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ORIGINAL ARTICLE

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Morphological design of occlusal wear facets for the mandibular first molar crown using different bite registration methods

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Abstract

Purpose: To compare the accuracy of occlusal wear facet morphology designed using different bite registration methods for mandibular first molar crowns.

Materials and methods: The posterior teeth and intraoral intercuspal occlusions of 12 participants were scanned. The abutment shape of the mandibular first molars for complete crowns was virtually designed, and the anatomic coping design method was used to design crowns. In the anatomic coping design, digital wax patterns were constructed by elevating the wear facets on the original surface of the first molars and then adjusting the facets with 2 types of virtual occlusions determined by buccal bite registration (BBR) or segmented tooth registration (STR) methods, where the displacement of teeth under bite force was considered (STR) or not (BBR). The occlusal distance between the original wear facets and the antagonists as well as 3D deviations between the facets on the designed crowns and on the surfaces of the original teeth were measured. Paired-samples t-test was used to analyze the results ($\alpha = 0.05$).

Results: Regarding occlusal distance, the mean 3D deviation and the root mean square (RMS) values of BBR were greater than those of the STR groups ($p < 0.001$ and $p =$ 0.008). The mean 3D deviations of the crowns of the BBR and STR groups were 0.19 ±0.04 mm and 0.14 ±0.06 mm, respectively and the RMS values were 0.22 ±0.03 mm and 0.18 ±0.04 mm ($p < 0.001$), respectively.

Conclusions: The morphology of occlusal wear facets of mandibular first molar crowns designed with the occlusion constructed using the segmented tooth registration method are more coincident with the original morphology.

KEYWORDS
tooth displacement, intercuspal occlusion, wear facet, intraoral scanner

Accurate construction of intercuspal occlusion (ICO) is a prerequisite for designing prostheses with suitable occlusal contacts and ensuring the clinical outcome.[1] The ICO of casts is influenced by the shrinkage of the impression materials and the expansion of the stone casts. The determined occlusion is also influenced by the change of stomatognathic system of the patients themselves, which includes physiological tooth displacement and dental arch deformation.[2–4] Non-rigidity of the bone and periodontal ligament allows minor tooth displacement under bite force and results in closer intercuspation.[5] The stone cast represents a rigid model[6] and cannot reproduce the physiological change with bite force, thus, the ICO of the casts may differ from the intraoral condition.[7]

To replicate better intraoral occlusion, several techniques have been proposed, such as the dual-arch impression technique[5,8] and functional bite impression (FBI) technique.[9–11] These techniques are not affected by mandible deformation or tooth displacement, and it is beneficial to obtain more occlusal contact areas and more equally distributed occlusal forces. One disadvantage of these techniques involves the need to perform complicated chairside steps and laboratory procedures, which may induce more errors caused by the physical property of the materials.[12] Intraoral scanners (IOSs) obtain virtual interocclusal records by scanning the buccal and labial surfaces of teeth in ICO and determine the virtual occlusion through a process termed the “buccal bite registration (BBR)” method, which may obtain a better ICO record.[13–16] However, virtual occlusion is not coincident with intraoral conditions, where perforations often occur between the surface of digital dentitions.[16–19] Prostheses made using these digital casts exhibit no contact or have light occlusal contacts, resulting in lower masticatory efficiency.[15,17]

Considering tooth displacement under bite force, a segmented tooth registration (STR) method was established[20] to construct virtual dental occlusion. The digital dentitions were segmented into single teeth, and the single teeth were aligned to buccal bite data respectively, to conform to the displacement of teeth under bite force. The results showed that the virtual dental occlusion constructed using the STR method demonstrated a better location, count, and area of intraoral occlusal contacts than that of the BBR method. But the occlusal contacts recorded with 100 μm articulating paper were set as the reference in the previous study.[20] All points less than 100 μm of the occlusal surfaces between casts can be calculated. The definite occlusal distance between antagonists of 2 types of virtual occlusions determined by BBR or STR methods were not calculated and the effect of the 2 methods on the morphology of prostheses was not determined. The purpose of this study was to design the morphology of occlusal wear facets of the mandibular first molar crown based on virtual ICO established using BBR and STR methods. The null hypothesis of the study was that the morphology of the occlusal wear facets designed using these two methods to construct virtual ICO would be similar.

MATERIALS AND METHODS

Data acquisition

Twelve participants (8 women and 4 men) aged 23 to 29 years and with an average age of 25.3 years from the Peking University School and Hospital of Stomatology were recruited. The sample size calculation was based on the mean three-dimensional (3D) deviation values of the pilot results using the paired-samples t-test. The sample size was 7, which was calculated by PASS software (NCSS, V11.0, US) based on a calculated effect size of 1.54, Type I error at $\alpha = 0.05$, and Type II error at $1\text{-}\beta = 0.90$. All participants provided their consent. The inclusion criteria for this clinical study were as follows: complete permanent dentition except for the third molars, sound periodontium and teeth, and stable occlusion with an angle class I occlusal relationship. Subjects with signs of malocclusion such as dental crowding and unilateral/bilateral crossbite, temporomandibular dysfunction, craniomandibular disorders, and orthodontic therapy were excluded from the study. This research was approved by the Bioethics Committee of Peking University School and the Hospital of Stomatology, China (PKUSSIRB-201951170).

The participants were guided to practice biting in the ICO under normal bite force repeatedly. The bite force was maintained at the most accustomed force that the individual felt, which is commonly used for clinical interocclusal recording and occlusal adjustment. The right and left mandibular first molars of the participants were selected as the target teeth. After calibration according to the manufacturer's instructions, the left mandibular first molar and ipsilateral posterior teeth under an open-mouth state were captured using an IOS (Trios 4 v20.1.2; 3Shape A/S, Copenhagen, Denmark) based on the recommended strategy. The buccal bite data of posterior teeth were scanned after instructing the participant to maintain the jaw in ICO with the trained force. The digital casts and buccal bite data on the right side were recorded similarly.

Virtual preparation of abutment and crown design

The abutment shape of the mandibular first molars for complete crowns was virtually designed using the "Sculpt Knife" tool of Geomagic software (Geomagic Studio 2013; 3D Systems Inc., Rock Hill, SC). The design was based on the original shape of the teeth and the following parameters: occlusal reduction of 1.5 mm, axial reduction of 1 mm, and supragingival chamfer preparation of 1 mm of depth.

Wear facets were defined as any wear line or plane on tooth surfaces characterized by smooth, polished, and usually well-delineated surfaces.[21,22] All wear facets of mandibular first molars were manually marked on the original casts with the aid of the "curvature map" displayed by Geomagic software. The digital wax patterns of the target teeth were made from the original tooth shape by elevating occlusal wear facets of 0.3 mm in the occlusal direction.[23]

After the virtual preparation of abutments and creation of digital wax patterns, the anatomic coping design method was used to design crowns on virtual abutments, where the surface of crowns was duplicated from the digital wax patterns.

Adjusting the wear facets on crowns with bite registration

Based on the registration of the upper and lower dentition model with the acquired buccal bite scan data, the dentitions were aligned to the ICO, and this process was termed the buccal bite registration (BBR) method. However, considering that the teeth alignment will be slightly altered under bite force, we proposed another method named segmented tooth registration (STR). Using the STR method, the boundaries along the gingival margins and the adjacencies of the crowns were drawn, and the maxillary and mandibular casts were segmented into single teeth. The segmented teeth were registered to the buccal bite data one by one using the 'Best Fit Alignment' function according to the common area, and the realigned teeth were saved as new casts (Fig 1).

The occlusal surfaces were adjusted by adapting to antagonists based on the virtual occlusion created by the BBR

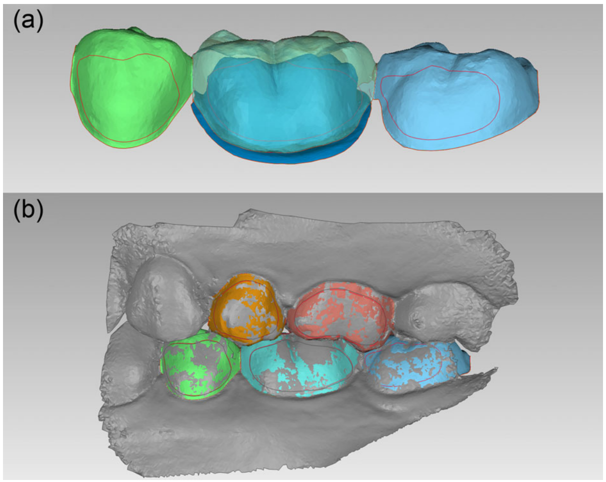

FIGURE 1 Digital casts and preparation. (a) Preparation of the left mandibular first molar. (b) Casts and occlusion of the segmented tooth registration group.

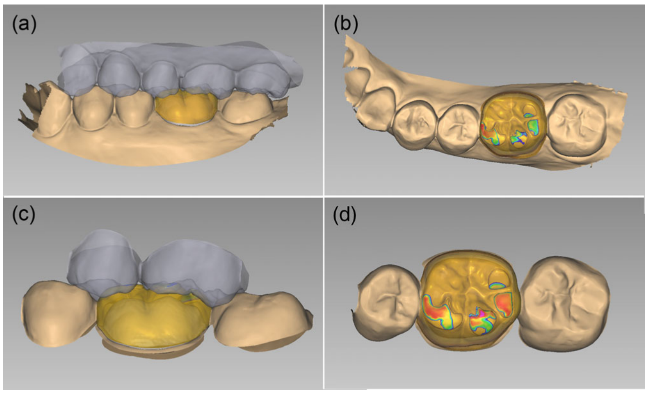

FIGURE 2 Design of mandibular first molar crowns. (a) Digital casts and wax pattern of the buccal bite registration group. (b) Occlusal contacts of the buccal bite registration group. (c) Digital casts and wax pattern of the segmented tooth registration group. (d) Occlusal contacts of the segmented tooth registration group.

and STR methods, where the distance between the designed crown and the opposing tooth was set as 0 mm, which means that the portions of facets invaded into the antagonist teeth surface were cut off (Fig 2).

Measurement and statistical analysis

The 3D deviations between occlusal wear facets of mandibular first molars and their antagonists of BBR and STR methods were calculated, indicating the occlusal distance. The crowns adjusted with BBR and STR occlusions were compared with the corresponding original occlusal wear facets using the Geomagic Studio 2013 software program. The mean value and root mean square (RMS) of the 3D deviation were measured (Fig 3). The 3D deviation is the shortest distance from the test object to any point on the reference object. The RMS[24] estimate was obtained based on the following equation:

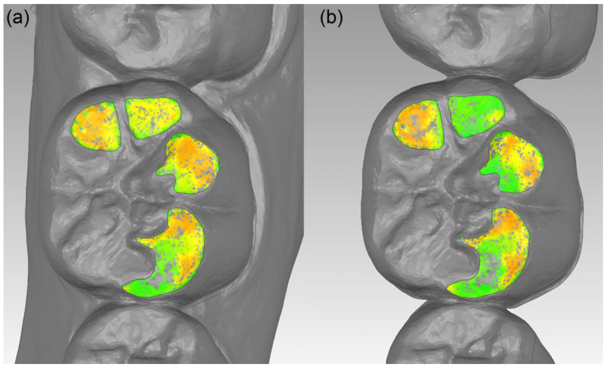

FIGURE 3 The three-dimensional deviation between crowns and original occlusal wear facets. (a) 3D deviation of the buccal bite registration group. (b) 3D deviation of the segmented tooth registration group.

$$\boldsymbol{RMS} = \sqrt{\frac{\sum_{i=1}^{N} (\boldsymbol{x_i})^2}{\boldsymbol{N}}},$$

where $\boldsymbol{x_i}$ is the point distance from the restorations to corresponding point $\boldsymbol{i}$ on the original wear facets and $\boldsymbol{N}$ is the total number of points.

The mean value indicates the superiority of positive or negative errors.[25] For basic quantitative analysis, RMS serves as a measure of the extent to which deviations between 2 different datasets vary from zero.[26]

The Shapiro-Wilk test for normality and Levene's test for equality of variances were performed. Paired-samples t-test or Wilcoxon signed rank test was used to analyze the influence of different bite registration methods on the morphology of occlusal wear facets via a statistical software program (SPSS Statistics, v19.0; IBM Corp, Armonk, NY) ($\alpha = 0.05$).

RESULTS

The occlusal distance results are shown in Figure 4. The results of 3D deviation of the mandibular first molar crown adjusted by BBR and STR occlusions are shown in Figure 5. The results were normally distributed with homogeneous variance ($p > 0.05$), and paired-samples t-test was used for statistical analysis. Regarding occlusal distance, the mean 3D deviations of the BBR and STR groups were 0.48 ±0.13 mm and 0.38 ±0.14 mm, respectively. A significant difference was noted between groups (t = 4.087, $p < 0.001$). The RMS values of the BBR group were significantly greater than those of the STR group, which were 0.59 ±0.15 mm and 0.54 ±0.17 mm, respectively (t = 2.902, $p = 0.008$). For the mandibular first molar crown, the mean 3D deviations of the BBR and STR groups were 0.19 ±0.04 mm and 0.14 ±0.06 mm, respectively, and the RMS values were 0.22 ±0.03 mm and 0.18 ±0.04 mm, respectively. The values of the BBR

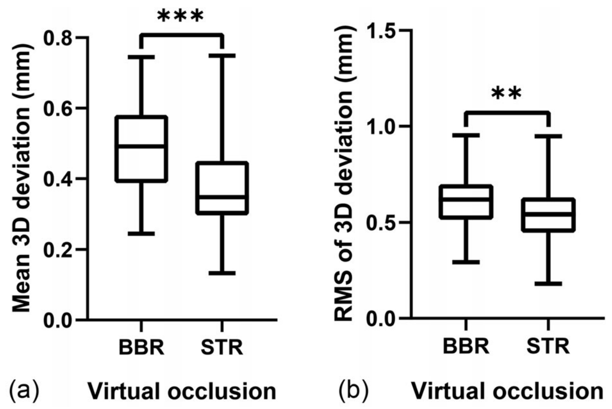

FIGURE 4 Occlusal distance of the two groups. (a) Mean 3D deviation. (b) RMS of 3D deviation. BBR, buccal bite registration; STR, segmented tooth registration; **: $p < 0.01$; ***: $p < 0.001$.

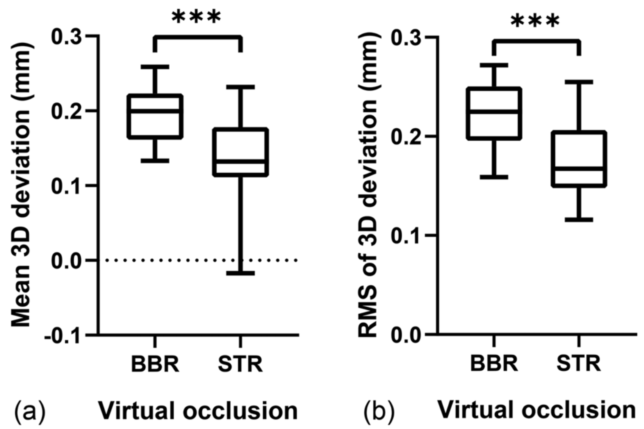

FIGURE 5 Three-dimensional deviation of mandibular first molar crowns adjusted by 2 intercuspal occlusions. (a) Mean 3D deviation. (b) RMS of 3D deviation. BBR, buccal bite registration; STR, segmented tooth registration; **: $p < 0.01$; ***: $p < 0.001$.

group were greater than those of the STR group (t = 4.354, $p < 0.001$ and t = 5.390, $p < 0.001$).

DISCUSSION

The the null hypothesis was rejected and results showed that the occlusal surfaces adjusted by the intercuspal occlusion constructed by the segmented tooth registration method were more coincident with the morphology of the occlusal wear facets on the original teeth.

In the present study, the IOS Trios 4 was used to scan the surface and buccal bite data of posterior teeth. The IOS Trios system works according to the principles of confocal microscopy and the projection of structured light (Ultrafast Optical Sectioning), capturing thousands of pictures.[27,28] The focal plane position is continuously varied in a periodic fashion with a predefined frequency without moving the scanner in relation to the object being scanned. Multiple scan images are obtained and stitched together to create a 3D digital cast using the software program.[29] Generally, the number of images increases as the scanning range increases. Cumulative errors in the stitching process with overlapping pictures result in decreased accuracy.[30,31] The accuracy of the full-arch scan by the IOSs was reported to be inferior to that of conventional impression making.[32–34] Therefore, only unilateral posterior teeth were scanned to ensure scanning accuracy.

The deviations of teeth position induced by tooth displacement and mandible deformation were eliminated by aligning single teeth to buccal bite data. The occlusal distance of the STR group was less than that of the BBR group. The STR group simulated the process in which the occlusal contact became tighter when the opposing teeth bite in ICO with bite force. The results showed that the crowns designed using the newly constructed occlusion were more similar to the original wear facets than those designed using conventional virtual occlusion. This finding may indicate that there were fewer occlusal interferences; therefore, fewer occlusal adjustments were needed. It can be deduced that the occlusion constructed using the STR method was more coincident with the actual intraoral occlusion.

The difference in accuracy between the STR and BBR methods was approximately 0.1 mm. Given that the accuracy of fabrication of a crown is approximately 30 to 50 µm, the difference of 0.1 mm (100 µm) is of clinical significance. Moreover, a greater difference for loosened teeth can be expected, which may have compromised periodontal conditions because obvious displacement will occur under bite force for these teeth. The investigation of teeth under different periodontal conditions represents an area of future research.

Maxillary and mandibular dentitions with intact surfaces were selected to perform the study. During the process of constructing a virtual ICO using the STR method, the intact mandibular first molars were taken as targets and moved to new positions. The transformation matrix of the target acted on the preparation and digital wax pattern to ensure that the 3 objects moved to the same position. In the clinic, the tooth to be restored is always not intact. To obtain the buccal surface of the tooth under bite force, the provisional crown should be adjusted or the defect tooth should be restored to ensure that the occlusal contacts of their surfaces are suitable and equally distributed. The dentition with an adjusted provisional crown or restored tooth should be scanned as well as the opposing dentition and the buccal surfaces under bite force. The restored dentition should be used to construct a virtual ICO using the STR method to reproduce the accurate position of the preparation. The presence and tightness of adjacent contacts influence tooth displacement and the occlusal records. The tooth displacement, including the preparation displacement after wearing the crown, can be taken into consideration using the mentioned method. Combining the library of the CAD software program, crowns with satisfactory surfaces can be designed to realize the unity of function and aesthetics.

For the reconstruction of wear facets, the occlusal surfaces were adapted to antagonists automatically based on the virtual occlusion under ICO without consideration of eccentric movements. In this study, several no-contact facets existed in ICO, suggesting that wear facets may form during eccentric movements. A virtual articulator function should be used in our further research to adjust the facets under eccentric movements. However, the methods in this study were clinically significant because the contact in ICO can simulate the contact under a hinge articulator, which is capable of single-crown restorations.

The morphology of the occlusal surface, occlusal contacts, proximal contacts, and marginal fitness are all responsible for the outcome of prostheses. The position, area, and tightness of proximal contact are closely related to the success of prostheses. In the present study, intact teeth were selected as targets, and only the morphology of occlusal wear facets was analyzed. In future studies, the technique to construct intercuspal occlusion by the segmented tooth registration method should be applied to clinical practice. The fitness of occlusal and proximal contacts should be analyzed.

CONCLUSIONS

Taking tooth displacement into consideration, the occlusal distance of intercuspal occlusion constructed using the segmented tooth registration method is tighter than that constructed using the buccal bite registration method. The morphology of occlusal wear facets of mandibular first molar crowns adjusted via the STR method is more coincident with the original morphology than that using the BBR method.

CONFLICT OF INTEREST

The authors do not have any conflicts of interest in regard to the current study.

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