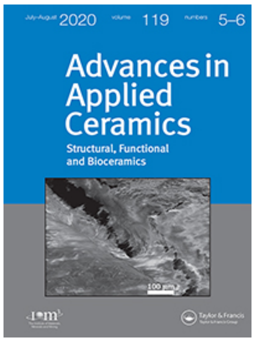

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RESEARCH ARTICLE

The application potential of self-glazed zirconia crowns confirmed by easy grinding and polishing of the enamel-like surface

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ABSTRACT
The surface profile roughness (Ra), surface area roughness (Sa), and surface topography of newly developed as-prepared, ground, and polished self-glazed zirconia (SGZ) were evaluated using a profilometer, 3D optical surface profiler, and SEM, with conventional dry-milled zirconia (CZ) as a reference. A statistical analysis was conducted using repeated measures analysis of variance (ANOVA) and the Bonferroni test ($\alpha = .05$). Results revealed that the material ($p = .005$), clinical adjustment procedure ($p < .001$), and interaction between factors ($p < .001$) had statistically significant effects on the Ra values. SGZ showed lower Sa values than CZ during the same period. Ten patient cases involving the restoration of the monolithic anatomic contour SGZ crowns were investigated. All crowns remained functional until the latest clinical follow-up and no further antagonist wear was observed. Thus, SGZ had relatively lower surface roughness, which was also more easily altered than that of CZ.

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Self-glazed zirconia; grinding; polishing; enamel wear; dental restorations

Introduction

High-strength zirconia ceramic prostheses often need to be veneered for anterior teeth to obtain symmetric aesthetic results. However, chipping of the veneer layer has become increasingly problematic while fabricating crowns and partial fixed dental prostheses [1]. To solve this problem, veneer-free monolithic zirconia crowns with a full anatomic contour have been widely used in dentistry. Their use was further motivated by their capacity for potential improvement to their aesthetic property as well as mechanical strength [2].

Conventionally, zirconia crowns have been fabricated from dry-milled blanks, which are prepared by the dry pressing of agglomerated nanoparticles sized 100–200 nm followed by cold isostatic pressing and partial pre-sintering [2,3]. This process caused numerous inherent microscopic defects and voids, and many scratches and ditches on the surface of zirconia crowns [3]. Because zirconia is harder than natural teeth, the wear of the monolithic anatomic contour zirconia crown against the enamel of antagonists has been a significant concern. However, the surface roughness of zirconia restorations has clearly been found to determine the extent of abrasion on the opposite teeth. Hardness is not the dominating factor affecting the extent of abrasion [4,5]. Polishing has thus been applied as a necessary processing step in the production of monolithic zirconia restorations with a smooth surface. Fine-polished monolithic zirconia showed significantly lower antagonistic teeth wear compared with glazed zirconia and veneered porcelain [6–8]. However, a persistent challenge is the difficulty in polishing monolithic zirconia, which is because of its high hardness and inhomogeneous fine-grained structure. When inappropriate polishing techniques and/or procedures are applied, particularly during clinical adjustment, the surface of the zirconia remains rough, inevitably resulting in excessive wear of the opposite teeth [9,10].

Recently, a new grade of monolithic zirconia restorations, self-glazed zirconia (SGZ), was successfully developed using a three-dimensional (3D) gel deposition approach [3,5]. Unlike conventionally blank-milled zirconia, this category of monolithic anatomic contour zirconia prostheses is modelled to achieve a gradient bulk structure consisting of fine grains and a characteristic surface structure with nanoscale roughness but micronscale smoothness that mimics the enamel structure [3,10,11]. The enamel-like smooth surface improves aesthetics and reduces the excessive wear on the opposite teeth. Owing to the homogeneous fine-grained structure, the grinding and polishing efficiencies of SGZ restorations were also observed to be significantly higher than those of the conventional blank-milled zirconia restorations [12]. A previous study conducted by Liu et al.

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revealed that SGZ zirconia provided improved aesthetic appearance while maintaining a similar wear performance to that of the well-polished zirconia crowns [3].

The aim of this study is to determine the clinical application potential of monolithic anatomic contour ceramic crowns made from the newly developed SGZ material using CZ as reference. Focus is placed on evaluating the surface roughness of the as-prepared, grinded, and polished surface; observing the surface characteristics, and evaluating the clinical outcomes. The null hypothesis is that no difference will be observed between the surface roughness of these two categories of zirconia ceramics.

Material and methods

In vitro evaluation of surface roughness and morphology

Sample preparation

Two types of bar-shaped dental zirconia specimens with a size of $22 \times 6 \times 7$ mm were prepared in this study (Figure 1). One type of specimen (Self-Glazed Zirconia, Lot 2016030101A, Erran Tech Ltd, Hangzhou, China) was fabricated using additive 3D gel deposition followed by green milling of an internal surface (Group SGZ, $n = 8$). The second type of specimen (Group CZ, $n = 8$) was produced using the conventional dry milling of partially sintered zirconia blanks (Zenostar, Lot T33162, Wieland Dental, Pforzheim, Germany). All specimens were sintered at 1450°C to attain sufficient density above 99.9% without further surface treatment.

As-prepared sample

Before grinding or polishing, the Ra of all specimens was measured using a profilometer (Surftest SJ 400, Mitutoyo Corp, Tokyo, Japan). For each specimen, three measurements were acquired, and the mean value of Ra was calculated.

One specimen in each group was randomly selected for the measurement of Sa using a 3D Optical surface profiler (ZYGO NexView^{TM}, Zygo Corp, Middlefield, U.S.A.). Scanning was conducted at one randomly selected location under a magnification of 10× and an image size of 834.37 × 834.37 µm. The Sa of each specimen was calculated using ZYGO"s Mx^{TM} software (Zygo Corp, Middlefield, U.S.A.).

Two randomly selected specimens from each group were processed for imaging the surface characteristics using a field-emission scanning electron microscope (TESCAN MIRA 3LMH, Czech Republic).

Grinding procedure

All specimens were ground for 60 s at 30,000 rev min^{-1} using a dental hand piece (PM 1:1, Bienair, Bienne, Swiss) and ceramic diamond grinders (Toboom, CD 2123, Shanghai, China, Figure 2) with an average grit size of 107 µm to simulate a clinical chairside occlusal adjustment. Thereafter, the Ra, Sa, and surface characteristics were observed via the same method.

Polishing procedure

After grinding, the specimens were polished using the rubber diamond polishing kit (Toboom, Shanghai, China, Figure 3) in three steps (60 s each) to simulate a clinical chairside polishing procedure. First, the specimens were polished using a grey coarse rubber diamond polisher (Toboom, RD 2164, 46 µm average grit size) at 25,000 rev min^{-1}. Second, the specimens were polished using a handpiece with 20,000 rev min^{-1} and a yellow medium rubber instrument (Toboom, RD 2165, average grit size was 25 µm). Finally, the white fine polishing procedure was carried out using a polisher (Toboom, RD 2166, 8 µm average grit size) at 20,000 rev min^{-1}. After polishing the specimens using each instrument, the surface roughness and morphology were determined.

In vivo evaluation of self-glazed zirconia crowns

Participants

Between September 2017 and March 2019, 10 patients who required a single crown or implant-supported crown restoration were recruited, which was

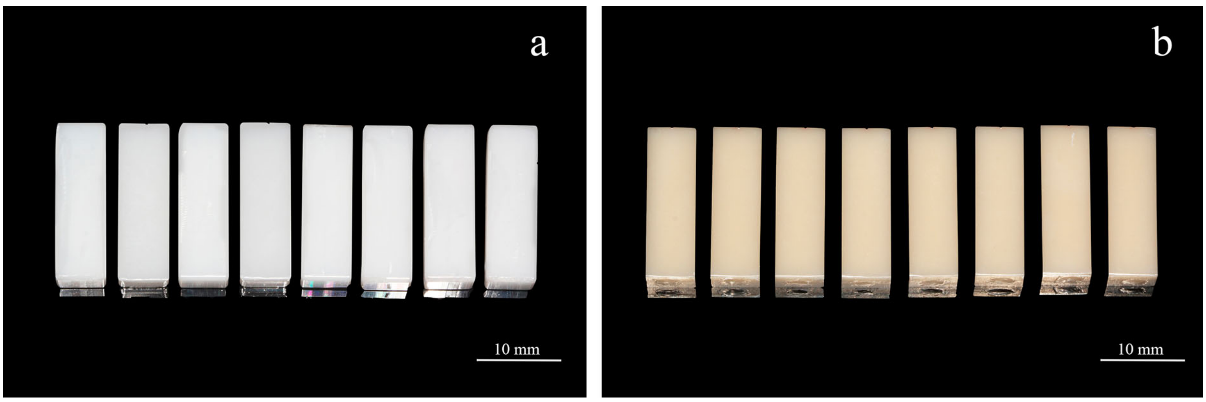

Figure 1. Two types of bar-shaped dental zirconia specimens. (a) SGZ specimens; (b) CZ specimens.

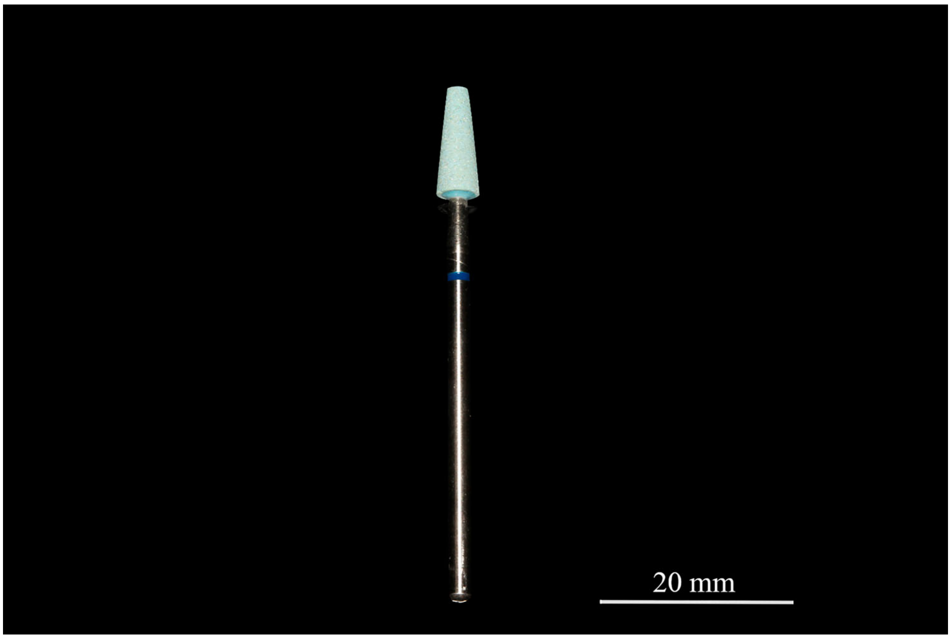

Figure 2. Ceramic diamond grinders used in this study.

performed at the Department of Prosthodontics of Peking University School and Hospital of Stomatology. Before the clinical evaluation was performed, the patients were informed of the investigation protocol, and they provided written informed consent. This clinical study was approved by the Peking University Hospital of Stomatology Biomedical Institutional Review Board (PKUSSIRB-201736077).

Fabrication of self-glazed zirconia crowns

All the prostheses were produced using a traditional partial digital workflow which involved some manual manipulations. After the preparation for full anatomic-contour crown or insertion of intraoral impression coping for dental implant, a full-arch impression was made using a silicone impression material (Variotime, Heraeus Kulzer GmbH, Hanau, Germany), which was then filled with type IV high-strength die stone (GC Fujirock EP, GC Europe, Leuven, Belgium). Working casts were scanned (3Shape D2000, 3Shape A/S, Copenhagen, Denmark) and the single crown was designed using the corresponding software (3Shape Dental System, 3Shape A/S, Copenhagen, Denmark). The anatomic contour SGZ single crowns were fabricated using the additive 3D gel deposition method.

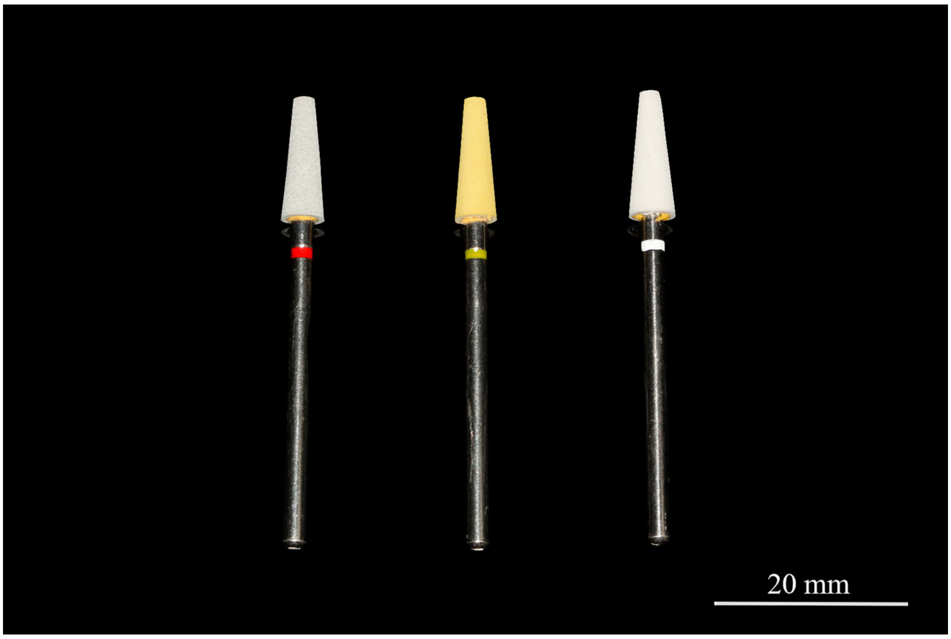

Figure 3. Rubber diamond polishers used in this study. Coarse grit (grey; left), medium grit (yellow; middle), and fine grit (white; right) polishers.

Table 1. Surface profile roughness (Ra value) of CZ and SGZ specimens after different surface adjustments.

	Surface adjustment		
Group	As prepared	After grinding	After polishing
CZ group (μm)	0.69 ± 0.20[a]	1.28 ± 0.05[b]	0.84 ± 0.06[c]
SGZ group (μm)	0.46 ± 0.03[A]	1.38 ± 0.04[B]	0.68 ± 0.03[C]

Note: Means with different superscript letters indicate significant differences using Bonferroni posthoc comparisons ($p < .05$).

Clinical evaluation

All the SGZ single crowns underwent minor occlusal adjustment during the clinical intraoral try-in period. Before cementing, the grinded occlusal surfaces were fine-polished via the aforementioned method. Patient follow-ups for clinical and radiographic examinations were performed after 3 months and then at 12-month intervals. Evaluation parameters were set according to the modified U.S. Public Health Service guidelines [13]. The focus of the evaluation included survival rate, opposing teeth wear and aesthetics.

Statistical analysis

The effects of grinding and polishing on Ra were analysed using repeated measures analysis of variance (ANOVA) and *post hoc* pairwise comparisons with the Bonferroni correction ($\alpha = .05$ for all tests). Continuous variables were reported as means and standard deviations. SPSS 20.0 was used for statistical analysis. (SPSS Inc., Chicago, IL, U.S.A.).

Results

The results of this study supported the rejection of the null hypothesis, which stated that there was no difference between the surface roughness of the two dental zirconia ceramics. Significant differences in surface roughness ($p < .05$) are shown in Table 1. The repeated measures ANOVA revealed that the material ($p = .005$), clinical adjustment procedure ($p < .001$), and interaction between factors ($p < .001$) had statistically significant effects on the Ra.

Under low magnification, characterisation by the white light interferometer revealed many disordered peaks (~2.5 μm) and valleys (~4 μm) on the blank-milled surface of a CZ sample (Figure 4(a); Sa = 0.488 μm), whereas such peaks and valleys were arranged in an orderly fashion on the green-milled internal surface of an SGZ sample (Figure 4(c); Sa = 0.437 μm). Compared with the few valleys found on the surface of the as-prepared SGZ sample (Figure 4 (b); Sa = 0.352 μm), more valleys (~3 μm) and lower ridges (~1.5 μm) were observed after the grinding (Figure 5(b); Sa = 0.905 μm) and polishing procedure (Figure 6(b); Sa = 0.687 μm). Compared with the Sa of the as-prepared SGZ sample, higher Sa values were observed on the surface of the CZ sample after grinding (Figure 5(a); Sa = 1.378 μm) and polishing treatments (Figure 6(a); Sa = 0.906 μm).

The morphologies of the as-prepared surfaces of the two zirconia samples observed by SEM are shown in Figure 7. Some voids and wide shallow ditches appeared on the surface of the CZ sample, but the surface of the SGZ sample was void-free, very smooth, and flat on microscale. The SEM images presented in Figure 8 reveal the ground and polished surfaces of both zirconia specimens. Compared with the intensive cracking and chipping observed on the ground surface of the CZ sample, the SGZ sample presented only fewer shallower scratches. After polishing, some wide and deep scratches remained on the surface of the CZ sample, but the SGZ sample was significantly smoother and flatter. Compared with the as-prepared surfaces (Figure 7), clinical chairside fine polishing for 3 min was evidently not sufficient to remove the cracks introduced during grinding.

During the clinical evaluation, 10 patients (two men and eight women), who were 27–65 years of age, were recruited. Eight participants received tooth-borne monolithic crowns and two participants received implant-borne monolithic crowns. All teeth remained

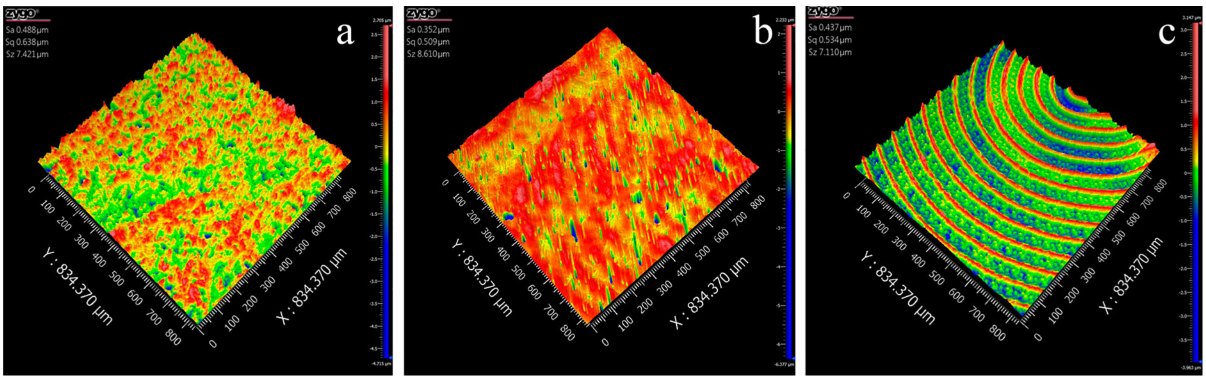

Figure 4. Surface area roughness (Sa) of CZ and SGZ specimens characterized by the white light interferometer. (a) Blank-machined surface of CZ before grinding procedure; (b) Surface of SGZ performed by 3D gel deposition process before grinding; (c) Green-machined internal surface of SGZ before grinding.

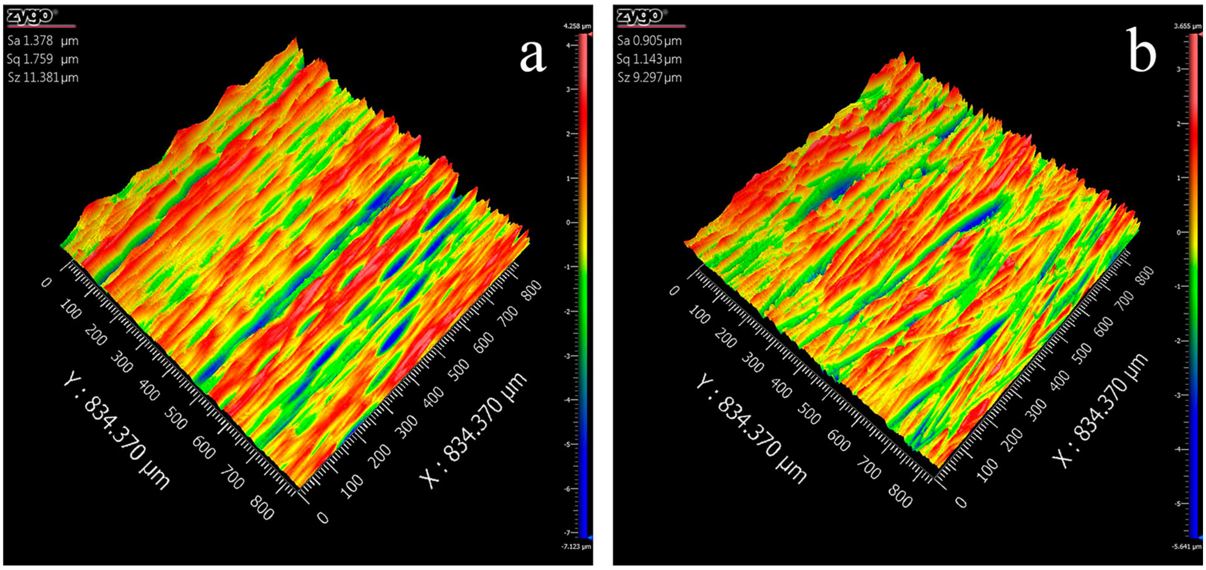

Figure 5. Surface area roughness (Sa) of CZ and SGZ specimens characterized by the white light interferometer. (a) Surface of CZ after grinding; (b) Surface of SGZ after grinding.

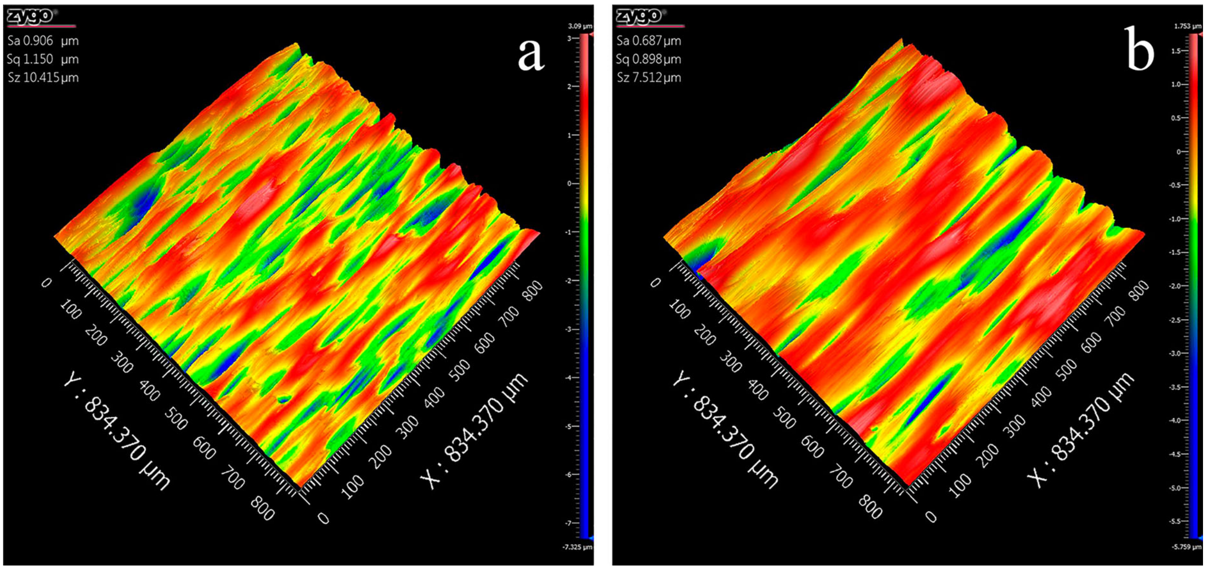

Figure 6. Surface area roughness (Sa) of CZ and SGZ specimens characterized by the white light interferometer. (a) Surface of CZ after polishing; (b) Surface of SGZ after polishing.

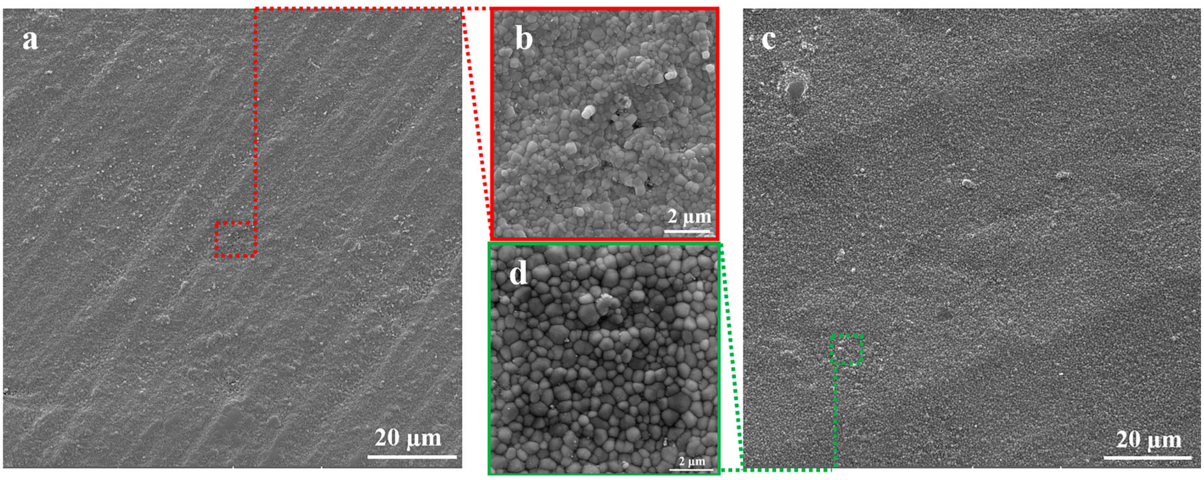

Figure 7. SEM images taken on the surface of the as prepared specimens. (a-b) Blank-machined surface of CZ; (c-d) Surface of SGZ prepared by 3D gel deposition.

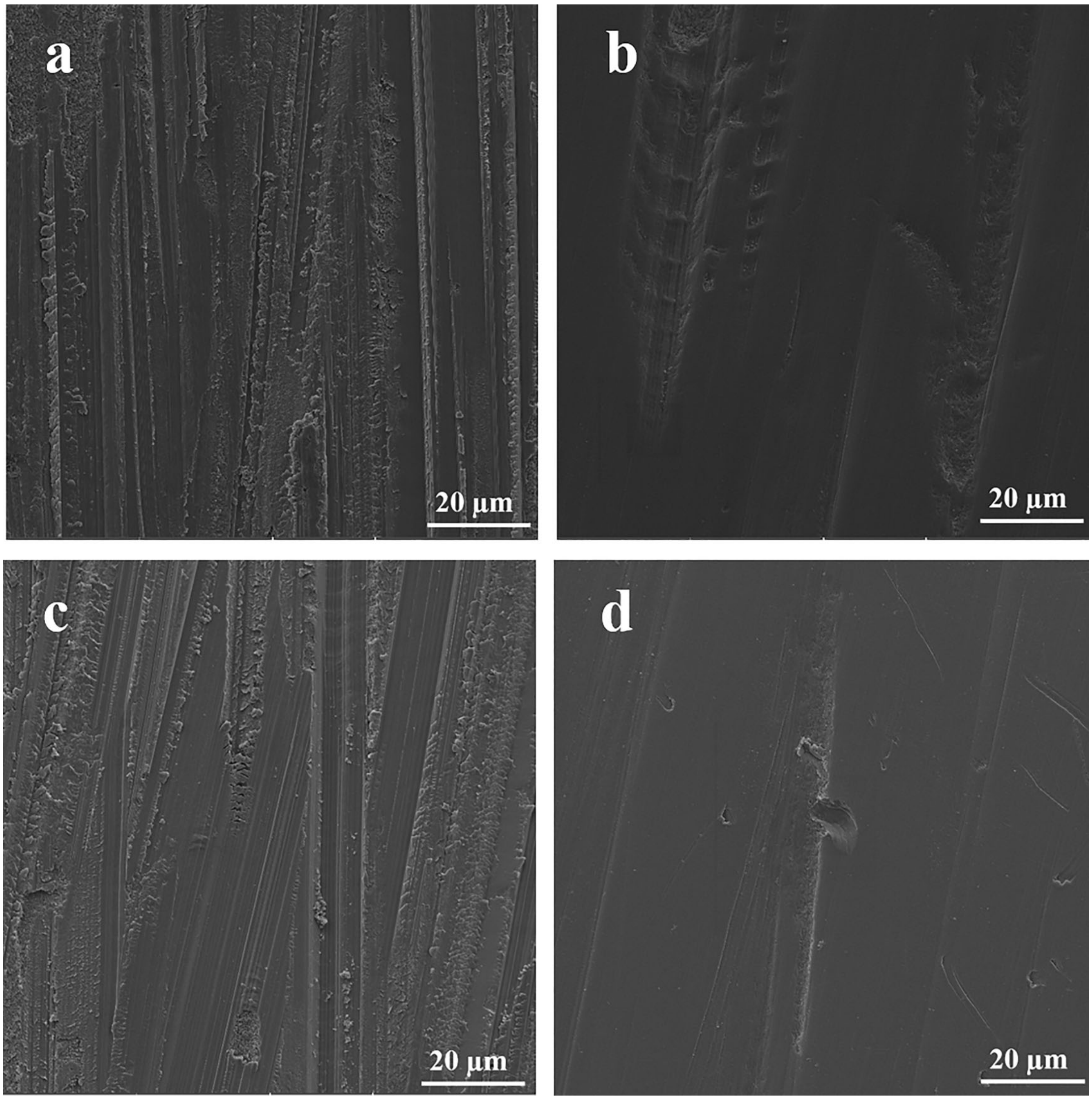

Figure 8. SEM images taken on the surface of the two different zirconia ceramics after surface treatment. (a) CZ specimen after grinding; (b) CZ specimen after polishing; (c) SGZ specimen after grinding; (d)SGZ specimen after polishing.

functional until the latest clinical examination (a mean follow-up period of 8.40 ± 3.50 months); the failure rate was 0%. No additional complications (including excessive wear of opposite teeth, gingivitis, gingival recession, marginal discolouration, and porcelain fracture) were detected within the short observation period. The examiner and participants were satisfied with the aesthetic effect of the crowns (Figure 9).

Discussion

In this study, the SGZ specimens yielded lower Sa than the CZ specimens at the same treatment stage (Figure 4–6). The ease in grinding and polishing of the SGZ specimens could be attributed to its denser and finer-grained structure with significantly higher structural homogeneity compared to the CZ specimens. The CZ crowns were fabricated by dry milling of the partially sintered zirconia ceramic blanks that evidently contained significantly more packing defects, which could not be sealed by sintering even up to 1550°C [14]. Because of the use of 3D gel deposition procedure that allowed dense stepwise packing of highly dispersed nanoparticles and green milling of the internal surface, the novel SGZ samples have sufficiently improved particle packing density and homogeneity compared to CZ samples, despite the introduction of a gradient structure. SGZ specimens exhibit a relatively smaller grain size and smoother as-prepared surface than the blank-milled zirconia [15]. Liu et al. reported the grain size of SGZ zirconia specimens to be 100–250 nm compared to the 200–600 nm grain size in CZ specimens [3]. Bin et al. illustrated that the grain size and surface roughness of zirconia influence the contact area of polyhedronal abrasive particles embedded in a rigid matrix and demonstrated that the grinding efficiency of SGZ specimens was enhanced by its small grain size and relatively higher density and homogeneity [12].

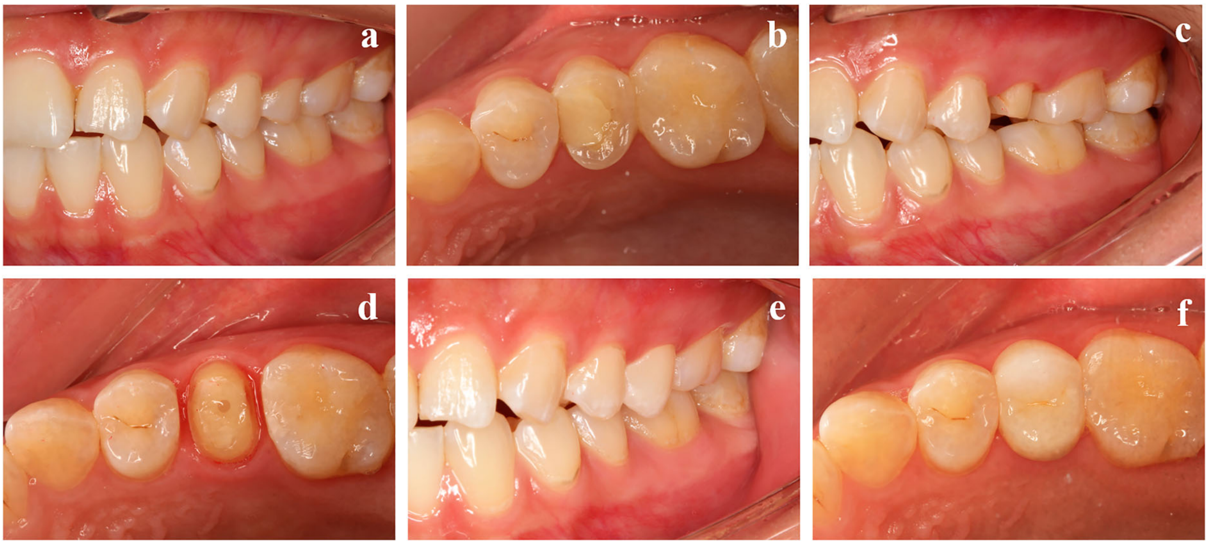

Figure 9. Restoration of normally coloured maxillary second premolar with SGZ monolithic zirconia crown. (a) Buccal view before restoration; (b) Occlusal view before preparation; (c) Buccal view after preparation; (d) Occlusal view after preparation; (e) Buccal view of evaluation of SGZ crown; (f) Occlusal view of evaluation of SGZ crown.

As for the ground samples, the SGZ sample showed a lower Sa (Figure 5(b); Sa=0.905 μm) than the CZ specimen (Figure 5(a); Sa = 1.378 μm), but a higher Ra value was yielded in the SGZ sample (Table 1, Ra = 1.38 ± 0.04 μm) than in the CZ specimen (Table 1, Ra = 1.28 ± 0.05 μm). Recalling the definitions of Sa and Ra are required to understand this observed difference. Ra is a quantitative calculation of the relative roughness of a linear profile, while Sa is calculated by averaging the Ra across several surface profiles. In addition, peaks and valleys on the surface can be observed using a 3D white light interferometer. After grinding, more and deeper valleys were observed on the CZ than on the SGZ surface (Figure 5), which was consistent with the SEM morphology (Figure 8). This could be attributed to the increased homogeneity and reduced packing defects in SGZ zirconia, which helps prevent deep cracks and chipping.

In Table 1, compared with the Ra value of CZ samples, SGZ specimens yielded a higher Ra value after grinding but a lower Ra value after polishing. The reason the SGZ sample yielded opposite results might be related to its inhomogeneous surface. The SEM images presented in Figure 8 reveal that the ground and polished surfaces of both zirconia specimens were uneven. The Ra value was affected by the selected linear profile; if the region had scratches, the Ra value would evidently be high. Although the SGZ specimens showed a higher Ra value than the CZ samples after the grinding procedure, both the Sa values (Figure 5) and the SEM images (Figure 8) illustrated that the surface roughness of SGZ specimens was lower.

After appropriate polishing, both the SGZ and CZ specimens showed significantly lower Ra (Table 1, after polishing, the Ra of CZ specimens = 0.84 ± 0.06 μm, the Ra of SGZ specimens = 0.68 ± 0.03 μm) and Sa values (Figure 6 (a), the Sa of CZ specimens = 0.906 μm; Figure 6(b), the Sa of SGZ specimens = 0.687 μm), but these values were still higher than their initial state (Table 1, the Ra of as-prepared CZ specimens = 0.69 ± 0.20 μm, the Ra of as-prepared SGZ specimens = 0.46±0.03 μm; Figure 4(a), the Sa of CZ specimens = 0.488 μm, Figure 4(b), the Sa of SGZ specimens = 0.352 μm). This demonstrates the necessity of implementing a full digital workflow to avoid clinic adjustment [16,17]. Upon clinical observation, all monolithic SGZ crowns achieved an acceptable clinical effect, but they all underwent some amount of occlusal adjustment. Any scratches left on the occlusal surfaces of SGZ crowns may affect the enamel wear of antagonists. Huh et al. demonstrated that a well-polished zirconia surface could significantly decrease the antagonist abrasion, and all examined zirconia polishing systems (including six systems) achieved clinically acceptable polishing performance [18]. Bai et al. demonstrated that glazed zirconia showed greater abrasive wear than polished zirconia. When the glaze layer was cracked and removed, the rough surface of the underlying zirconia could cause aggressive damage [19]. Therefore, when clinical treatment becomes necessary, a rigorous and standard polishing treatment is required to avoid excessive abrasive wear.

In summary, this study revealed that the SGZ specimens yield relatively lower surface roughness after clinical grinding and polishing. Monolithic self-glazed zirconia crowns fabricated by novel 3D gel deposition are recommended for clinical practice because of their desirable aesthetic appearance and enamel-like surface, which should reduce the enamel wear of antagonists. Further randomized controlled clinical trials are required to confirm the reduction in antagonist enamel wear when SGZ instead of CZ crowns are used.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

(1) Compared with the conventional dry-milled zirconia specimens, the specimens fabricated using the novel 3D gel deposition procedure yielded lower surface roughness and were easier to grind and polish.
(2) The novel anatomic contour SGZ crowns were found to be both practical and reliable for restoring posterior teeth.

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Disclosure statement

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

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References

[1] Rueda AO, Anglada M, Jimenez-Pique E. Contact fatigue of veneer feldspathic porcelain on dental zirconia. Dent Mater. 2015;31:217–224.
[2] Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008;24:299–307.
[3] Liu Y, Wang Y, Wang D, et al. Self-glazed zirconia reducing the wear to tooth enamel. J Eur Ceram Soc. 2016;36:2889–2894.
[4] Passos SP, Torrealba Y, Major P, et al. In vitro wear behavior of zirconia opposing enamel: a systematic review. J Prosthodont. 2015;23:593–601.
[5] Zhang Y, Han JM, Zheng G, et al. Fatigue behaviours of the zirconia dental restorations prepared by two manufacturing methods. Adv Appl Ceram. 2017;116:368–375.
[6] Park JH, Park S, Lee K, et al. Antagonist wear of three CAD/CAM anatomic contour zirconia ceramics. J Prosthet Dent. 2014;111:20–29.
[7] Hmaidouch R, Müller W-D, Lauer HC, et al. Surface roughness of zirconia for full-contour crowns after clinically simulated grinding and polishing. Int J Oral Sci. 2014;6:241–246.
[8] Malkondu Ö, Tinastepe N, Akan E, et al. An overview of monolithic zirconia in dentistry. Biotechnol Biotechnol Equip. 2016;30:644–652.
[9] Oh W-S, DeLong R, Anusavice KJ. Factors affecting enamel and ceramic wear: A literature review. J Prosthet Dent. 2002;87:451–459.
[10] Shi A, Wu Z, Huang J, et al. Wear performance of self-glazed zirconia crowns with different amount of occlusal adjustment after 6 months of clinical use. Adv Appl Ceram. 2018;117:445–451.
[11] Shen Z, Liu L, Xu X, et al. Fractography of self-glazed zirconia with improved reliability. J Eur Ceram Soc. 2017;37:4339–4345.
[12] Bin J, Alganyi AA, Jing Z, et al. Grinding and polishing efficiency of a novel self-glazed zirconia versus the conventional dry-pressed and sintered zirconia ceramics. Adv Appl Ceram. 2018;118:46–55.
[13] Cvar JF, Ryge G. Reprint of criteria for the clinical evaluation of dental restorative materials. 1971. Clin Oral Investig. 2005;9:215–232.
[14] Denry I, Holloway JA. Ceramics for dental applications: a review. Materials (Basel). 2010;3:351–368.
[15] Zhang J, Hu W, Stijacic T, et al. Bonding of novel self-glazed zirconia dental ceramics. Adv Appl Ceram. 2019;118:37–45.
[16] Wen R, Faliang D, Zhijian S, et al. The workflows of a novel self-glazed zirconia for dental prostheses fabrication: case reports. Adv Appl Ceram. 2018;117:1–8.
[17] Wu J, Huang Z, Yang L, et al. The application of net-shape-formed self-glazed zirconia prostheses via a complete digital workflow in oral implant and restoration: a clinical case report. Adv Appl Ceram. 2019;118:309–312.
[18] Huh YH, Park CJ, Cho LR. Evaluation of various polishing systems and the phase transformation of monolithic zirconia. J Prosthet Dent. 2016;116:440–449.
[19] Bai Y, Zhao J, Si W, et al. Two-body wear performance of dental colored zirconia after different surface treatments. J Prosthet Dent. 2016;116:584–590.