Three-dimensional fit of self-glazed zirconia monolithic crowns fabricated by wet deposition

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This study evaluated the 3-dimensional (3D) fit of self-glazed zirconia monolithic crowns fabricated by wet deposition, in comparison with milled zirconia and lithium disilicate monolithic crowns. Dual-scan protocol was used to assess the fit of crowns. Root mean squares (RMS) and uniformity index (UI) were calculated to describe the gap size and uniformity. The self-glazed zirconia crowns had significantly lower RMS values for the gaps at axial wall and transition regions than the milled zirconia crowns, and for the gaps at occlusal region than both milled crowns. All 3 types of crowns had comparable RMS values for the gaps at marginal and chamfer regions and comparable UI values for both marginal and internal gaps. The 3D fit of the self-glazed zirconia monolithic crowns was clinically acceptable and they exhibited better fit at occlusal region than the milled crowns.

Keywords: Marginal gap, Internal gap, RMS, Uniformity

INTRODUCTION

The monolithic all-ceramic dental restorations have become more popular in recent years¹. Compared with the multi-layered restorations, the monolithic restorations can avoid chipping and fracture of the porcelain veneers, and minimize the amount of tooth preparation²,³. The commonly used monolithic zirconia and glass-ceramic restorations were mainly fabricated by subtractive milling the pre-sintered blanks. After sintering, the definitive restorations need to be further polished or glazed. Otherwise, their rough outer surface could induce excessive abrasion to opposing natural teeth⁴,⁵.

A novel additive wet deposition manufacturing technique of monolithic zirconia restoration has been developed⁶. The green body is formed by depositing zirconia gel firstly and then its intaglio surface is green milled. After sintering, the definitive restorations, self-glazed zirconia, exhibit an enamel-like smooth outer surface, which can be used directly without any further manual processing⁷.

Fit is an important factor for the longevity and clinical success of dental restorations⁸,⁹. The advantage of the wet deposition technique in achieving excellent trueness and marginal quality has been proved¹⁰,¹¹. It may benefit the fit of the restorations, which has not been extensively studied yet. Both 2-dimensional (2D) and 3-dimensional (3D) measuring methods are available to evaluate the fit of restorations. Previous study has shown that 3D measuring method has greater potential for accurate and consistent clearance measurements than 2D measuring method¹². Three-dimensional measuring method can efficiently evaluate the inner surface of a restoration and reproduce the gap without the loss of data due to the limited selection of cutting planes¹³. Moreover, 3D measuring method is conducive to data preservation and provides a convenient technique for repeated measurement¹⁴.

The purpose of this in vitro study was to evaluate the 3D fit of the self-glazed zirconia monolithic crowns by using dual-scan protocol, in comparison with 2 widely used zirconia and lithium disilicate monolithic crowns fabricated by subtractive milling. The null hypothesis was that there is no significant difference in either gap size or uniformity among the 3 types of monolithic crowns.

MATERIALS AND METHODS

Manufacture of crowns

The research protocol was approved by the Institutional Review Board of the Stomatology Hospital of Zhejiang Chinese Medical University (#202000106). A mandibular first molar with no defects which had been extracted due to periodontitis was used as the master model. The tooth was prepared with an occlusal reduction of 1.0–1.5 mm, and an axial wall reduction of 1.0 mm with a 0.8–1.0 mm circumferential chamfer. The taper was controlled at 2°–5°. After preparation, an intraoral scanner (CS3600, Carestream Dental, Atlanta, GA, USA) was used to acquire the abutment data. Then, a 5-axis milling machine (Ardenta, CS100-5W, Arix CNC Machines, Tainan, China) was used to mill 10 identical resin abutments from denture resin (Acrylic Disk, Yamahachi Dental, Changshu, China) according to the scan data of the abutment. The taper was controlled at 2°–5°. After preparation, an intraoral scanner (CS3600, Carestream Dental, Atlanta, GA, USA) was used to acquire the abutment data. Then, a 5-axis milling machine (Ardenta, CS100-5W, Arix CNC Machines, Tainan, China) was used to mill 10 identical resin abutments from denture resin (Acrylic Disk, Yamahachi Dental, Changshu, China) according to the scan data of the abutment. To improve the adhesion of the replica impression to the resin abutments, the surface of the resin abutments was sandblasted with alumina grit. Ten square bases with 4 hemispheres (φ=8 mm and

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A dual-scan protocol described by Kane et al. was used to assess the fit of the crowns. A dental laboratory scanner (D810, 3Shape, Copenhagen, Denmark) with a reported accuracy of ±15 μm was used to scan the resin abutment and the silicone replica-coated resin abutment. Firstly, the resin abutments were digitized (Fig. 1a, b). Secondly, the corresponding crowns were filled with a thin layer of light-body silicone (Coltene AFFINIS light body, Coltene Whaledent, Altstätten, Switzerland), and then seated on the abutments. The crowns were held under a 50 N load until the light-body silicone was set. The excess silicone was removed from the edges. The crowns were carefully removed from the abutments, leaving the light-body silicone intact. Then the silicone replica-coated resin abutment was digitized (Fig. 1c, d). Thirdly, the measuring software (Geomagic Control X, Geomagic, Rock hill, SC, USA) was used to superimpose the 2 digital files with the 4 hemispheres on the bases as reference. An area that remained unchanged before and after gap replication was used to check the accuracy of the alignment, and RMS value less than 20 μm was considered satisfactory.

Measurement of the gap size and uniformity
The mean area of each abutment obtained by scanning was about 146 mm², and the number of points measured on average was about 197,000. Five regions, including marginal, chamfer, axial wall, transition, and occlusal, were defined for 3D measurement (Fig. 2). The latter 4 regions represented the internal gap.

Gap size was described as the distance between the resin abutment and the silicone replica-coated resin abutment. A color difference map was generated and the root mean square (RMS) was calculated according to the following formula:

\[ RMS = \sqrt{\frac{1}{n} \sum (X_{1,i} - X_{2,i})^2} \]

where \( X_{1,i} \) is the measuring point in the resin abutment, and \( X_{2,i} \) is the measuring point.
Mean RMS values for the marginal and internal gaps of the 3 groups ranged from 78.07–84.21 μm, and 96.32–120.62 μm, respectively (Table 1). There was no significant difference among the 3 groups regarding the marginal gap ($p>0.05$). However, the milled zirconia crowns exhibited a significantly greater internal gap than the self-glazed zirconia and milled lithium disilicate crowns ($p<0.001$). Furthermore, the internal gaps at the axial wall, transition, and occlusal regions of the milled zirconia crowns were significantly greater than those of the self-glazed zirconia crowns ($p<0.001$ for all) and the milled lithium disilicate crowns ($p=0.001$, $p=0.026$, respectively) (Fig. 3). There was no significant difference of UI values for marginal and internal gaps among the 3 groups ($p>0.05$) (Table 1).

The difference of RMS values for the gaps at 4 internal regions within each group are presented in Fig. 3. For the self-glazed zirconia crowns, the RMS values for the gaps at 4 internal regions were similar ($p>0.05$). For the milled zirconia crowns, the RMS value for the

![Fig. 3](image)

**Fig. 3** Mean and standard deviation of RMS values for the gaps at 4 internal regions. One-way ANOVA was used to analyze the differences. Significant differences among regions within each group were indicated by horizontal lines with asterisks (* means $p<0.05$). Significant differences at the same region among the 3 groups were indicated by different lowercase letters ($p<0.05$).

| Groups                  | RMS (μm)          | UI (μm)         |
|-------------------------|-------------------|-----------------|
|                         | Marginal$_A$  | Internal$_A$  | Marginal$_B$ | Internal$_B$ |
| Self-glazed zirconia    | 81.40±20.62*     | 96.32±9.51*    | 26.59±9.61*  | 37.07±8.70*   |
| Milled zirconia         | 84.21±25.69*     | 120.62±13.09*  | 29.75±8.95*  | 40.72±6.58*   |
| Milled lithium disilicate| 78.07±19.49*    | 98.81±13.29*   | 36.07±9.11*  | 34.35±7.39*   |

A: One-way ANOVA was used to analyze the differences among groups. B: Non-parametric Kruskal-Wallis H test was used to analyze the differences among groups. Different lowercase letters indicate statistical differences among groups ($p<0.05$).
gaps at occlusal region was significantly higher than that at chamfer (p=0.030). For the milled lithium disilicate crowns, the significant difference of RMS values existed between the chamfer and axial wall regions (p=0.016), the axial wall and occlusal regions (p=0.002), and the transition and occlusal regions (p=0.037).

**DISCUSSION**

The null hypothesis of the present study was partially rejected. Three types of the monolithic crowns had comparable gap uniformity; however, statistically significant differences were found between the size of internal gaps among them.

The clinically acceptable gap size of dental restorations is less than 120 μm for marginal gap\(^2\);\(^3\)\(^4\)\(^5\), and 200–300 μm for internal gap\(^\text{19,20}\), respectively. In the present study, both marginal and internal gaps of all 3 groups met clinical requirements. Regarding milled lithium disilicate and milled zirconia crowns, they had comparable marginal gaps, but the internal gap of milled zirconia was significantly greater. Ricci et al.\(^\text{20}\) reported the similar finding that the marginal gaps of milled zirconia and lithium disilicate crowns were comparable. However, some studies showed different results.\(^\text{21,22}\). Freire et al.\(^\text{21}\) found that the marginal gap of milled zirconia crowns (58.08±16.6 μm) was obviously larger than that of milled lithium disilicate crowns (27.95±9.37 μm). Whereas, Martinez-Rus et al.\(^\text{23}\) compared the milled lithium disilicate crowns with zirconia crowns, and got the opposite conclusion. The variations of outcomes can be attributed to different research designs, evaluation methods, samples, and milling equipments. For internal gap, most previous studies proved that milled zirconia crowns had inferior internal fit than milled lithium disilicate crowns\(^\text{20,20}\). It may be ascribed to different sintering shrinkage rate of two materials. Zirconia had 20%–25% shrinkage, 30%–40% for lithium disilicate, and 20%–25% shrinkage after sintering.

In the present study, self-glazed zirconia crowns fabricated by wet deposition exhibited comparable marginal and internal gap size to milled lithium disilicate crowns, and significantly smaller internal gap than milled zirconia crowns. Both zirconia crowns had a similar sintering shrinkage rate, and the difference may be due to the different manufacturing processes. For milled zirconia crowns, the intaglio surface was dry milled from partially sintered blanks by a brittle fracture mechanism. The interior packing defects of the blanks, like large aggregates and voids, will cause extensively chippings on the intaglio surface during dry milling.\(^\text{25}\) In contrast, the green bodies of self-glazed zirconia crowns that formed by depositing the homogeneous zirconia gel had fewer packing defects than the zirconia blanks. And their intaglio surfaces were milled at the green stage. Sintering neck between individual grains had not formed yet and the main mechanism of green milling was ductile deformation.\(^\text{26}\) Therefore, fewer defects would be generated on the intaglio surface of self-glazed zirconia crowns than that of milled zirconia crowns\(^\text{7,24}\). Furthermore, obviously greater gaps at the occlusal region of milled lithium disilicate and milled zirconia crowns were found in the present study. Kunii et al.\(^\text{25}\) illustrated that this gap was created by the anisotropic shrinkage of blanks, and the sintering shrinkage in the tooth axis was smaller than that in the horizontal axis. While for self-glazed zirconia crowns fabricated by wet deposition, the internal gaps were much comparable across different regions.

Uniformity of the gap between the abutment and restoration has received attention in recent years. A uniform gap is conducive to the flow of cement and the dissipation of occlusal forces and shear forces.\(^\text{26,27}\). In contrast, a non-uniform gap may lead to the disintegration of the adhesive, thus resulting in the failure of cement or restorations.\(^\text{28}\). In 2D methodology, the UI was calculated as the ratio of the gap size at the occlusal and axial regions based on limited data.\(^\text{29}\). In the present study, UI was calculated as the standard deviation of the gaps at 197,000 data points of each abutment acquired by 3D measurement; thus it might be a more accurate protocol. The results showed that all 3 groups had comparable uniformity of both marginal and internal gaps. It demonstrated the superiority of CAD-CAM technology in obtaining high-precision restorations.

Besides the excellent fit of self-glazed zirconia crowns, the novel wet deposition process also improved the other important properties of the definitive restorations. During depositing zirconia gel to form the green body, a nano-gradient microstructure was formed. From the bulk to the outer surface, the average grain size of self-glazed zirconia was decreased from 250 nm to 100 nm, which is much smaller than that of milled zirconia, 200–600 nm.\(^\text{30}\) The as-sintered outer surface with fine grains and no milling defects showed obviously lower frictional coefficient against natural enamel than the milled zirconia, and exhibits sufficient aesthetics.\(^\text{30,31}\) Benefit from the dense and homogeneous microstructure with limited defects, the bending strength of self-glazed zirconia bulk is 1,120±70 MPa with a high Weibull modulus around 18.\(^\text{32}\) No matter with and without subjecting to fatigue, the self-glazed zirconia bridge showed higher fracture force than the milled zirconia.\(^\text{24}\)

Some limitations of the present study should be considered. The in vitro tests and standardized crowns were different from the clinical conditions. Only the fit of single crowns was evaluated in the study. Furthermore, a slight and incomplete light reflection of crowns generated during scanning might affect the digitizing accuracy to some extent.\(^\text{30}\). Therefore, in vivo studies on the fit of various kinds of self-glazed zirconia restorations by using different assessing methods are needed.

**CONCLUSION**

Within the limitations of this in vitro study, the following conclusions were drawn. The 3D fit of self-glazed zirconia monolithic crowns fabricated by wet
deposition was clinically acceptable. Self-glazed zirconia crowns exhibited better internal fit at occlusal region than the milled zirconia and lithium disilicate crowns. The 3 types of crowns had comparable uniformity and comparable marginal fit.

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