is limited by human visual perception of 60 $\mu$m\textsuperscript{16}, or quantitative including, image magnification medium, a profile projector, and microscope\textsuperscript{17}. There are no clear guidelines on determination of a clinically and biologically acceptable marginal and internal fit. The American Dental Association specification\textsuperscript{18} states that the luting cement film thickness for a crown restoration should be no more than 25 $\mu$m using a type 1 luting agent, or 40 $\mu$m with a type II luting agent. However, Øilo and Evje DM suggested that a marginal gap that ranges from 25–40 $\mu$m is a clinical goal\textsuperscript{19}. Nonetheless, Christensen reported that the clinically detectable marginal discrepancy for subgingival margins is 34–119 $\mu$m, and 2–51 $\mu$m for supra-gingival margins. He also related, that marginal discrepancies of 39 $\mu$m or more in visually accessible surfaces are unacceptable\textsuperscript{20}. However, several authors have considered that marginal discrepancies between 100 and 150 $\mu$m are clinically acceptable\textsuperscript{21–26}.

In the present study, mean marginal misfit for copings fabricated using System-1 (Vitablocks® Mark II) and System-2 (CAD/CAM Cerec® inLab) was 25.7 $\mu$m and 18.1 $\mu$m, respectively. However, previous studies have shown higher misfit values with an average of 43 $\pm$ 23 $\mu$m\textsuperscript{27} and 53 $\mu$m to 66 $\mu$m\textsuperscript{28} using the same CAD-CAM systems. In addition, copings in System-1 showed significantly higher misfit values compared to System-2 copings. Interestingly, the material and milling machine in these systems were similar; however, the scanning devices were different. System-1 utilized InEos Red Scan; however, a Cerec® AC Connect with BlueCam was employed in System-2 coping fabrication. Therefore, the scanning device appears to be accountable for the significant difference found for marginal gap measurements between copings made in System-1 and System-2. A possible explanation may be derived from the fact that System-1 (InEos Red Scan) has a manual adjustable knob for image focusing on the preparation, meaning that the InEos Red scan needs a larger focal depth distance to scan the die to get an acceptable marginal gap measurement, while the System-2 (Cerec® AC Connect with BlueCam) has an automatic image capture system, an anti-shake function, as well as an extensive depth of field of 14 mm\textsuperscript{29–31}. These features could have influenced the accuracy of stone model scanning for the two systems. In addition, the parameters for System-1 were optimized by the operators to simulate with other systems as their parameters were fixed according to manufacturers’ instruction. This may have influenced the outcomes of the study.

Interestingly, copings fabricated using System-3 (Zirconia-NobleProcera™ Optical Scanner Noble-Procera™ milled) showed significantly lower marginal misfit among all systems tested, irrespective of the margin design. In contrast to other systems used in the study, the NobleProcera™ Optical Scanner has the “new conoscopic holography;” which has more measurement stability and is less susceptible to external light. It also, can digitalize convex and concave geometries and measure steep slopes up to 85º, and has a focal depth between 8 and 10 mm\textsuperscript{32}. These features of advanced comprehensive scanning, in the authors’ opinion, are responsible for the high accuracy of the copings milled using System-3.
In the present study, finish line configuration showed significant affect on the marginal misfit for System-2 and System-3 specimens; however, for System-1 there was no difference observed (Table 1). It was hypothesized that, remarkably, varying the depression area at the coping margins has an effect on their misfit; no significant difference of varying depressions at the finish line was observed in the System-1 specimen. DeHoff and Anusavice, have reported previously that the design of the margin did not affect the ultimate fit of the restoration. A similar study suggested that no significant differences were observed when marginal gaps among metal-ceramic crowns with shoulder, shoulder-bevel, and chamfer finish line were compared. Interestingly, System-2 and System-3 outcomes had a significant difference between finish line design types, which could point to the scanner’s focal depth to detect the depression area at the finish line, and its compensatory mechanism. Among CAD-CAM scanners, it is critical to have the camera stable, with correct angulation and height from the tooth to capture an acceptable image; this suggests that as depression area at the finish line area gets deeper it is challenging for some scanners, such as BlueCam, to scan outside of their range. By contrast, the NobleProcera™ Optical Scanner has increased accuracy with higher focal depth and ability to digitize complex shapes. It exhibited minimum influence of margin design on the marginal misfit, with mean values ranging from 12 to 16 µm. Moreover, it is important to mention that the Procera CAD/CAM system designs and mills a die that is 15–20% larger than the original. However, Cerec inLab compensates for the sintering by machining, which enlarges the work by 25–30%. This may have an impact on the misfit discrepancies among the study groups. Furthermore, it is suggested that the cutting efficiency, sequence, and duration of use of burs can influence the properties of ceramics including its surface. The burs were continuously changed on the manufacturers’ recommendations, which differed between systems. This, possibly, affected the outcomes of coping misfit.

The marginal misfits were significantly different among the CAD-CAM systems tested; however, these were well within the clinically acceptable limits. Furthermore, based on the misfit findings, System-3 copings can be recommended clinically over other systems. These outcomes should be considered in light of the facts that in-vitro marginal assessments are lower compared to clinical marginal opening. In addition, methodological limitations such as scanning sprayed stone dies, no use of cement, extra oral scanning, and circular dies with circumferential uniform margins prepared on plastic teeth may have influenced the outcomes of the present study.

Conclusion

The CAD-CAM manufactured Y-TZP copings exhibited a marginal gap ranging from 12.49 to 26.6 µm. The CAD-CAM fabrication system was a significant factor influencing the marginal misfit of Y-TZP’ copings. Margin design exhibited system dependent influence on the marginal misfit. The NobleProcera Optical Scanner–Noble Procera™ milling machine–Procera zirconia copings exhibited significantly lower marginal misfit compared to other systems. Marginal misfit observed for all systems were within clinically acceptable parameters.

Author Contributions

KAA, FV and TA: data collection; study design; manuscript writing; and final manuscript approval. AM, AA and MSB: data collection; study design; manuscript drafting; data analysis; and manuscript approval. AAh, SA and TA: data collection; manuscript approval; and data interpretation. KAH, LA and HK: data collection; writing; revision; editing; and final manuscript approval.

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