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The Effect of Residual Dentition on the Dynamic Adjustment of Wear Facet Morphology on a Mandibular First Molar Crown

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Keywords
Virtual articulator; wear facet; residual dentition; mandibular movement; average-value articulator.

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Abstract

Purpose: To evaluate the effect of different residual dentitions on the dynamic adjustment of wear facet morphology on a single mandibular first molar crown with a virtual articulator.
Materials and Methods: Gypsum casts (N = 12) of natural full dentitions were mounted on an articulator and scanned. The mandibular right first molar (#46) was prepared and a copy of the tooth before it was prepared and used to design the crown. The wear facets on the original #46 were selected and elevated by 0.3 mm in the occlusal direction to generate high points. The #46 with high points was segmented to create a digital wax pattern. Then different teeth were virtually removed to generate 4 types of residual dentitions: Type I (no teeth), Type II (adjacent teeth), Type III (ipsilateral posterior teeth and canine), and Type IV (all teeth). The crowns were adjusted dynamically with different residual teeth to guide mandibular movement of the virtual articulator. Three-dimensional deviations, negative and positive volumes between crowns and wear facets on the original #46 were analyzed. The Kruskal-Wallis test was used to analyze the results.
Results: The mean deviation values and positive volumes decreased with the decrease in residual teeth, and the negative volumes showed an opposite trend. The mean deviation values, root mean square, and positive volumes were not significantly different. The negative volume of the crowns of Type I was different from that of Type IV ($p = 0.031$).
Conclusions: Residual dentition affects the dynamic adjustment of wear facet morphology. When there are insufficient residual teeth, mandibular movements should be accurately measured.

Ideal individual restoration morphology is difficult to design because it requires optimal contact in maximum intercuspation and no interference in dynamic occlusion.[1–5] Wear facets are any wear lines or planes on tooth surface caused by attrition or abrasion,[6] characterized by smooth, polished, and usually well-delineated surfaces.[7,8] The wear facets guide gliding between antagonists,[9] and it is important to restore the wear facets of defected teeth.[10]

With the advancement of digital technology, virtual articulators are increasingly used in the design of restorations. Virtual articulators may be more advantageous because they can achieve greater accuracy and precision[11–13] and visualize dynamic contacts.[14] Thus, virtual articulators are able to design restorations dynamically by moving digital occlusal surfaces against each other. Virtual articulators also allow the study of mandibular movements at specific times.[15] Virtual articulators are divided into mathematically simulated virtual articulators based on existing mechanical articulators and articulators designed to reproduce the exact movement paths of the mandible.[16–19] The mathematically simulated virtual articulator was introduced by András Szentpétery, [20] and most dental computer-aided design-computer-aided manufacturing (CAD/CAM) systems are equipped with this. Many practitioners have attempted to acquire custom values of mandibular movement using electronic jaw movement registration system, and several methods have been used to directly align casts to virtual articulators.[21–28] However, registration systems are expensive and sophisticated. For their limited accuracy, none of these methods for virtual mounting has been validated for use in prosthodontics.

The computer-generated mandibular path driven by a mathematically simulated virtual articulator is restricted by the articulator settings and teeth morphology. Therefore, the articulator values and morphology of resident reference teeth are determinants in the occlusal surface design of restorations. The influence of articulator settings on occlusal design has been previously investigated. Olthoff et al[29] investigated the effect of virtual articulator settings on the occlusal morphology of the mandibular right first molar (#46) and found that high and low setting values required considerable adaptation to prevent occlusal interferences. Oancea et al[30] concluded that sagittal condylar inclination mostly influenced the teeth morphology, but canine and molar morphologies were strongly influenced by Bennett angle and immediate lateral translation. However, the influence of residual reference teeth on occlusal design has not been studied.

This study aimed to analyze the effect of residual reference teeth on the dynamic adjustment of wear facet morphology on the #46 crown, with the aid of a virtual articulator with default articulator settings. The null hypothesis was that there were no significant differences in occlusal wear facet morphologies of crowns adjusted with different residual reference teeth.

Materials and methods

This research has been approved by the Bioethics Committee of Peking University School and the Hospital of Stomatology, P. R. China (No.PKUSSIRB-201951170). Written informed consent was obtained from all participants. Sample size calculation was based on the mean three-dimensional (3D) deviation values, using 1-way analysis of variance (ANOVA). The calculated sample size was 11, based on a significance level of .05 and power of 80%.

Twelve participants (9 women and 3 men) were included. The average age was 25.6 years (range from 23 to 28 years). The inclusion criteria were complete permanent dentition with an intact occlusal surface; absence of carious lesions, restorations, or other defects of tooth hard substances; and absence of signs of temporomandibular dysfunction. Participants with signs of malocclusion were excluded from the study.

Impressions of the mandibular jaws of the participants were made using polyether impression material (Impregum Penta; 3M ESPE Dental Products, St. Paul, MN). Irreversible hydrocolloid impression material (Heraeus Kulzer GmbH, Hanau, Germany) was used for opposing impressions. The impressions were poured on the same day with type V dental stone (PEMACO, Inc., Louis, USA). After 24 hours, the gypsum casts in the maximum intercuspal position (MIP) were mounted on an average-value articulator (Artex, AmmanGirrbach, Co, Ltd., Pforzheim, Germany) with zero-expansion articulator stone (ZERO arti, Dentona AG, Dortmund, Germany) and without the facebow. The Smart Optics 880 Dental Scanner (Smart Optics Sensortechnik GmbH, Bochum, Germany) was used to scan the surface of casts, and the buccal images of the casts in MIP fixed by the transfer device. The digital casts and buccal bite data were saved in standard tessellation language format (STL) as the original data after the registration process. The single crown preparation of the #46 was prepared, with minimal occlusal removal of the tooth substance of 1.5 mm and circular 1 mm. Then, the prepared mandibular casts were scanned and saved. The digital data were imported into the Geomagic Studio 2013 software program (3D Systems Inc., Rock Hill, SC). The digital mandibular casts with preparation were aligned to the original mandibular casts and set as the test casts. The test casts with all residual reference teeth were set as type I. Two adjacent teeth second molar and second premolar (type II), ipsilateral second molar, premolars, and canine (type III) and all mandibular teeth except the preparation (type IV) were virtually removed separately. The details are shown in Figure 1. The corresponding mandibular casts were stored after virtually removing teeth.

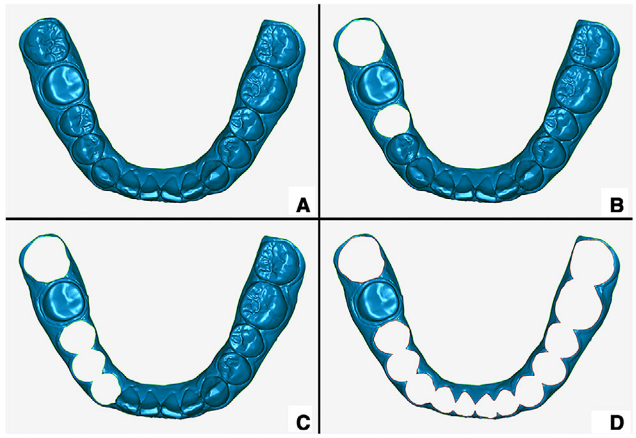

Figure 1 Different set of mandibular reference teeth. A, type I. B, type II, right second molar and premolar removed virtually. C, type III, right second molar, premolars and canine removed virtually. D, type IV, all teeth apart from target tooth removed virtually.

Wear facets on the #46 were manually marked by drawing curves. The mandibular casts with wear facet boundaries were duplicated. The "Sculpt Knife" command was used to form high points on the wear facets by elevating facets by 0.3 mm in the occlusal direction and manually modifying the sharp areas. The #46 with high points were segmented and saved as digital wax patterns (Fig. 2).

The design and adjustment of the crowns were performed by using the Exocad software program (Align Technology, Inc., Redwood City, CA). Digital mandibular casts with preparation and different reference teeth, maxillary casts, and wax patterns were imported into the software program. The source morphology of the wax patterns was from the origin #46 after elevating the occlusal wear facets by 0.3 mm. The maxillary casts were mounted on the virtual articulator (Virtual Artex CR) by determining three points, mesial buccal cusp tips of the maxillary first molars, and maxillary central incisal point (Fig. 3). The following settings of the virtual articulator were set: Bennett angle = 10°, sagittal condylar inclination = 30°, immediate side shift = 0.5 mm, and height of incisal guide pin = 0

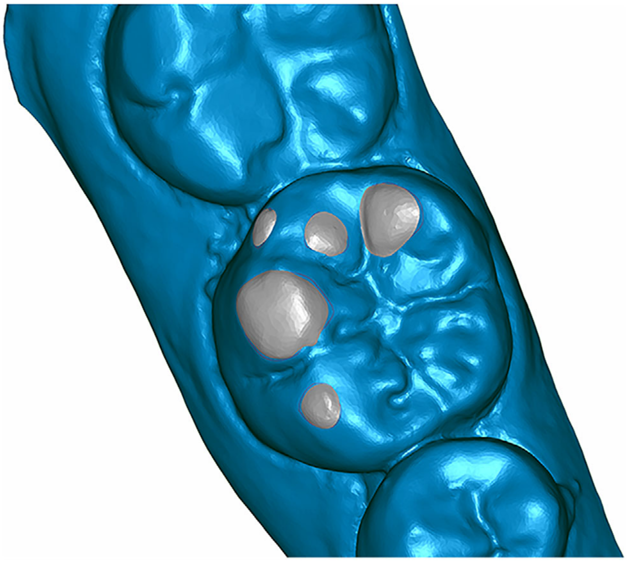

Figure 2 Digital wax pattern for single crown. Gray areas indicating the high points.

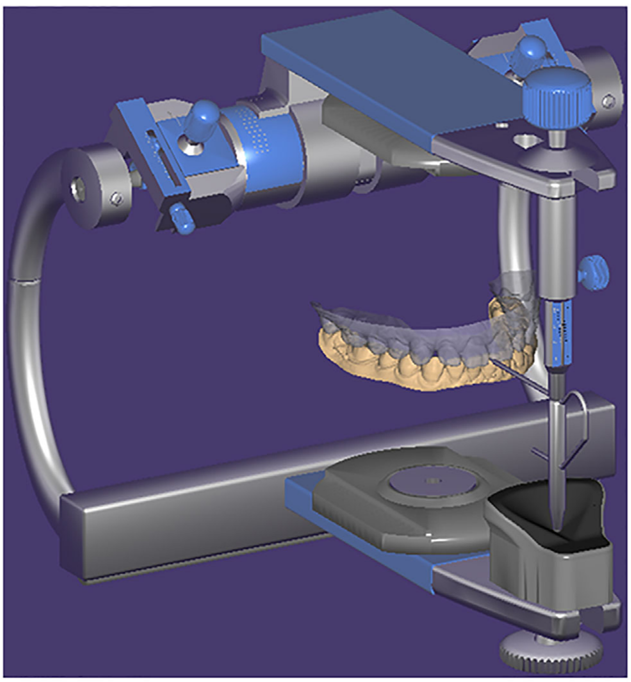

Figure 3 Digital casts mounted on virtual articulator.

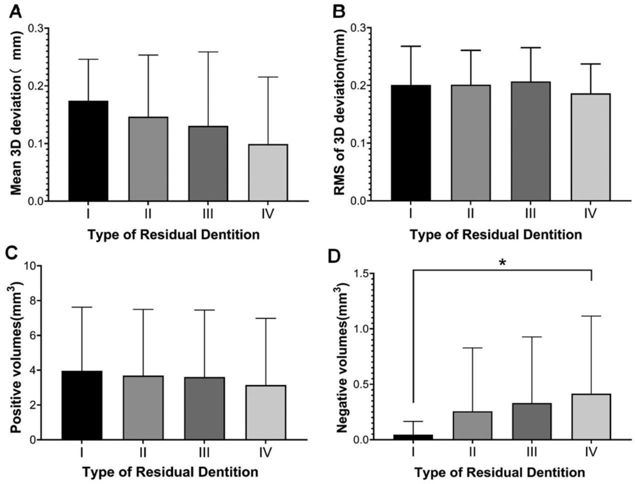

Figure 4 Results of 3D deviations and volumes. A, mean deviation values. B, root mean square of 3D deviations. C, volumes in the occlusal direction of the wear facets on the original mandibular right first molar. D, volumes in the gingival direction of the wear facets on the original mandibular right first molar.

mm. Crowns were designed by adapting digital wax patterns. Dynamic virtual laterotrusive and protrusive movements were used to sculpt the design, and a file of the design was saved.

Restored crowns were imported into Geomagic software program. The wear facets on the original #46 were set as the reference objects and the crowns designed by different residual reference teeth were set as the test objects. The 3D deviation analysis between reference and test objects was conducted. The mean value and root mean square (RMS) estimate of 3D deviation were recorded. The mean value indicates the superiority of positive and negative errors.[31] RMS can serve as a measure of how far deviations between 2 different datasets vary from zero. Low RMS scores indicate high 3D congruency of 2 superimposed digital data.[32]

The “Boolean Subtraction” tool was used to determine areas of crowns located in the gingival and occlusal directions of the wear facets on the original #46. The volume in the gingival direction of the original occlusal surface was defined as V- and that in the occlusal direction as V+. The effect of different residual reference teeth on the dynamic adjustment of wear facets morphology on the #46 crown was analyzed by using SPSS 19.0 statistical software program (IBM Inc., Armonk, NY). Normal distribution and equality of variance were tested by using the Shapiro-Wilk and Levene tests. The Kruskal-Wallis test was used, and simple effects were analyzed by pairwise comparisons adjusted by the Bonferroni’s method for non-normally distributed data ($\alpha = 0.05$).

Results

In this study, the occlusal wear facets of crowns were dynamically adjusted by a virtual articulator with default settings. The detailed results of 3D deviations and volumes between crowns and the occlusal wear facets on original #46 are shown in Figure 4, Table 1, and Table 2. The highest mean deviation value (0.17 ± 0.07 mm) and V+ (3.96 ± 3.66 mm^3) were noted in the crown of type I, and the lowest mean value (0.10 ± 0.12 mm) and V+ (3.15 ± 3.83 mm^3) in type IV. The mean deviation values and V+ decreased with the decrease in the reference teeth. However, V- showed an opposite trend. The highest V- (0.42 ± 0.70 mm^3) were noted in the crown of type IV, and the lowest V- (0.05 ± 0.12 mm^3) in type I. There was less difference in the RMS values (ranged from 0.19 ± 0.05 mm to 0.21 ± 0.06 mm). The data were not normally distributed with homogeneous variance, so the Kruskal-Wallis test

Table 1 3D deviations and volumes between crowns and occlusal wear facets on the original mandibular right first molar (mean ± standard deviation, N = 12)

Type	Mean deviation values (mm)	RMS(mm)	V+(mm^3)	V-(mm^3)
I	0.17 ± 0.07	0.20 ± 0.07	3.96 ± 3.66	0.05 ± 0.12
II	0.15 ± 0.11	0.20 ± 0.06	3.69 ± 3.80	0.26 ± 0.57
III	0.13 ± 0.13	0.21 ± 0.06	3.61 ± 3.85	0.33 ± 0.60
IV	0.10 ± 0.12	0.19 ± 0.05	3.15 ± 3.83	0.42 ± 0.70
p^a	0.318	0.787	0.583	0.020*

I-IV, type I-IV crowns designed dynamically with different residual reference teeth; RMS, root mean square; V+, the volume in the occlusal direction of the wear facets on the original mandibular right first molar ; V-, the volume in the gingival direction of the wear facets on the original mandibular right first molar.
[a]Kruskal-Wallis test.
*Mean difference significant ($p < 0.05$).

Table 2 Pairwise comparisons of V- differences among types of reference teeth

Sample 1	Sample 2	Test statistic	Std. error	p^a
I	II	−4.542	5.644	1.000
	III	−8.792	5.644	0.716
	IV	−17.000	5.644	0.016*
II	III	−4.250	5.644	1.000
	IV	−12.458	5.644	0.164
III	IV	−8.208	5.644	0.875

I-IV, type I-IV crowns designed dynamically with different residual reference teeth; Std. Error, standard error.
[a]Adjustment for pairwise comparisons: Bonferroni's method.
*Mean difference significant ($p < 0.05$).

was used. The V- values had significant difference ($p = 0.020$) and further pairwise comparison showed that the V- value of the crown of type IV was higher than that of type I with significant difference ($p = 0.031$). The mean deviation values, RMS, and V+ had no statistically significant difference.

Discussion

The results partially reject the null hypothesis. The crowns without reference teeth have more negative volumes than those with all reference teeth.

There is an ongoing debate on how much individual registration is actually needed to maintain occlusal interference within acceptable tolerance limits.[33] Mehl et al[4,34,35] concluded that the use of individual settings on a semi-adjustable articulator and the additional use of a facebow do not provide any significant advantages over the use of average-value settings, in situations where the remaining teeth are in good condition and only single-tooth restorations or small bridges are to be fabricated. In the clinical practice of CAD/CAM dental restoration design, digital casts are frequently mounted on the virtual articulator with the manufacturer's recommendation to simulate a routine virtual mounting practice for an average patient, followed by default articulator values to simulate mandibular movement. Therefore, in this study, the articulator parameters were set as default values to simulate average virtual patients, and the influence of different reference teeth was analyzed.

The results showed that there were negative volumes in some crowns, and with the decrease in the number of reference teeth, the negative volumes showed an increasing trend. This indicates that average-value articulation cannot represent individual mandibular movement when there are insufficient residual reference teeth to constrain the path. The casts need to be mounted using more information from the patient, and mandibular movement information needs to be collected to program the virtual articulator if there are insufficient residual reference teeth.

In contrast to the previous literature, only the occlusal wear facet morphology in relation to the facets on original #46 was analyzed, not the entire occlusal surface. The facets result from actual jaw movements and resistance of the antagonists.[9] The procedure of teeth wear can adjust the crown-root ratio, reduce the burden of periodontal tissue, avoid occlusal trauma, and form a more stable intercuspal occlusion. The first molar, as the key to occlusion, is the main undertaker to the occlusal force in masticatory movement. Therefore, in this study, the occlusal wear facets of the #46 were selected as the interesting areas. To the best of our knowledge, this is the first study that quantitatively addresses the effect of different reference teeth on the dynamic adjustment of occlusal wear facet morphology.

The limitation was that all occlusal wear facets of the #46 were selected as the reference. The number, size, and shape of teeth occlusal wear facets vary dynamically over time. Therefore, not all wear facets are in contact during current oral function. Further investigations should select the intraoral contact areas as the reference to avoid the influence of wear facets having no contact with the antagonist. With the improvement of scanning accuracy and the application of color intraoral scanners, 3D morphology of the tooth, along with a photorealistic copy of the intraoral contact areas marked by articulating paper may be obtained simultaneously. Another limitation was that any mandibular movement information was not collected to program the virtual articulator. If there is electronic jaw movement registration system, another group of crowns should be designed with custom articulating settings and compared with the present 4 groups. The maxilla-mandibular relationship was determined by the original casts with complete dentition. But, for type IV, the occlusion need to be constructed by wax dam and then transferred to virtual environment in clinic, and the occlusion may be different from that determined in this study. Further clinical study should be carried out to verify the clinical difference of this study.

Conclusions

Residual reference teeth affect the dynamic adjustment of wear facet morphology; with a decrease in reference teeth, it is more likely to result in non-contacting areas of crowns. Determinants of mandibular movements should be accurately measured and transferred to the articulator in the process of restoration if there are insufficient reference teeth to constrict mandibular movement.

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