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CLINICAL RESEARCH

Assessment of CAD-CAM zirconia crowns designed with 2 different methods: A self-controlled clinical trial

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ABSTRACT

Statement of problem. In computer-aided design and computer-aided manufacturing (CAD-CAM) dentistry, the correlation method is an efficient way to design complete crowns. However, the occlusal relationship and patient satisfaction with prostheses fabricated using this method remain unclear.

Purpose. The purpose of this clinical trial was to compare the occlusion of monolithic zirconia crowns designed using the correlation and library methods.

Material and methods. Twenty-three teeth of 21 participants received 2 monolithic zirconia crowns designed by using the correlation or the library method. Defective teeth were scanned using an intraoral scanner to obtain references and working casts from before and after the preparation. Before cementation, the occlusal relationship of both crowns and patient satisfaction were evaluated, and the occlusal adjustment time was recorded.

Results. The correlation method resulted in less lateral occlusal interference of the crowns than the library method ($P<.01$). The occlusal adjustment times of the correlation and library conditions were 455.8 ±357.1 seconds and 575.3 ±488.0 seconds, respectively ($P>.05$). Relative occlusal force was significantly higher in the correlation than in the library condition and was related to before preparation relative occlusal force ($r=0.706$, $P<.01$). The visual analog score before occlusal adjustment was higher in the correlation than in the library condition ($P<.05$). The occlusal contacts, occlusal contact distributions, and number of occlusal contacts did not differ between conditions ($P>.05$).

Conclusions. Better eccentric occlusion and reduced lateral occlusal interference were obtained when the correlation method was used to design crowns. The correlation method yielded higher relative occlusal force, which helped to restore the original occlusal force. (J Prosthet Dent 2018;120:686-92)

Since its introduction in the late 1980s, computer-aided design and computer-aided manufacturing (CAD-CAM) technology has been used in dentistry to increase productivity and accuracy.[1] CAD-CAM techniques were developed to help automate the production process, to optimize the quality of restorations, and to use new biocompatible and esthetic materials.[2-5] CAD-CAM prostheses reportedly have clinical performance similar to that of conventional prostheses in terms of marginal fit, esthetics, and mechanical properties.[6-8]

However, the occlusal morphology of CAD-CAM restorations is mainly generated by CAD software, which is based on standard libraries[9-11] and therefore requires individual adaptation.[10,11] Additionally, an operator is still needed to customize designs for most patients.[12] Marked amounts of clinical adjustment are also often needed, which is time consuming and may affect the strength of the restoration.[13]

Although virtual articulators that simulate or reproduce mandibular movements are now available in CAD-CAM systems[14]; most of these articulators require special equipment and considerable effort. The correlation technique is a method that copies the existing

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Clinical Implications

Crowns designed by using the library method often lack occlusal accuracy. Conversely, the correlation method was an easier and more accurate way to produce CAD-CAM complete crowns. Crowns designed using the correlation method had better eccentric occlusion than those designed using the library method and higher relative occlusal force. Participants were more satisfied with crowns designed using the correlation method at the trial placement.

occlusal anatomy to the definitive restoration.[15] Kurbad et al[16] reported good results with digital copying of the interim crowns. Other studies have used the correlation method to copy the anatomy of interim restorations or diagnostic waxing to the definitive restorations.[17-19] When a tooth is diagnosed with pulpitis, the correlation technique can record the occlusion surface of the tooth before endodontic access.

However, the present authors are unaware of a controlled clinical trial that compared occlusion designed with the correlation with that designed with the library method. Therefore, this clinical trial evaluated and compared clinical occlusal relationships and patient satisfaction with monolithic zirconia crowns designed by using the correlation method with those designed by the library method. The null hypothesis was that no differences would be found in occlusal relationship between crowns designed with these 2 methods.

MATERIAL AND METHODS

The clinical trial was registered with the Chinese Clinical Trial Registry and with the World Health Organization (ChiCTR-INR-16008559). Ethics committee approval was obtained from the Peking University School of Stomatology Biomedical Institutional Review Board (PKUSSIRB-201523086). The clinical trial was conducted in accordance with tenets of the Declaration of Helsinki and the Good Clinical Practice guidelines. Informed consent was provided by each participant. Inclusion criteria specified individuals were between 18 and 60 years of age with a single posterior tooth, with at least two-thirds of the occlusal surface intact, and requiring a complete crown and in good oral health. Exclusion criteria specified individuals with bruxism, clenching, or grinding, acute or chronic temporomandibular joint disorder, sensory or mental abnormalities, debilitating medical conditions, and pregnant or lactating women.

Sample size calculation was based on the number of participants required to demonstrate a 120-second difference in mean occlusal adjustment time between the 2 conditions, using a paired sample Student *t* test. The sample size was calculated to be 12 participants, based on a significance level of .05, a power of 80%, and a SD of ±132 seconds for occlusal adjustment[12] under both conditions.

A composite resin (Clearfil AP-X; Kuraray America, Inc) foundation restoration was placed to restore anatomy and ideal occlusal contacts (Fig. 1). The participant was instructed to follow a soft diet. After 2 weeks, the tooth and at least 2 adjacent teeth were scanned with an intraoral scanner (TRIOS; 3Shape A/S) and marked with articulating paper (BK 51 Blue, BK 52 Red, and Arti-Fol BK 25 Red; Dr. Jean Bausch GmbH). The relative occlusal force (ROF) (T-Scan III; Tekscan Inc) and jaw muscle electromyography (EMG) findings (BioEMG; BioResearch Inc) were recorded. The tooth was then prepared for a monolithic zirconia crown. The preparation finish lines were placed at the gingival level or did not extend more than 0.5 mm subgingivally. The preparation was scanned immediately after rinsing and air drying of the prepared tooth. All clinical procedures were performed by one of the authors (R.Z.).

Digital files obtained from the intraoral scanner before and after tooth preparation were uploaded to restoration design software (3Shape Dental System; 3Shape A/S). For each participant, 2 zirconia crowns were designed by using both the correlation method and the library method. The cement spacer was set to 60 μm at the axial and occlusal surfaces and at 20 μm at the margin.[20] The proximal contacts were adjusted to overlap the adjacent teeth by 0.01 mm. All settings, other than the occlusal design, were the same for both methods (Fig. 2).

To design the crown using the correlation method, we superimposed digital scans obtained after preparation on the digital model made before the preparation by using a best-fit algorithm. The crown was designed by copying the occlusal surface of the pre-preparation tooth. Subtle changes were made in the axial anatomy, and the surface was smoothed.

To design the crown using the library method, we selected an appropriate tooth element from the library and shaped it to fit the remaining dentition. Proximal contacts were adjusted to adjacent teeth, and intercuspal occlusion was adjusted to fit with opposing teeth, to 0 mm.

Data from the 2 crown designs were exported in standard tessellation language (STL) format and sent to a 5-axis milling machine (Zenotec T1; Wieland Dental). Intrinsically colored monolithic zirconia blocks (Zenostar; Wieland Dental) were milled and then sintered according to the manufacturer's recommendations.

During the clinical evaluation, occlusal adjustment, and reevaluation processes, participants were blinded to the design methods used to develop the 2 crowns. The

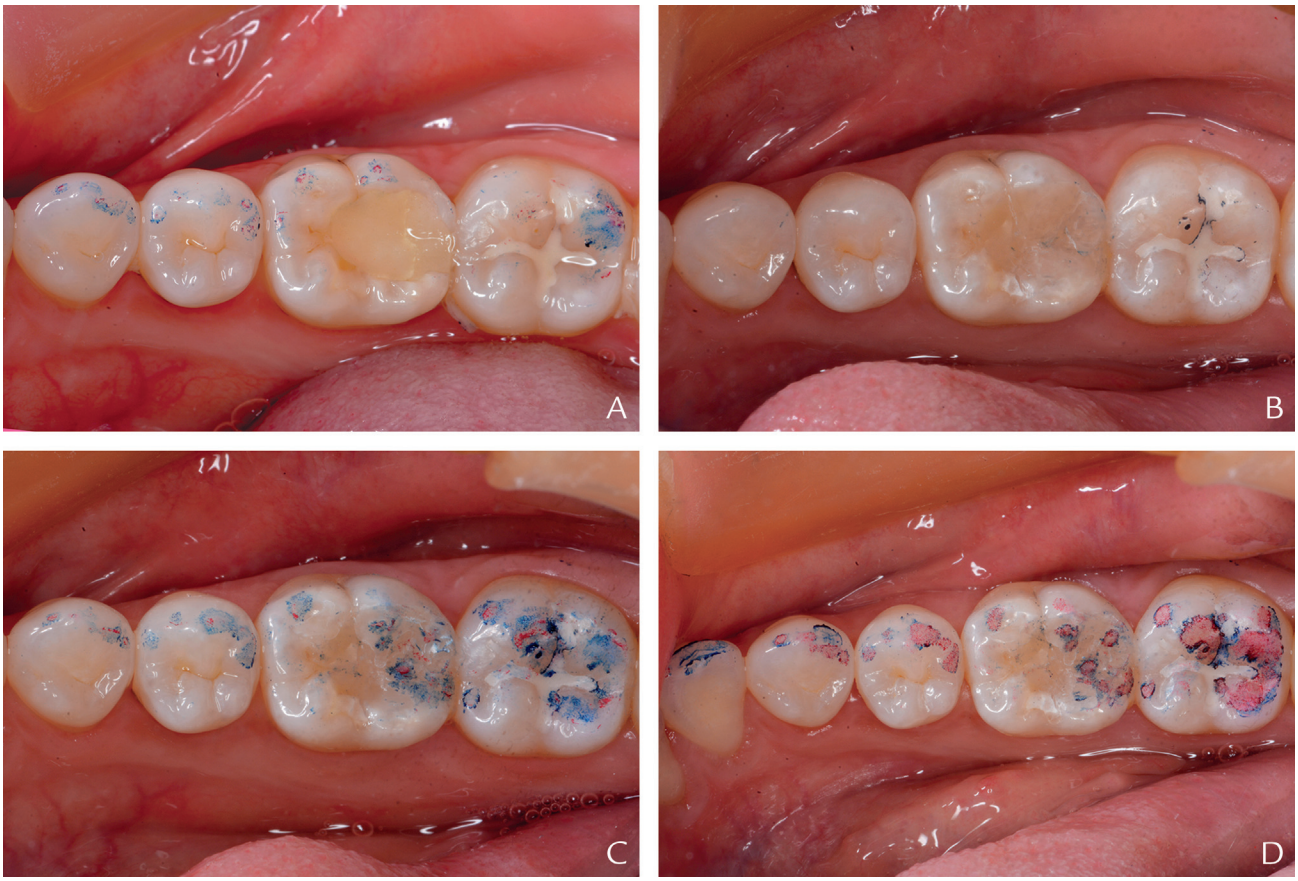

Figure 1. Occlusion of right mandibular first molar restored with composite resin. A, Occlusal view before foundation restoration. B, Occlusal view after foundation restoration. C, Occlusal contact at intercuspal position after restoration (100-μm blue and 12-μm red articulating paper). D, Lateral occlusal contact after restoration (100-μm blue and 100-μm red articulating paper).

evaluation orders of the 2 conditions were randomly allocated by envelope. After we performed proximal and internal evaluations, the occlusal relationship of each condition of zirconia crowns was evaluated (Fig. 3).

Intercuspal occlusion and lateral interference were evaluated and recorded by using articulating paper (BK 51 Blue, BK 52 Red, and Arti-Fol BK 25 Red; Dr. Jean Bausch GmbH). Then, occlusal adjustment was made, and the time required was recorded. After occlusal adjustment was made (R.Z.), the 2 conditions of the crowns were re-evaluated by using articulating paper, T-Scan, and EMG. The patient's subjective evaluation was recorded. After evaluation, the crowns were transferred to the laboratory and polished. The participant chose either the correlation or library condition of the zirconia crown for cementation (RelyX U200; 3M ESPE).

Identification of occlusal contacts was performed by a 2-phase method using both 100-μm and 12-μm articulating paper (BK 51 Blue, BK 52 Red, and Arti-Fol BK 25 Red; Dr. Jean Bausch GmbH). Clinical photographs were made immediately. After the clinical photographs of all participants had been randomly numbered by using a random selection program (IBM SPSS Statistics, v20.0; IBM Corp), another 2 prosthodontists made separate evaluations. The occlusal contacts (OC), occlusal contact distributions (OD) (Table 1), and number of occlusal contacts (NC) were rated based on modified criteria of the World Dental Federation.[21] Inter-rater agreement was then assessed by using weighted kappa statistics (linear weights). The scores of only 1 rater were used for analysis.

Before preparation of the teeth and after occlusal adjustment of the correlation condition and the library condition, we made T-Scan and EMG examinations. Participants were seated in a relaxed upright position with the Frankfurt plane oriented horizontally.[22] The appropriate sensors for the T-Scan (100 μm) were placed,[23] and the appropriate sensitivity range for acquisition of occlusal data was established. Participants were asked to clench in intercuspal position. The ROF and jaw muscle EMG in the maximum occlusal contact frame (μV) were recorded 3 times. The detection range was maintained in the same location with respect to the patient's dentition to ensure data consistency.

During the clinical evaluation, before and after occlusal adjustment, participants were asked to evaluate the occlusal comfort of the crowns on a 100-mm visual

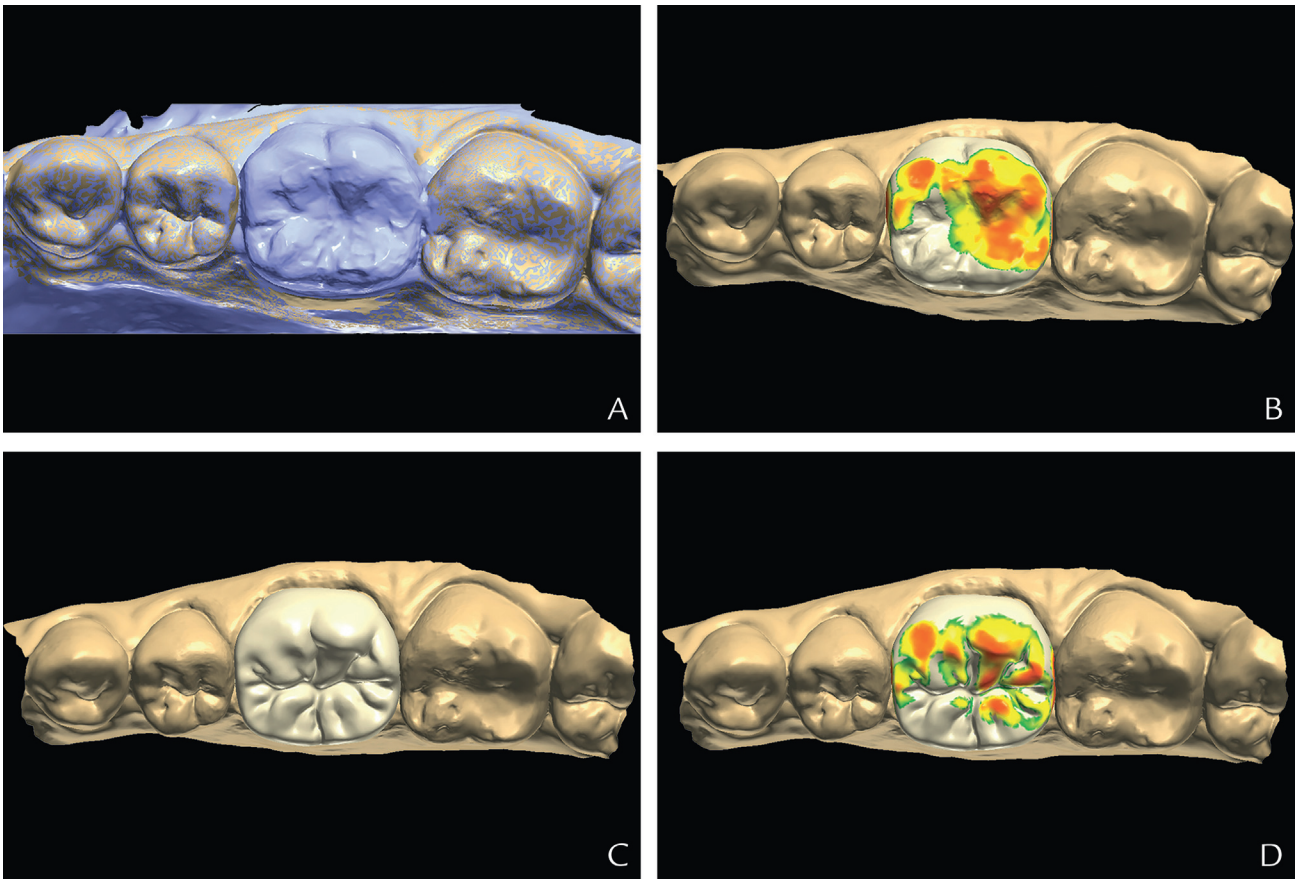

Figure 2. Design of complete crown of right mandibular first molar by using correlation and library methods. A, Superimposition before preparation using correlation method. B, Occlusal contacts of complete crown designed with correlation method. C, Occlusal view of complete crown designed with library method. D, Occlusal contacts of complete crown designed with library method.

analog scale (VAS), with "perfect" at the 100-mm and "intolerable" at the zero point. The distance in millimeters between the zero point and the participant's marks on the line was measured and converted into a VAS score (0 to 100 mm).

Data were collected and analyzed by using statistical software (IBM SPSS Statistics, v20.0; IBM Corp). The Wilcoxon test was used to compare OC, OD, and NC values of the correlation condition with those of the library condition. The McNemar test was used to compare the 2 conditions in terms of functional interference. Paired Student *t* tests were used to compare the ROF and EMG values. Correlation of the ROF before and after occlusal adjustment was tested by using Spearman correlation analysis (α=.05).

RESULTS

Twenty-one participants (13 women, 8 men; mean age, 27.2 years) agreed to participate in this clinical trial. Twenty-three teeth were included, 15 from the maxilla, and 8 from the mandible. Eighteen molars and 5 premolars were treated.

Table 2 shows the number of crowns with and without lateral interference in the 2 conditions. The McNemar test revealed that the correlation condition had more reduced lateral interference than the library condition (P<.01). Occlusal adjustment times for the correlation and the library conditions were 493.4 ±455.9 seconds and 570.3 ±444.5 seconds, respectively, which were not significantly different (P>.05).

After we made occlusal adjustments, the ROF was significantly different (P<.05) between the correlation (13.53 ±7.02%) and the library (11.14 ±7.64%) conditions. The pre-preparation ROF was 12.23 ±6.24%. Spearman bivariate correlation analysis revealed a significant positive correlation between the correlation condition and pre-preparation ROF (r=0.706, P<.01). No significant correlation was found between the library condition and the pre-preparation ROF (r=0.378, P>.05).

The mean ±SD EMG raw values of all tested muscles are shown in Table 3. No statistically significant differences were found between the correlation and library conditions on either side of the masseter or anterior temporalis muscle (P>.05).

Figure 3. Occlusion of right mandibular first molar after complete crown restoration. A, Occlusal view of complete crown designed with correlation method. B, Occlusal contact of complete crown designed with correlation method at intercuspal position after restoration (100-μm blue and 12-μm red articulating paper). C, Occlusal view of complete crown designed with library method. D, Occlusal contact of complete crown designed with library method at intercuspal position after restoration (100-μm blue and 12-μm red articulating paper).

Table 1. Evaluation criteria of occlusal contracts and occlusal contact distribution in intercuspal occlusion

Score	Occlusal Contacts	Occlusal Contact Distribution
4 Excellent	Occlusal contact points on the crown and adjacent teeth, equally strong (both 100- and 12-μm articulating paper imprints exist on the crown and adjacent teeth); no supra- or infraocclusion	Good occlusal contact distribution; occlusal contacts between supporting cusps and opposing fossa or ridge
3 Good	Occlusal contact points on the crown and adjacent teeth, unequally strong (only 100-μm articulating paper imprints exist on adjacent teeth)	Individual occlusal contact points missing or deviated but occlusal contacts on main supporting cusp; crown still functional
2 Satisfactory	Contact points only on crown (crown too high, thus supraocclusion)	No occlusal contacts on supporting cusps but contacts present on other parts of occlusal surface
1 Unsatisfactory	No occlusal contact points on crown (infraocclusional)	No occlusal contacts or distribution detrimental to stability of crown

Before occlusal adjustment, the VAS scores of the correlation and library conditions were 61.7 ±25.5 and 53.9 ±25.7, respectively. Significant differences were found between the 2 conditions ($P<.05$). After occlusal adjustment, the scores of the correlation and library conditions were 89.7 ±7.2 and 90.8 ±7.6, respectively. No significant differences were found between the 2 conditions ($P>.05$).

The weighted kappa (linear weights) values for OC, OD, and NC, as rated by 2 dentists, were 0.858, 0.721, and 0.746, respectively, indicating high agreement between the 2 raters. The OC and OD scores are listed in Table 4. No differences in scores were found between the correlation and library conditions before and after occlusal adjustment (both $P>.05$). The median NC (Q1, Q3) of the correlation and library condition were 3 (3, 4)

Table 2. Number of crowns with and without lateral interference in two conditions

	Correlation Method		
Library Method	**Lateral Interference**	**No Lateral Interference**	***P***
Lateral interference	13	8	.008
No lateral interference	0	2	

Table 3. Mean ±SD EMG μV of correlation and library conditions in T-Scan maximum occlusal area frame

	MA		TA	
	Left	**Right**	**Left**	**Right**
Correlation method	71.67 ±37.2	71.88 ±22.5	136.55 ±55.2	134.50 ±63.1
Library method	70.50 ±35.0	77.39 ±26.5	137.87 ±60.4	139.18 ±68.8
t value	.23	-1.54	-.20	-.81
P	.82	.14	.84	.43

EMG, electromyography; MA, masseter muscles; TA, anterior temporalis muscles; μV, EMG values.

Table 4. OC and OD scores for intercuspal occlusion before and after restoration of intercuspal occlusion according to one rater

	OC				OD				
Score	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**Sum**
PRE	0	2	0	21	0	2	14	7	23
CL(B)[a]	0	10	3	10	0	8	9	6	23
LB(B)[a]	0	12	4	7	2	4	16	1	23
CL(A)[b]	0	0	3	20	1	5	11	6	23
LB(A)[b]	1	1	5	16	2	4	10	7	23

CL(A), correlation condition after occlusal adjustment; CL(B), correlation condition before occlusal adjustment; LB(A), library condition after occlusal adjustment; LB(B), library condition before occlusal adjustment; OC, occlusal contacts; OD, occlusal contacts distribution; PRE, before preparation. Lowercase superscript letters show Wilcoxon test results revealed no significant differences between 2 conditions of both OC and OD scores ($P>.05$).

and 3 (3, 4), respectively, before occlusal adjustment and 4 (3, 5) and 4 (2, 4), respectively, after occlusal adjustment. No significant differences ($P>.05$) were found between the 2 conditions.

DISCUSSION

Results of this clinical trial support rejection of part of the null hypothesis: no significant differences were found in occlusal relationship between the correlation and library conditions, including number of crowns introducing lateral interference, relative occlusal force, and patient subjective evaluation before occlusal adjustment; thus, the data support rejection of the null hypothesis for these variables. However, no differences were found in occlusal relationship between the correlation and library conditions, including articulating paper examination, occlusal adjustment time, EMG muscle activity values, and patient subjective scores after occlusal adjustment; thus, the data do not support rejection of this null hypothesis.

The present clinical trial used composite resin to restore both static and dynamic occlusal contacts before tooth preparation. Through 2 weeks of adaptation, the occlusal surface conformed to the participant's occlusion. In this clinical trial, the correlation condition showed significantly less lateral interference than the library condition, indicating that the correlation method yielded functional occlusion that was improved compared with that of the library method. Olthoff et al[24] investigated differences between crowns designed with the library method and the occlusal generated path technique and concluded that more correction of the static occlusion design was needed to allow functioning without interference; this was in agreement with the findings of the current clinical trial.

Yeliz et al[25] evaluated the occlusal contacts generated by using 3 different biogeneric design modes (individual, copy, and reference modes) of Cerec software and concluded that the biogeneric individual (library) method showed significantly better occlusion than the biogeneric copy design (correlation) method. This conclusion was contrary to our findings. The reason for these differences may be that the study by Yeliz et al[25] did not involve fabricating the designed restorations but rather that the occlusion was evaluated by computer.

The T-Scan offers the opportunity to observe occlusion with dynamic quantitative analysis.[26] The ROF of molar teeth becomes larger with the increase in the total occlusal force.[27] T-Scan data with similar masticatory muscle strength were selected for comparisons to avoid the change in the occlusal force ratio caused by the inconsistency of the total occlusal force. The ROF of the correlation condition was larger than that of the library condition, suggesting that crowns designed with the correlation method restored occlusal force better. The positive correlation between the correlation condition and pre-preparation ROF is conducive to maintaining the original occlusal force of the teeth, as the correlation condition has an occlusal surface nearly the same as that of the pre-preparation teeth, whereas the occlusion in the library condition is not sufficiently personalized to maintain the original occlusal force of the defective tooth.

In this clinical trial, no significant differences were found in muscle EMG between the correlation and library conditions, which may be because the change caused by the restoration of a single tooth was not sufficient to affect masticatory muscle strength. However, changes in occlusion and masticatory muscle strength are inextricably linked.[28] When performing various forms of fixed restorations, especially complete-mouth rehabilitations, dentists must pay close attention to the changes in the masticatory muscles.

The VAS is a measurement instrument that has been used widely to evaluate patient satisfaction with crowns.[29-31] The occlusal surface of crowns designed with the correlation method is similar to that of original teeth, which is probably why the correlation condition had higher VAS scores than the library condition. After

occlusal adjustment, the 2 conditions had similar VAS scores, revealing that the dissatisfaction stemmed mainly from supraocclusion of the crowns.

Although the comparison between the 2 conditions was reliable because of the good self-control of the participants, a limitation of this clinical trial was that it did not include a long-term follow-up; the participants could only receive 1 crown, chosen by themselves, and randomized grouping was difficult to achieve. Further studies are needed to investigate the accuracy and precision of the correlation method for restoring multiple defective teeth.

CONCLUSIONS

Within the limitations of this clinical trial, the following conclusions were drawn:

1. Crowns designed by using the correlation method produced improved occlusal relationships compared with those designed using the library method, especially the initial fit.
2. The ROF of crowns designed by using the correlation method was higher than that of crowns designed using the library method and correlated positively with the force of the tooth before preparation.
3. Participants were more satisfied with crowns designed using the correlation method at the trial placement.
4. Compared with the library method, the correlation method is an easier and more accurate way to fabricate CAD-CAM complete crowns.

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