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CLINICAL RESEARCH

Esthetic appearances of anatomic contour zirconia crowns made by additive wet deposition and subtractive dry milling: A self-controlled clinical trial

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ABSTRACT

Statement of problem. Anatomic contour zirconia crowns are widely used in clinical dental practice because of their mechanical reliability and improved appearance. However, few studies have performed clinical evaluations of the esthetics of these crowns in terms of color and translucency gradient.

Purpose. The purpose of this clinical trial was to compare the esthetic effect and color-matching behaviors of anatomic contour zirconia crowns manufactured with 3-dimensional (3D) gel deposition and dry milling methods.

Material and methods. Twenty-seven premolar teeth of 27 participants received 2 identical anatomic contour zirconia crowns fabricated by additive 3D gel deposition or dry milling. Color differences (ΔE) between the crown and natural control teeth were measured by a dental shade-matching device. Subjective color matching was rated by professionals using an extended visual rating scale for appearance match (EVRSAM) and by participants using a visual analog scale (VAS). Data were analyzed by using repeated measures ANOVA, the Bonferroni test, paired Student *t* test, Pearson chi-square test, and Wilcoxon test (α=.05).

Results. Significant differences were found in ΔE between zirconia crown and core types (P<.05); however, there was no significant interaction between these factors (P>.05). The average ΔE of crowns made by wet deposition and dry milling were 2.45 ±1.60 and 4.55 ±1.54 (P<.05). The mean crown ΔE was significantly higher if a gold cast post-and-core was placed rather than a prefabricated fiber post and composite core (P<.05). Consistent with these findings, subjective color matching was significantly higher in the wet deposition group than in the dry milling group as rated by EVRSAM and VAS (P<.05).

Conclusions. Anatomic contour zirconia crowns fabricated by additive wet deposition were better matched to adjacent teeth and had excellent esthetics in terms of color and translucency gradient. (J Prosthet Dent 2020;123:442-8)

Developments in computer-aided design and computer-aided manufacturing (CAD-CAM) technologies and materials science have popularized yttria partially stabilized zirconia polycrystal for the fabrication of crowns and partial fixed dental prostheses. This is because of its metal-free character and high flexural strength of 900 to 1200 MPa.[1,2] Typical zirconia is a white, low-translucency ceramic material. To achieve tooth-like color and enamel-like translucency, high strength zirconia structures are conventionally layered or pressed with esthetic silicate-based veneering porcelain.[3] However, clinical studies have shown that veneering porcelain is associated with high chipping and fracture rates ranging from 0% to 30% after 2 to 5 years of use.[4]

Recent trends in prosthetic dentistry have minimized or eliminated veneering porcelain coverage of molar restorations to overcome chipping or fracture-related issues.[5-7] With optical improvements in presintered zirconia blocks,[3] anatomic contour zirconia crowns without veneering porcelain have become an effective alternative in clinical practice.[8,9] Efforts are being made to increase overall cubic phase content while reducing grain

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Clinical Implications

Anatomic contour zirconia crowns fabricated by a novel additive 3D gel deposition approach are recommended for restoring endodontically treated premolar teeth based on their optimal esthetics. Additional follow-up is required to assess long-term outcomes.

size, distribution of defects, and porosity to improve the translucency of dental zirconia.[10,11]

Despite these efforts, zirconia restorations with monolithic structures fabricated by the dry milling method have been reported not to sufficiently mask a colored abutment or have acceptable esthetic properties.[6,12] A recent clinical report demonstrated that anatomic contour zirconia restorations achieve acceptable but suboptimal esthetics compared with those of veneered zirconia prostheses.[5] This has driven the more recent development of novel monolithic anatomic contour zirconia restorations with esthetic properties exceeding those of conventional dry-milled zirconia crowns.

Recently, an additive 3D gel deposition approach to fabricating a new grade of self-glazed zirconia (SGZ) ceramics has been described.[13] Applying a wet rather than dry process minimizes defect concentration and achieves gradient nanostructures by close, stepwise packing of well-dispersed nanoparticles. This yields smooth surfaces that imitate the optical appearances of natural enamel, hence the term "self-glazed."[14] The novel additive wet deposition process not only uses reduced raw zirconia material but also allows zirconia restorations to be directly generated with gradient nanostructures and enamel-like surfaces. Studies have hypothesized that anatomic contour SGZ restorations may offer improved esthetic appearances in terms of color and translucency gradient compared with those of conventional dry milling methods.[15]

The purpose of this clinical trial was to compare the esthetics of anatomic contour zirconia crowns manufactured using an additive wet deposition method and a conventional subtractive dry milling process. The null hypothesis was that no difference would be found in the color-matching and esthetics of crowns manufactured with these 2 methods.

MATERIAL AND METHODS

This clinical trial was registered with the Chinese Clinical Trial Registry and the World Health Organization (ChiCTR-IOR-17013958). The protocol was approved by the Peking University Hospital of Stomatology Biomedical Institutional Review Board (PKUSSIRB-201734031), and all participants provided written informed consent before treatment. After application of the inclusion and exclusion criteria (Table 1), 27 participants (22 women, 5 men, aged 33.5 ±9.8 years) were included, providing 27 teeth for evaluation. The sample size was calculated as at least 4 specimens per group based on a color difference ΔE of 3.7, a standard deviation of ±1.7, an alpha level of .05, and a power of 80% using a paired sample Student *t* test.[16] To improve the reliability and reduce the effect of random errors, the sample size was expanded and 27 participants of 27 paired specimens were included.

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
One premolar root canal treatment needing single crown or post-and-core crown.	Severe parafunctional activities such as bruxism or clenching.
Complete dentition in maxillary and mandibular arches.	Unacceptable oral hygiene and active carious lesions.
Natural adjacent and antagonistic teeth with no crown restorations.	Acute or chronic temporomandibular joint disorder.
Stable occlusion.	Visual or auditory impairment.
Healthy periodontal tissue with no signs of bone resorption.	Poor medical condition (ASA III or higher).

ASA, American Society of Anesthesiologists.

When teeth were endodontically treated with extensive coronal destruction, a prefabricated fiber post (RelyX Fiber Post; 3M ESPE) or gold cast post-and-core was selected a priori for the definitive crown restoration (Fig. 1). Because background color may cause a color mismatch of the restoration, the abutment teeth were classified into 3 groups based on the difference in the foundation material, PFP, prefabricated fiber post and composite core (n=7); GCP, gold cast post-and-core (n=10); and WP, without post-and-core (n=10). The abutment teeth were then prepared in accordance with treatment guidelines for anatomic contour crowns.[17-20] All abutment teeth were prepared for monolithic zirconia crowns using diamond rotary cutting instruments (DIA-BURS; MANI). The occlusal reduction was 1.0 to 1.5 mm along the anatomic contours of the cusps and fossae, the axial reduction was 1.0 mm, the occlusal convergence was 2 to 5 degrees, the finish line was located 0.5 mm subgingivally on the buccal surface (for esthetic reasons), the chamfer preparation was 0.6 to 0.8 mm,[19] and the internal line angles were rounded (Fig. 2).

After preparation, impressions for working casts were made by using silicone impression material (Variotime; Kulzer GmbH). For each participant, the adjacent or antagonist premolar was selected as the control tooth, and a dental shade-matching device (Vita Easyshade; Vita Zahnfabrik) was used for shade selection. Evaluation records were acquired by using silicone material (O-Bite; DMG). Interim restorations were fabricated with

Figure 1. Endodontically treated premolar restored with post-and-core. A, Before restoration. B, After gold cast post-and-core foundation. C, Before restoration. D, After prefabricated fiber post and resin core foundation.

chairside composite resin material (Protemp4; 3M ESPE) and cemented with a eugenol-free interim cement (RelyX Temp NE; 3M ESPE). The definitive casts were made by using Type IV gypsum (GC Fujirock EP; GC America) and scanned with a dental cast scanner (3Shape D2000; 3Shape A/S). The 3D data were used to design crown shapes by using the 3Shape Dental System software program (3Shape Dental System; 3Shape A/S). The design document was exported in standard tessellation language (STL) format and sent to 2 manufacturing centers simultaneously.

Two anatomic contour monolithic zirconia crowns of identical shape and shade were fabricated for each participant. One of the crowns was fabricated by additive wet deposition process (Self-Glazed Zirconia; Erran Tech, the additive wet deposition group). The other was produced by the conventional subtractive dry milling process (Zenostar; Wieland Dental, the subtractive dry milling group) using a 5-axis milling machine (Zenotec Select Hybrid, Wieland Dental). The occlusal fissures of the crowns in the additive wet deposition group and the overall external surface of the crowns in the subtractive dry milling group were colored with coloring liquid (Zenostar Color Zr; Wieland Dental) before sintering and

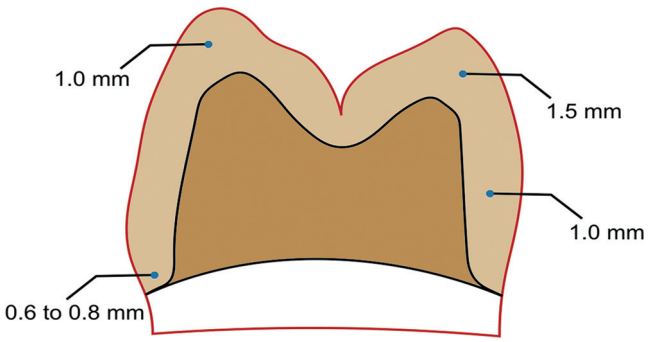

Figure 2. Schematic representation of tooth preparation design.

polishing. The crowns were then returned for clinical intraoral evaluation (Figs. 3, 4). Participants were blinded to the manufacture of the 2 crowns, and the evaluation order of the 2 conditions was randomized by envelope allocation. The operator (C.X.) was excluded from the following color-matching evaluation.

The chromatic values (CIE1976-L* a* b*) of the 2 anatomic contour zirconia crowns and the natural control tooth were measured with the dental shade-matching device. Color differences (ΔE) between crown and control tooth were calculated using the following equation[21]:

Figure 3. Restoration of severely discolored mandibular second premolar with anatomic contour zirconia crowns. A, Buccal view of evaluation of gel deposition crown. B, Occlusal view of evaluation of gel deposition crown. C, Buccal view of evaluation of dry milling crown. D, Occlusal view of evaluation of dry milling crown.

$\Delta E=\{(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2\}^{1/2}=\{(L_1^*-L_2^*)^2+(a_1^*-a_2^*)^2+(b_1^*-b_2^*)^2\}^{1/2}$, where L* refers to brightness, a* is redness to greenness, and b* is yellowness to blueness. The values ΔL^*, Δa^*, and Δb^* are differences in the color parameters for the 2 specimens measured for comparison. Subscript 1 refers to the restoration and subscript 2 refers to the control tooth. As in the study by Johnston and Kao,[22] ΔE values were classified into 3 levels (<3.70, 3.70 to 6.80, and ≥ 6.80), where 3.70 was selected as a perceptibility threshold and 6.80 was selected as a borderline between color match and mismatch.

In addition to chromatic value measurement, color matching was evaluated subjectively by 2 examiners according to the EVRSAM criteria for appearance match (Table 2).[22] When there were discrepancies of greater than 2 scores between examiners, a third examiner (W.X.) provided consensus input. Evaluators were blinded to treatment. Participants were asked to complete a questionnaire including a 100-mm VAS ranging from 0 (intolerable) to 100 (perfect) to assess the degree of color matching satisfaction.[23] Finally, participants selected the preferred crown to be cemented onto the prepared premolar using a dual-polymerize self-adhesive universal resin cement (RelyX U200; 3M ESPE). Participant follow-ups occurred after 3 months and at 12-month intervals by using modified U.S. Public Health Service guidelines.[24,25] The focus of the evaluation and criteria are shown in Table 3.

Statistical analyses were performed by using a statistical software program (IBM SPSS Statistics, v21.0; IBM Corp). The normality of each data distribution was investigated using the Shapiro-Wilk test. After verification, repeated measures ANOVA was used to assess the effects of crown and core on mean ΔE. Post hoc pairwise comparisons between groups were performed with Bonferroni correction. The paired Student *t* test was used to compare the mean VAS scores. When data were non-normally distributed, the Pearson chi-square test was used to analyze the distributions of crowns, and the Wilcoxon test was used to compare the EVRSAM scores (α=.05 for all tests).

RESULTS

During the clinical evaluation, 2 participants felt that their restorations were excessively contoured, although both were comfortable after adjustment. After the clinical

Figure 4. Restoration of normally colored mandibular second premolar with anatomic contour zirconia crowns. A, Buccal view of evaluation of gel deposition crown. B, Occlusal view of evaluation of gel deposition crown. C, Buccal view of evaluation of dry milling crown. D, Occlusal view of evaluation of dry milling crown.

evaluation, 26 wet deposition crowns and 1 dry milling crown were selected by participants.

The ΔE (mean ±SD) for anatomic contour zirconia crowns restored with 3 core types are shown in Table 4. The repeated measures ANOVA revealed that crown ($P<.001$) and core type ($P=.003$) had statistically significant effects on ΔE; however, there was no significant interaction between factors ($P>.05$). Table 5 shows the numbers of crowns assigned to 3 levels of ΔE values. Crowns in the additive wet deposition group offered a significantly lower ΔE level than the subtractive dry milling group ($P<.05$).

The VAS scores of the additive wet deposition group and subtractive dry milling group were 89.7 ±12.6 and 70.7 ±22.6 ($P<.05$). The numbers of crowns assigned to each EVRSAM score are shown in Table 6. The Wilcoxon test revealed that color matching was higher in the additive wet deposition group than in the subtractive dry milling group ($P<.05$).

None of the participants were lost to follow-up. Participants were followed up after a mean of 12.2 ±3.5 months. The crown survival rate was 100%, and all crowns were classified as Alfa for marginal fitness and marginal staining condition. Only 1 crown made by wet deposition was classified as Bravo because of slight overcontouring of the anatomic form. The patient was satisfied after adjustment and polishing.

Table 2. Extended visual rating scale for appearance match (EVRSAM) criteria

Rating	Description
0	Excellent esthetic match; restoration can only be identified with difficulty.
2	Very slight mismatch with good to very good esthetics.
4	Obvious mismatch but within acceptable range for most participants.
6	Poor esthetics on borderline of acceptability for most participants.
8	Very poor esthetics beyond range of acceptability for nearly all participants.
10	Totally unacceptable esthetics for all participants.

DISCUSSION

The results of this clinical trial supported rejection of the null hypothesis; anatomic contour zirconia crowns made by wet deposition were better than crowns made by dry milling in terms of color and translucency gradient.

Table 3. Modified U.S. Public Health Services guidelines

Parameters	Alfa (A)	Bravo (B)	Charlie (C)
Fracture	No chipping	Chipping, but polishing possible	Chipping, but polishing impossible
Marginal fitness	Probe does not catch	Probe catches slightly, but no gap detectable	Gap with dentin or cement Exposure
Marginal staining	Absence of marginal discoloration	Discoloration on less than half of circumferential margin	Discoloration on more than half of circumferential margin
Anatomic form	Ideal anatomic shape; good proximal contact	Slightly overcontoured or undercontoured; weak proximal contact	Highly overcontoured or undercontoured; open proximal contact

Table 4. Mean and standard deviation of ΔE values for anatomic contour zirconia crowns in 3 different core conditions

	Types of Core			
Types of Zirconia Crowns	PFP	GCP	WP	Total
Additive wet deposition	1.78 ±1.34	3.17 ±1.99	2.20 ±1.12	2.45 ±1.60
Subtractive dry milling	3.39 ±0.56	5.31 ±1.52	4.59 ±1.63	4.55 ±1.54
Total	2.59 ±1.29[a]	4.24 ±2.04[b]	3.39 ±1.83[a,b]	3.50 ±1.88

GCP, gold cast post-and-core; PFP, prefabricated fiber post and composite core; WP, without post-and-core. Means with different superscript letters indicate significant differences using Bonferroni post hoc comparisons ($P<.05$).

Table 5. Numbers of crowns assigned to 3 levels of ΔE values

	Level				
Types of Zirconia Crowns	<3.7	3.7-6.8	≥6.8	Sum	*P*
Additive wet deposition	23	3	1	27	<.001
Subtractive dry milling	10	15	2	27	

$P<.05$ indicates statistically significant differences (Pearson chi-square test).

Table 6. Numbers of crowns assigned to each EVRSAM score

	Score							
Types of Zirconia Crowns	0	2	4	6	8	10	Sum	*P*
Additive wet deposition	14	11	2	0	0	0	27	<.001
Subtractive dry milling	1	12	13	1	0	0	27	

$P<.05$ indicates statistically significant differences (Wilcoxon test).

Additionally, all but 1 patient opted for bonding of a crown made by wet deposition.

In the subtractive dry milling group, 2 crowns made by subtractive dry milling were clinical mismatches ($\Delta E \geq 6.80$); 17 crowns were distinguishable from adjacent teeth ($\Delta E \geq 3.70$); and 12 crowns were rated 2 scores, and 13 crowns were rated 4 scores as per the EVRSAM criteria. The results are consistent with the finding of previous studies that anatomic contour zirconia restorations made by dry milling achieve acceptable but often suboptimal esthetic effects.[5]

The additive wet deposition group scored higher than the subtractive dry milling group in color-matching and esthetic appearance; 14 crowns made by additive wet deposition were excellent esthetic matches, and 11 were slight mismatches according to EVRSAM criteria. These results are consistent with findings of 3 recent nonclinical evaluations of SGZ restorations.[13-15] Kim et al[12] controlled zirconia translucency by regulating the raw material preparation method and applying additional processing techniques, regardless of the coloring procedure. In this clinical trial, the novel additive 3D gel deposition approach yielded denser gradient structures and a structure with finer grains than conventional dry milling crowns.[15] Zhang et al[14] measured grain sizes in 2 types of zirconia ceramics and concluded that novel SGZ restorations offered a significantly smaller grain size (200 nm) than conventional well-polished zirconia ceramics (350 to 600 nm). This could explain the improved color matching and excellent esthetics of the SGZ restorations.

The clinical trial showed significantly higher color-matching and esthetic scores in the PFP group than in the GCP group, indicating that dark backgrounds may reduce a crown's color-matching ability. Oh et al[26] reported that zirconia crowns might not be shade matched with adjacent teeth when placed on a gold alloy post. The current findings agree with those of Suputtamongkol et al,[27] who found background shade affects the overall color of posterior zirconia restorations.

Upon clinical evaluation, 2 participants in this trial felt that their restorations were slightly excessively contoured. Both were comfortable with the anatomic form after adjustment; however, the subtractive dry milling procedure exposed the white base, necessitating further staining to improve color matching. In contrast, crowns made by additive wet deposition were not stained except for occlusal pits and fissures, with no changes in color matching noted after adjustment. During clinical follow-up, 1 SGZ crown was classified as Bravo due to slightly excessively contoured anatomic form. No external staining was necessary after adjustment and polishing, and a good color match was maintained. This suggests that the use of additive wet deposition eliminates the need for manual operations such as characterization and glazing after adjustment.[13]

Restoring severely discolored teeth is a difficult task in clinical practice. In this clinical trial, 1 premolar of the patient with severe tetracycline staining was restored with an SGZ crown (Fig. 3) and obtained excellent color matching to adjacent teeth. This success indicates that anatomic contour monolithic zirconia crowns made by additive wet deposition may have the potential for reproducing challenging shade matches. Further studies which specifically evaluate this approach in participants with severe discoloration are necessary to confirm this finding.

The present clinical trial had some limitations. Owing to sample size limitations, the conclusion regarding the influence of the type of core foundation on color matching in restorations requires further confirmation. Although the comparison of the 2 crowns in this clinical trial was reliable because of a self-controlled design, it was limited by participants only selecting 1 crown for bonding and further follow-up. Additionally, the follow-up period was short; future studies are required to determine long-term outcomes.

CONCLUSIONS

Based on the findings of this clinical trial, the following conclusions were drawn:

1. Anatomic contour monolithic zirconia crowns made using an additive 3D gel deposition approach offered better color matching than conventional zirconia crowns made using subtractive dry milling.
2. Participant satisfaction with esthetic appearances was higher with wet deposition crowns than with dry milling crowns upon clinical evaluation.

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