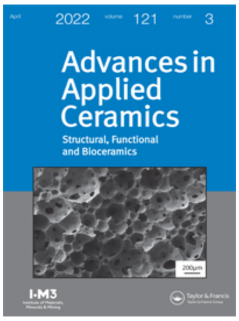

Taylor & Francis
Taylor & Francis Group

Advances in Applied Ceramics
Structural, Functional and Bioceramics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/yaac20

Fitness of self-glazed zirconia onlays using conventional and digital impressions

Kun Qian, Bingqing Li, Tingting Pu, Tianyi Bai & Yihong Liu

To cite this article: Kun Qian, Bingqing Li, Tingting Pu, Tianyi Bai & Yihong Liu (2022) Fitness of self-glazed zirconia onlays using conventional and digital impressions, Advances in Applied Ceramics, 121:3, 93-100, DOI: 10.1080/17436753.2022.2069988

To link to this article: https://doi.org/10.1080/17436753.2022.2069988

ADVANCES IN APPLIED CERAMICS
2022, VOL. 121, NO. 3, 93–100
https://doi.org/10.1080/17436753.2022.2069988

IOM3 Institute of Materials, Minerals & Mining
Taylor & Francis
Taylor & Francis Group

Fitness of self-glazed zirconia onlays using conventional and digital impressions

Kun Qian[a], Bingqing Li[a], Tingting Pu[b], Tianyi Bai[a] and Yihong Liu[a]

[a]Department of General Dentistry, Peking University School and Hospital of Stomatology, Beijing, People's Republic of China; [b]Dental Laboratory, Peking University School and Hospital of Stomatology, Beijing, People's Republic of China

ABSTRACT
The fitness of self-glazed zirconia (SGZ) onlays fabricated with computer-aided design/computer-aided manufacturing was analysed, and conventional impressions (CIs) were compared with intraoral digital impressions (DIs). Onlay preparation was applied on a typodont left mandibular first molar to create 22 copy dies, which were divided into DI and CI groups. The marginal gap of DI-fabricated onlays was smaller than that of CI-fabricated onlays ($p < 0.05$). In both groups, the marginal gap was larger in the distal gingival than in other regions ($p < 0.05$), and a trend of decreasing marginal accuracy after thermal cycling was observed. SGZ onlays performed well for internal fitness; the overall internal gaps were 72.05 ± 8.16 and 100.96 ± 22.53 µm in Groups DI and CI, respectively. SGZ onlays exhibited clinically acceptable marginal and internal fitness values. The marginal adaptation of DI-fabricated onlays was better than that of CI-fabricated onlays.

ARTICLE HISTORY
Received 14 July 2021
Revised 12 April 2022
Accepted 21 April 2022

KEYWORDS
Self-glazed zirconia; onlay; fitness; digital impression

Introduction

Self-glazed zirconia (SGZ) is a newly developed material for dental restorations. Unlike traditional blank-machined zirconia, SGZ has an enamel-like smooth surface, so there is no further veneering or glazing required. Additionally, SGZ has an adjustable optical translucency and adequate aesthetic behaviour. Hence, this material is suitable for computer-aided design and computer-aided manufacturing (CAD/CAM) systems to customise full-contour monolithic restorations, avoiding the conventional manual work of grinding/polishing, veneering, and glazing [1]. Unlike traditional zirconia restorations, which are dry milled on partially sintered zirconia blanks, SGZ restorations are formed using a precision additive 3D gel deposition approach based on the hybrid gelation principle [2], which avoids microscopic defects and voids caused by traditional partial pre-sintering milling [3].

An onlay is a type of partial-coverage restoration, now widely used in clinics, which restores one or more cusps and adjoining or entire occlusal surfaces, and is retained by mechanical or adhesive means [4]. Few reports related to the restoration type influencing the marginal gap (MG) suggest that the crown tends to have the least MG compared to those of the onlay and inlay [5]. The MG of the onlay/inlay ranges from 36 to 222.5 µm and can be influenced by many factors, such as a complex geometry [6]. Fitness, including marginal and internal fit, is very important for the longevity of restorations, especially those with long margins and complex geometries, such as an onlay [7]. It has been shown that the five-year survival rate for onlays exceeds 90%, while caries caused by poor marginal fit accounted for 20% of the total failures [8]. Meanwhile, a poor internal fit can result in reduced retention, incomplete bonding interfaces [9], and reduced fracture resistance [6,10,11,12].

The accuracy of the impression directly affects the fitness of the restoration [13]. With the development of CAD/CAM systems, intraoral digital impressions (DIs) have become an alternative to conventional impressions (CIs). DI, owing to its reduced deformation while impressing and casting, has better accuracy than that of CI [14–16]. However, the accuracy of intraoral DI can be influenced by intraoral conditions and operator skills [17,18]. Seelbach et al. [19] and Abdel-Azim et al. [16] reported CI and DI to have similar accuracy. In contrast, Syrek et al. [20] and Pradíes et al. [21] demonstrated that the marginal fits of crowns manufactured using DI were better than those of crowns manufactured using conventional techniques. Furthermore, Heike's [22] study clarified that tooth shape is an important factor influencing the accuracy of intraoral DI. The geometry of the onlay is considered more complex than that of the crown, which makes intraoral scanning more difficult, hampering its accuracy. Therefore, it is necessary to

CONTACT Yihong Liu kqliuyh@163.com Department of General Dentistry, Peking University School and Hospital of Stomatology & National Clinical Research Center for Oral Diseases & National Engineering Laboratory for Digital and Material Technology of Stomatology & Beijing Key Laboratory of Digital Stomatology, 22 Zhongguancun South Avenue, Haidian District, Beijing 100081, People's Republic of China

investigate the viability of DI for complex situations, such as onlays.

Numerous techniques evaluate fitness, which indirectly reflects the accuracy of the impression. Among these, the direct measurement technique (2D technique) and 3D replica technique are the most commonly used [23]. The 2D technique has been proven to be an effective technique for evaluating marginal adaptation in many studies [24–27]. The MG was measured directly using a stereomicroscope, but internal fit could not be obtained, making it usable only for in vitro studies. The 3D technique, which provides multiple point measurements and internal adaptation analysis, has been introduced in previous studies on crowns [14,28]. Silicone replica fills the space between the restoration and die. The dies with and without silicone replicas were digitised using a model scanner, and the three-dimensional information of the silicone replica was obtained. This technique is affected by the accuracy of the scanner and the software to an extent [28]. In this situation, it is important to evaluate the consistency of the 2D and 3D techniques in fitness analysis.

The aim of this in vitro study was to evaluate the fitness of SGZ onlays in which 2D and 3D replica techniques were used for both CIs and intraoral DIs. The null hypothesis was that there is no difference in the fitness (marginal and internal) of SGZ onlays obtained using CI and DI, and the 3D technique was consistent with the 2D technique in the fitness evaluation of onlays.

Materials and methods

Manufacturing of the specimens

A standardised typodont left mandibular first molar (A5SAN-500, NISSIN, Yokohama, Japan) was used for onlay preparation. The cavity design is shown in Figure 1(a). The occlusal box was of 3 mm width and 2 mm depth. The walls of the occlusal and proximal boxes exhibited a 15° divergence. The buccal cusp was prepared 1.5 mm with a rounded shoulder margin of 1 mm width. The lingual cusp was prepared 1 mm. The gingival finishing lines were 1 mm above the cemento-enamel junction in both the mesial and distal proximal boxes. All internal angles of the cavities were rounded. Preparation quality was checked under a stereomicroscope (Leica MZ 16A, Leica Microsystems, Switzerland).

The prepared die was digitised using a model scanner (3Shape D2000, 3Shape A/S, Copenhagen, Denmark). The scanned data were exported to an STL file. Next, twenty-two copy dies with poly (methyl methacrylate) (PMMA) resin blocks (HuGe Dental Material Co., Ltd, Shandong, China) were milled using Ideal Mill W (SinoDigital, Beijing, China). All copy dies were fixed in typodonts. Subsequently, the typodonts were fixed in dental simulators (NISSIN, Yokohama, Japan) to simulate the oral conditions.

The copy dies were divided into two groups, as follows.

Group DI: the dies restored with SGZ (Erran Tech Ltd., Hangzhou, China) using DIs. ($n = 11$).

Group CI: The dies restored with SGZ using CIs ($n = 11$).

Fabrication of restorations

The workflow is illustrated in Figure 2. In Group DI, DIs were obtained using Omnicam intraoral scanners (Sirona Dental System GmbH, Bensheim, Germany). In Group CI, the CIs of polyether impression material (Impregum Penta Soft, 3M ESPE, St Paul, MN, USA) were obtained according to the instructions of the manufacturer using individual trays. After 1 h, stone casts were made using type IV gypsum (Heraeus, Hanau, Germany). All casts were then digitised using a model scanner, D2000. Based on the data obtained from the scan, onlay restorations in both groups were designed using the corresponding software (3Shape Dental System, 3Shape A/S, Copenhagen, Denmark). The simulated cement thickness was set to 50 μm, which was 1 mm from the margin. SGZ onlays were fabricated using an additive 3D gel deposition method developed by Erran Tech, Ltd.

Fitness evaluation using the 3D replica technique

The 3D replica technique was used to analyse the fitness of the onlays. The copy dies were removed from the typodonts based on the methods described by Liu [29]. For each measurement, the copy die was digitised using a model scanner, D2000. The scan data were exported as an STL file and named 'A.' Light-body addition silicone (Aquasil Ultra XLV; Dentsply, Germany) was applied to the internal surface of the restoration. The restoration was placed on its corresponding copy die with a 2-kg load for 5 min. Excess silicone was removed using a scalpel. The onlay restorations were then carefully removed. Therefore, the silicone replica on the copy die represented the space between the restoration and copy die. Then, D2000 was used to scan the copy die covered with the silicone replica, and the data were exported as an STL file named 'B.'

Reverse engineering software (Geomagic 12) was used to analyse the differences between A and B. Best-fit alignment was performed between the two datasets. The root mean square of the selected area was recorded to represent the internal gap of the

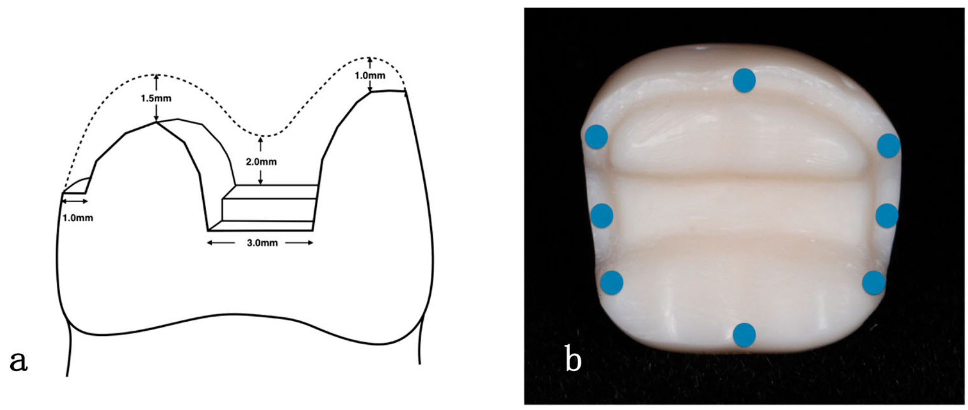

Figure 1. Schematic showing the (a) designed parameters of the onlay and (b) location of the points where the marginal gaps were measured.

corresponding area. Each specimen was separated into eight locations for MG evaluation (Figure 1(b)): two on the gingival surface (one mesial and one distal); four on the axial surface (one mesial-buccal, one distal-buccal, one mesial-lingual, and one distal-lingual); and two on the occlusal surface (buccal and lingual). The overall internal fitness was also calculated. Figure 3 illustrates the workflow.

Fitness evaluation using the 2D technique

After 3D replica analysis, the silicone replica was removed. The restorations were then cemented into their corresponding copy dies using adhesive resin cement RelyX Ultimate Clicker (3M ESPE, St Paul, MN, USA). All cementation procedures were performed following the recommendations of the manufacturer. The restorations were loaded with a 2-kg load when cemented. The restorations were light-cured for 40 s on each surface. Excess cement was removed using a scalpel.

MGs were measured using a stereomicroscope (Leica MZ 16A, Leica Microsystems, Switzerland). Similar to the 3D technique, eight locations on each specimen were observed (Figure 1(b)).

Thermal cycling procedures

After 2D analysis, the specimens were subjected to thermal cycling in water baths between 5 and 55°C. The dwell time was 30 s at each temperature, and the transfer time was 3 s. The MGs were measured using a stereomicroscope (similar to the 2D analysis) at 5000 cycles.

Statistical analysis

Statistical analysis was performed using SPSS 20.0 (IBM SPSS Statistics, IBM Corp, NY, USA), and

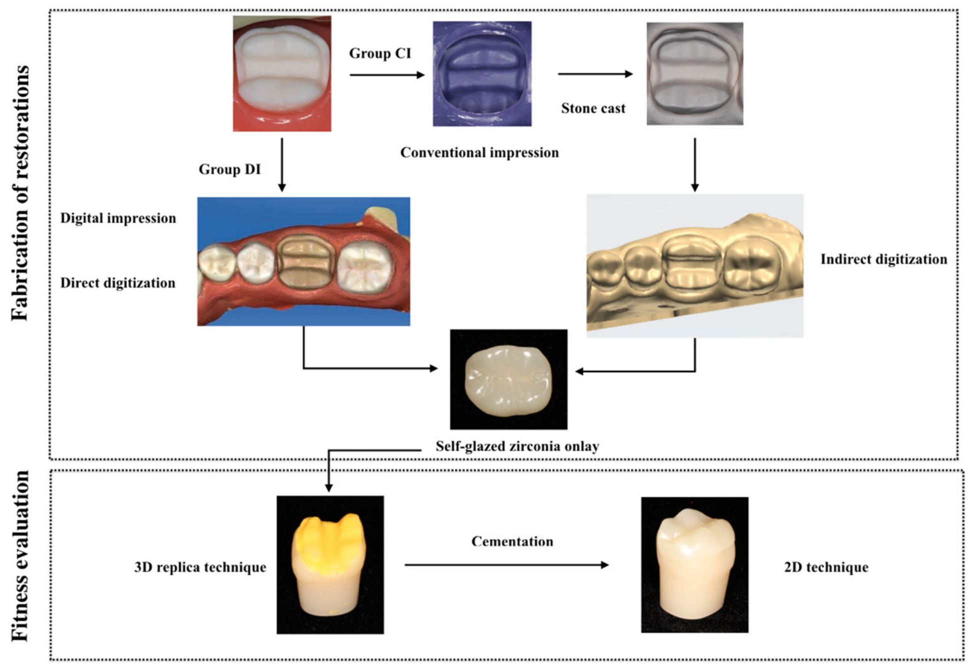

Figure 2. Workflow for the fabrication of restorations.

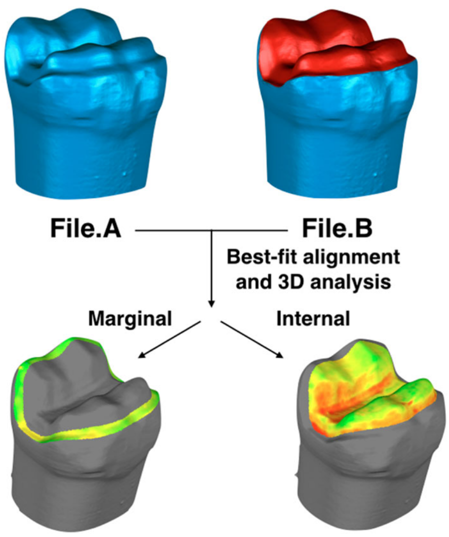

Figure 3. Workflow for fitness evaluation using the 3D replica technique.

statistical significance was established at $\alpha = 0.05$. Independent samples T-test was performed to test the differences in overall marginal/internal gaps between groups. Paired samples T-test was performed to evaluate the differences between the two techniques. Paired samples T-test was also performed to evaluate the differences between samples, before and after thermal cycling. One-way ANOVA combined with the LSD post hoc test was used to test the differences among the MGs at eight locations in each group. Statistical significance was set at $p < 0.05$.

Results and discussion

The mean MGs (MMGs) (μm) of the DI and CI groups assessed using the 3D and 2D evaluation techniques are summarised in Table 1 and shown in Figures 4 and 5. The MMGs of the DI and CI groups were <120 μm. Although no consensus has been reached, previous studies have suggested that clinically acceptable MG values for dental restorations should not exceed 120 μm [10,29,30]. The SGZ onlay in this study exhibited clinically acceptable marginal adaptation based on a previous suggestion. In previous studies, the MGs of the CAD/CAM-fabricated all-ceramic onlay were reported to be in the range of 54–96 μm [5,31–33]. The luting space setting date in the software could influence the marginal fit of the CAD/CAM restorations, which was not reported in any of these studies. Under these circumstances, the results of the aforementioned studies are not comparable.

Evaluation using the 2D technique indicated that Group DI has significantly lower MG values than those of Group CI ($F = 8.767$, $t = -3.512$, $p = 0.002$), which was similar to the results obtained using the 3D technique ($F = 11.25$, $t = -3.222$, $p = 0.004$). The MMG evaluated using the 3D and 2D techniques for DI-fabricated onlays (Group DI) was smaller than that for CI-fabricated onlays (Group CI) ($p < 0.05$). The methods of impression affected the marginal adaptation of onlay restorations, and the null hypothesis stating no difference in the fitness of SGZ onlays obtained using CIs and DIs was rejected.

The mean and standard deviation of the MGs in the CI group were higher than those in the DI group, indicating that indirect digitisation had lower accuracy and precision than those of direct digitisation. Based on previous studies, type IV dental stone reported an expansion of 0.07–0.09% at room temperature (23 ± 2°C) and ~50% relative humidity [34]. Marcos et al. found that the linear dimensional change of type IV dental stone ranged from 0.12 to 0.34% in a room with no temperature and humidity control [35]. The calculated linear dimensional change of the samples in the CI group was ~0.2% in this study, similar to that reported by Marcos et al., which suggested that the larger gaps in the CI group may be related to the expansion of dental stones. The size of the plaster models was larger than that of the originally prepared dies owing to gypsum expansion, and the dimensional deformation along the process chain may also increase the error of indirect digitalisation [36–38].

The MGs of the different regions are shown in Figure 6. The distal gingival MG was larger than that of the other regions ($F = 2.775$, $p = 0.001$) regardless of the impression methods and evaluation techniques used. To simulate real oral conditions, typodonts were fixed in dental simulators. In the DI group, the distal gingival margin was the most difficult part of the intraoral scan, as the scanning head had to be adjusted in multiple directions to acquire an intact image. As the angle between the perpendicular of the scanned surface and the scanning direction increased, the accuracy of the digitisation decreased. For angles >60°, the accuracy of

Table 1. MMGs (μm) of self-glazed zirconia onlays.

Group (n = 11)	Phase	Technique	Min	Mean	Max	Median	SD	SE	CI-95%
DI	Before thermal	3D	61.01	75.41	89.45	75.66	8.66	2.61	69.59–81.23
DI	Before thermal	2D	62.14	74.43	84.96	77.52	8.25	2.49	68.89–79.97
DI	After thermal	2D	73.21	84.07	97.71	84.63	7.31	2.58	77.96–90.17
CI	Before thermal	3D	71.14	119.32	206.96	118.24	44.35	13.37	89.52–149.12
CI	Before thermal	2D	70.66	111.45	176.53	100.22	33.97	10.24	88.62–134.27
CI	After thermal	2D	81.75	124.77	186.23	117.44	34.47	14.07	88.59–160.94

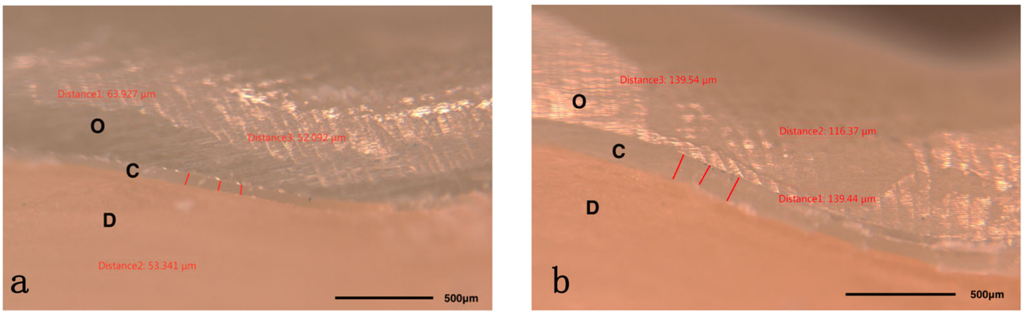

Figure 4. Marginal gaps of (a) DI and (b) CI groups under optical microscopy (T: tooth, C: cement, O: onlay).

digitisation declined significantly based on a former study [39]. The larger distal gingival MG in the CI group may be related to the deformation of the polyether impression. Martins et al. [40] found that the shrinkage of the Impregum Penta Soft impression material was 0.13 ± 0.19%. The density and duration of the strain force applied upon the removal of an impression are important for the permanent deformation of elastomeric impression materials [41]. Figure 7 shows that the thickness of the impression material is asymmetrical around the dies depending on the presence of adjacent teeth. Removal of the impression from the dental arch posed a greater risk of distortion in the thinner areas of the polyether impression [42]. The process of impression removal leaves deformations in the gingival area, especially in the distal region, leading to larger distal gingival MGs. Increasing the convergence angle of the proximal boxes, optimising the cavity design, and relocating the cervical margin may be helpful in reducing impression deformation, which requires further confirmation.

Considering the evidence that the microleakage of restoratives is influenced by their thermal properties, the MGs of the SGZ onlays before and after thermal cycling were determined in this study. Thermal cycling simulated the temperature changes in the oral cavity and showed a dissimilar coefficient of thermal expansion between the preparation and restorative materials [43,44]. The bath temperature and dwell time in this study were selected based on a previous study [45]. After 5000 thermal cycles, the MGs increased significantly in Group DI ($t = -2.634$, $p = 0.017$), and no distinct change was observed in Group CI ($t = -0.769$, $p = 0.454$). Although a trend of decreasing marginal accuracy was demonstrated in both groups, the MMGs were clinically acceptable after thermal cycling. Numerous *in vitro* [46,47] and *in vivo* [48,49] studies have provided evidence that the marginal quality of ceramic restorations tends to deteriorate over time following adhesive cementation. The increase in the MG width after thermal cycling may be attributed to hydrolytic activity. The luting composite may absorb water, and the resultant volume expansion may lead to an increase in the MG width [46]. However, to ensure the consistency of the specimens, PMMA copy dies were used in this study instead of human teeth; therefore, the thermal cycling was not consistent with the intraoral situation.

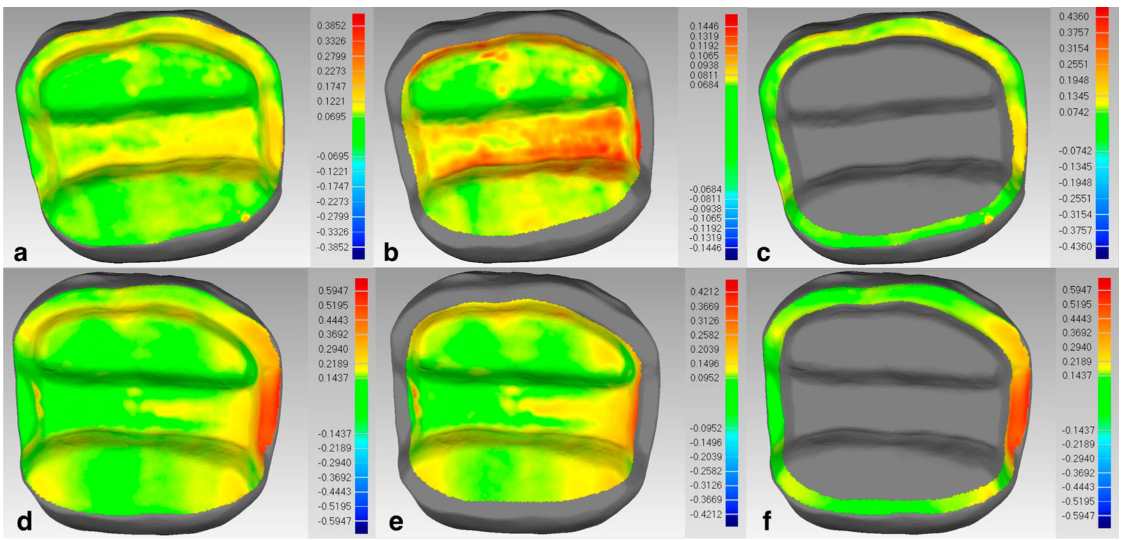

Figure 5. Colour-coded difference images showing the fitness of different groups. (a) Overall gap of Group DI; (b) internal gap of Group DI; (c) marginal gap of Group DI; (d) overall gap of Group CI; (e) internal gap of Group CI; and (f) marginal gap of Group CI.

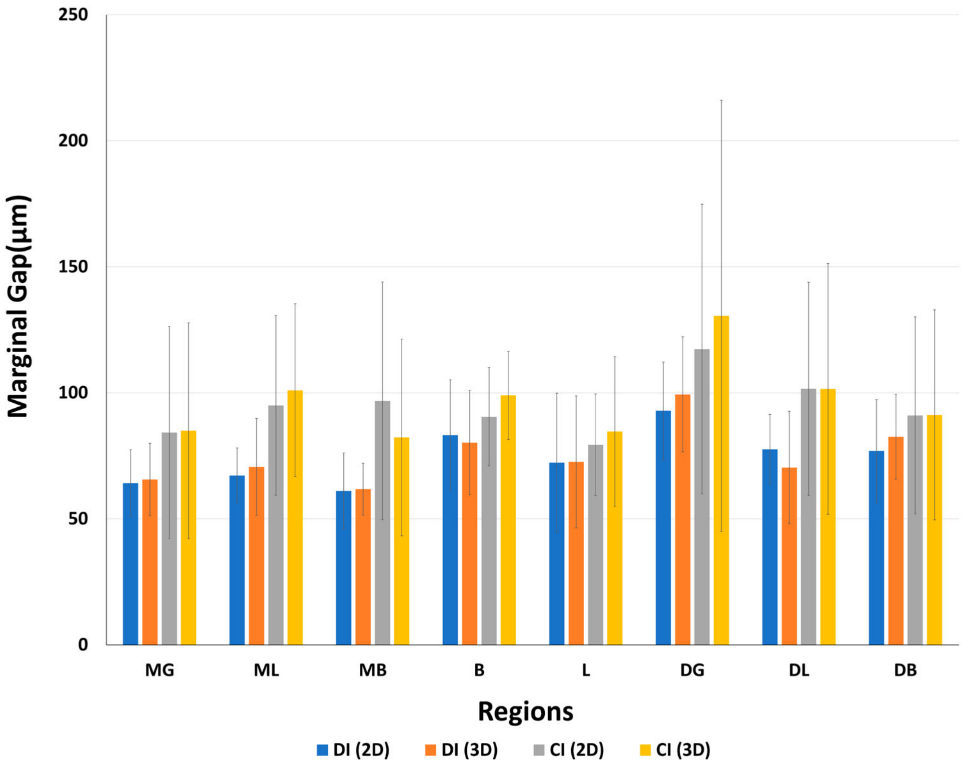

Figure 6. Trend of the marginal gaps of different regions for each group.

The internal fitness of the SGZ onlay was analysed using the 3D technique in this test. The detailed results are presented in Table 2 and Figure 5. The measurements were separated into two regions: the axial and pulp walls, and the overall internal gaps were recorded. As shown in Table 2, the overall internal gap of Group DI was smaller than that of Group CI ($F = 4.059$, $t = -4.001$, $p = 0.00$), which was consistent with the marginal fitness. In the CI group, there was no significant difference between the axial and pulp regions ($t = 0.101$, $p = 0.92$). In the DI group, the internal gaps in the pulp regions were larger than those in the axial regions ($t = 2.968$, $p = 0.01$). The internal fit values of the partial-coverage restorations were 91–308 µm in a previous study [50]. It has been proposed that internal fit values between 50 and 100 µm could result in adequate clinical performance [6]. Compared with previous studies, the internal fitness of SGZ onlays of all groups performed relatively well in this study. Furthermore, the internal gaps of Group CI were uniformly larger than those of Group DI. A possible reason for this was the expansion of type IV dental stones, which also resulted in larger MGs in Group CI. Accordingly, it is suggested that the thickness of the simulated cement should be appropriately reduced in the clinical application of indirect digitalisation to compensate for errors in the casting process. The internal gaps were not uniform in Group DI, and larger gaps were observed on the pulp wall ($p < 0.05$). This result was similar to that of Rippe et al. [51], who demonstrated that the maximum values of the internal gap were obtained on the pulp wall of the inlay produced by direct digitisation. The uneven internal gaps may be related to the quality of image capture in direct digitisation. The increase in the depth of the pulpal floor made optical capture more difficult [52]. Therefore, cavity design optimisation is very important for the clinical protocols of onlays.

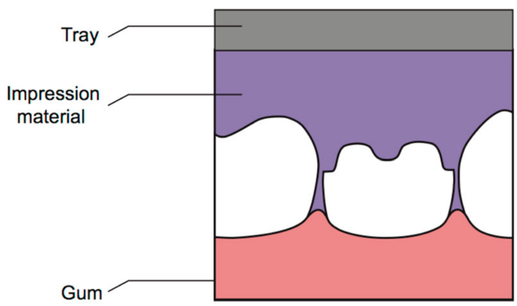

Figure 7. Schematic of impression taking.

In this study, no difference was found between 3D and 2D techniques (Group DI: $t = 0.68$, $p = 0.512$; Group CI: $t = 1.358$, $p = 0.204$) in the fitness evaluation of onlays (Table 1). Because the 3D technique provided multiple point measurements and internal adaptation analysis, which cannot be achieved with the 2D technique, we recommend using 3D techniques to evaluate the fitness of onlays with complex shapes and internal angles (Figure 5). Additionally, the preparation of finishing lines can be evaluated continuously using this method; the marginal and internal gaps can be observed from multiple directions using the 3D technique.

Table 2. Internal gaps (μm) of self-glazed zirconia onlays.

Group (*n* = 11)	Region	Min	Mean	Max	Median	SD	SE	CI-95%
DI	Axial wall	63.6	71.40	80.8	69.6	5.51	1.66	67.70–75.10
DI	Pulp wall	65.1	82.73	100.4	83.0	11.39	3.43	75.07–90.38
DI	Overall	64.0	72.05	85.0	67.7	8.16	2.46	66.57–77.54
CI	Axial wall	67.7	102.63	151.4	93.8	22.48	6.77	87.52–117.73
CI	Pulp wall	49.1	100.81	233.4	85.2	55.20	16.64	63.72–137.90
CI	Overall	67.8	100.96	141.4	102.4	22.53	6.79	85.83–116.10

Conclusion

Within the limitations of this in vitro study, the following conclusions were drawn.

(1) SGZ onlays exhibited clinically acceptable marginal and internal fitness.
(2) The marginal adaptation of DI-fabricated onlays was better than that of CI-fabricated onlays. A trend of decreasing marginal accuracy after thermal cycling was demonstrated in both groups.
(3) The distal gingival margin of the onlays presented larger MGs than those in other regions, in both CI and DI groups.
(4) The 3D technique was consistent with the 2D technique in the fitness evaluation of onlays. Furthermore, the 3D technique provides multiple point measurements and internal adaptation analysis, which cannot be achieved with the 2D technique.

Acknowledgements

The authors thank Erran Tech Ltd. for manufacturing the onlays via wet deposition.

Disclosure statement

No potential conflict of interest was reported by the author (s).

Funding

This study was supported by the National Natural Science Foundation of China [grant numbers 52111530189 and 51772007].

References

[1] Liu Y, Wang Y, Wang D, et al. Self-glazed zirconia reducing the wear to tooth enamel. J Eur Ceram Soc. 2016;36(12):2889–2894.
[2] Shen Z, Liu L, Xu X, et al. Fractography of self-glazed zirconia with improved reliability. J Eur Ceram Soc. 2017;37(14):4339–4345.
[3] Tao Y, Cui X, Zhang D, et al. The application potential of self-glazed zirconia crowns confirmed by easy grinding and polishing of the enamel-like surface. Adv Appl Ceram. 2020;119(5–6):1–8.
[4] [4] Ferro KJ, Morgano SM, Driscoll CF, et al. The glossary of prosthodontic terms: ninth edition. J Prosthet Dent. 2017;117(5): C1, e1–e105.
[5] Merrill TC, Mackey T, Luc R, et al. Effect of chairside CAD/CAM restoration type on marginal fit accuracy: a comparison of crown, inlay and onlay restorations. Eur J Prosthodont Restor Dent. 2021;29(2):119–127.
[6] Alexis G, Hazem A, Pierre C, et al. Marginal and internal fit of CAD-CAM inlay/onlay restorations: a systematic review of in vitro studies. J Prosthet Dent. 2019;121(4):590–597.e3.
[7] Larson TD. The clinical significance of marginal fit. Northwest Dent. 2012;91(1):22.
[8] Vagropoulou GI, Klifopoulou GL, Vlahou SG, et al. Complications and survival rates of inlays and onlays vs complete coverage restorations: a systematic review and analysis of studies. J Oral Rehabil. 2018;45 (11):903–920.
[9] Schaefer O, Watts DC, Sigusch BW, et al. Marginal and internal fit of pressed lithium disilicate partial crowns in vitro: a three-dimensional analysis of accuracy and reproducibility. Dent Mater. 2012;28(3):320–326.
[10] Kim DY, Kim JH, Kim HY, et al. Comparison and evaluation of marginal and internal gaps in cobalt-chromium alloy copings fabricated using subtractive and additive manufacturing. J Prosthodont Res. 2018;62(1):56–64.
[11] Uzgur R, Ercan E, Uzgur Z, et al. Cement thickness of inlay restorations made of lithium disilicate, polymer-infiltrated ceramic and nano-ceramic CAD/CAM materials evaluated using 3D X-ray microcomputed tomography. J Prosthodont. 2018;27(5):456–460.
[12] Tuntiprawon M, Wilson PR. The effect of cement thickness on the fracture strength of all-ceramic crowns. Aust Dent J. 1995;40(1):17–21.
[13] Güth JF, Edelhoff D, Schweiger J, et al. A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. Clin Oral Investig. 2016;20 (7):1487–1494.
[14] Kim KB, Kim JH, Kim WC, et al. Three-dimensional evaluation of gaps associated with fixed dental prostheses fabricated with new technologies. J Prosthet Dent. 2014;112(6):1432–1436.
[15] Yang X, Lv P, Liu Y, et al. Accuracy of digital impressions and fitness of single crowns based on digital impressions. Materials. 2015;8(7):3945–3957.
[16] Abdel-Azim T, Rogers K, Elathamna E, et al. Comparison of the marginal fit of lithium disilicate crowns fabricated with CAD/CAM technology by using conventional impressions and two intraoral digital scanners. J Prosthet Dent. 2015;114(4):554–559.
[17] Flügge TV, Schlager S, Nelson K, et al. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model

scanner. Am J Orthod Dentofac Orthop. 2013;144 (3):471–478.
[18] Giménez B, Özcan M, Martínez-Rus F, et al. Accuracy of a digital impression system based on active wavefront sampling technology for implants considering operator experience, implant angulation, and depth. Clin Implant Dent Relat Res. 2015;17(1):e54–e64.
[19] Seelbach P, Brueckel C, Wöstmann B. Accuracy of digital and conventional impression techniques and workflow. Clin Oral Investig. 2013;17(7):1759–1764.
[20] Syrek A, Reich G, Ranftl D. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent. 2010;38(7):553–559.
[21] Pradíes G, Zarauz C, Valverde A. Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions based on wavefront sampling technology. J Dent. 2015;43 (2):201–208.
[22] Rudolph H, Luthardt RG, Walter MH. Computer-aided analysis of the influence of digitizing and surfacing on the accuracy in dental CAD/CAM technology. Comput Biol Med. 2007;37(5):579–587.
[23] Jemt T, Hjalmarsson L. In vitro measurements of precision of fit of implant-supported frameworks. A comparison between "virtual" and "physical" assessments of fit using two different techniques of measurements. Clin Implant Dent Relat Res. 2012;14(1):e175–e182.
[24] Qian K, Yang X, Feng H, et al. Marginal adaptation of different hybrid ceramic inlays after thermal cycling. Adv Appl Ceram. 2020;119(5–6):284–290.
[25] Weaver JD, Johnson GH, Bales DJ. Marginal adaptation of castable ceramic crowns. J Prosthet Dent. 1991;66(6):747–753.
[26] Keshvad A, Hooshmand T, Asefzadeh F, et al. Marginal gap: internal fit, and fracture load of leucite-reinforced ceramic inlays fabricated by CEREC in lab and hot-pressed techniques. J Prosthodont. 2011;20(7):535–540.
[27] Oz FD, Bolay S. Comparative evaluation of marginal adaptation and fracture strength of different ceramic inlays produced by CEREC omnicam and heat-pressed technique. Int J Dent. 2018;2018:1–10.
[28] Liu Y, Ye H, Yong W, et al. Three-dimensional analysis of internal adaptations of crowns cast from resin patterns fabricated using computer-aided design/computer-assisted manufacturing technologies. Int J Prosthodont. 2018;31(4):386–393.
[29] Kale E, Seker E, Yilmaz B, et al. Effect of cement space on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns. J Prosthet Dent. 2016;116(6):890–895.
[30] Sailer I, Feher A, Filser F, et al. Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont. 2007;20(4):383–388.
[31] Guess PC, Vagkopoulou T, Zhang Y, et al. Marginal and internal fit of heat pressed versus CAD/CAM fabricated all-ceramic onlays after exposure to thermo-mechanical fatigue. J Dent. 2014;42(2):199–209.
[32] De Nissen H, Dozi A, Zel J, et al. Marginal fit and short-term clinical performance of porcelain-veneered CICERO, CEREC, and Procera onlays. J Prosthet Dent. 2000;84(5):506–513.
[33] Revilla-León M, Olea-Vielba M, Esteso-Saiz A, et al. Marginal and internal gap of handmade, milled and 3d printed additive manufactured patterns for pressed lithium disilicate onlay restorations. Eur J Prosthodont Restor Dent. 2018;26(1):31–38.
[34] Duke P, Moore BK, Haug SP, et al. Study of the physical properties of type IV gypsum, resin-containing, and epoxy die materials. J Prosthet Dent. 2000;83 (4):466–473.
[35] Silva M, Vitti RP, Consani S, et al. Linear dimensional change: compressive strength and detail reproduction in type IV dental stone dried at room temperature and in a microwave oven. J Appl Oral Sci. 2012;20 (5):588–593.
[36] Ahrberg D, Lauer HC, Ahrberg M, et al. Evaluation of fit and efficiency of CAD/CAM fabricated all-ceramic restorations based on direct and indirect digitalization: a double-blinded: randomized clinical trial. Clin Oral Investig. 2016;20(2):291–300.
[37] Güth JH, Keul C, Stimmelmayr M, et al. Accuracy of digital models obtained by direct and indirect data capturing. Clin Oral Investig. 2013;17(4):1201–1208.
[38] Rudolph H, Salmen H, Moldan M, et al. Accuracy of intraoral and extraoral digital data acquisition for dental restorations. J Appl Oral Sci. 2016;24(1):85–94.
[39] DeLong R, Pintado MR, Ko CC, et al. Factors influencing optical 3D scanning of vinyl polysiloxane impression materials. J Prosthodont. 2001;10(2):78–85.
[40] Martins F, Patrícia B, José R, et al. Dimensional stability of two impression materials after a 6-month storage period. Acta Biomater Odontol Scand. 2017;3(1):84–91.
[41] Akalin ZF, Ozkan YK, Ekerim A. Effects of implant angulation, impression material, and variation in arch curvature width on implant transfer model accuracy. Int J Oral Maxillofac Implants. 2013;28(1):149–157.
[42] Persson A, Odén A, Andersson M, et al. Digitization of simulated clinical dental impressions: virtual three-dimensional analysis of exactness. Dent Mater. 2009;25(7):929–936.
[43] Nalcai A, Ulusoy N. Effect of thermocycling on microleakage of resin composites polymerized with LED curing techniques. Quintessence Int. 2007;38:433–439.
[44] Wendt SL, McInnes PM, Dickinson GL. The effect of thermocycling in microleakage analysis. Dent Mater. 1992;8:181–184.
[45] Raskin A, D'Hoore W, Gonthier S, et al. Reliability of in vitro microleakage tests: a literature review. J Adhes Dent. 2001;3:295–308.
[46] Stappert CF, Denner N, Gerds T, et al. Marginal adaptation of different types of all-ceramic partial coverage restorations after exposure to an artificial mouth. Br Dent J. 2005;199:779–783.
[47] Schmalz G, Federlin M, Reich E. Effect of dimension of luting space and luting composite on marginal adaptation of a class II ceramic inlay. J Prosthet Dent. 1995;73:392–399.
[48] Felden A, Schmalz G, Federlin M, et al. Retrospective clinical investigation and survival analysis on ceramic inlays and partial ceramic crowns: results up to 7 years. Clin Oral Investig. 1998;2:161–167.
[49] Krämer N, Frankenberger R, Pelka M, et al. IPS empress inlays and onlays after four years – a clinical study. J Dent. 1999;27:325–331.
[50] Krejci I, Lutz F, Reimer M. Marginal adaptation and fit of adhesive ceramic inlays. J Dent. 1993;21(1):39–46.
[51] Rippe MP, Monaco C, Volpe L, et al. Different methods for inlay production: effect on internal and marginal adaptation, adjustment time, and contact point. Oper Dent. 2017;42(4):436–444.
[52] Hopp CD, Land MF. Considerations for ceramic inlays in posterior teeth: a review. Clin Cosmet Investig Dent. 2013;5:21–32.