Evaluation of biogeneric design techniques with CEREC CAD/CAM system

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PURPOSE. The aim of this study was to evaluate occlusal contacts generated by 3 different biogeneric design modes (individual (BI), copy (BC), reference (BR)) of CEREC software and to assess the designs subjectively. **MATERIALS AND METHODS.** Ten pairs of maxillary and mandibular casts were obtained from full dentate individuals. Gypsum cast contacts were quantified with articulating paper and digital impressions were taken. Then, all ceramic crown preparation was performed on the left first molar teeth and digital impressions of prepared teeth were made. BI, BC, and BR crowns were designed. Occlusal images of designs including occlusal contacts were superimposed on the gypsum cast images and corresponding contacts were determined. Three designs were evaluated by the students. **RESULTS.** The results of the study revealed that there was significant difference among the number of contacts of gypsum cast and digital models ($P<.05$). The comparison of the percentage of virtual contacts of three crown designs which were identical to the contacts of original gypsum cast revealed that BI and BR designs showed significantly higher percentages of identical contacts compared with BC design ($P<.05$). Subjective assessment revealed that students generally found BI designs and BR designs natural regarding naturalness of fissure morphology and cusp shape and cusp tip position. For general occlusal morphology, student groups generally found BI design "too strong" or "perfect", BC design "too weak", and BR design "perfect". **CONCLUSION.** On a prepared tooth, three different biogeneric design modes of a CAD/CAM software reveals different crown designs regarding occlusal contacts and morphology. ***[J Adv Prosthodont 2015;7:431-6]***

KEY WORDS: Crowns; Dental prosthesis design; Dental occlusion

INTRODUCTION

When restoring the occlusal surfaces of the posterior teeth, the common consensus include that the occlusal design of restorations should stay in harmonic relation to adjacent teeth, interference-free functioning occlusal contacts should be established, and natural looking morphology of the occclusal surface with functional fissures and cusps should be provided.[1-3] In fabrication of conventional cast or ceramic restorations, the accomplishment of these goals are expected from dental technician whereas occlusal design of computer-aided designed and computer-aided manufactured (CAD/CAM) restorations are generated by CAD software systems.[1,2]

At the beginning of development of CAD/CAM systems, the software was based on designing a standard morphology, which needed individual adaptation.[4-7] Then software systems were developed using algorithms to adjust the occlusal surface to the bite registrations.[8,9] The most recent way to generate tooth morphology in CAD/CAM is the "biogeneric tooth model".[1,2] This model is based on 3D data library of hundreds of scans of intact posterior human teeth.[3] The biogeneric tooth model was first used to mathematically construct a missing surface of a tooth by analyzing remaining tooth substance for production of partial crowns, and inlays. The software developments led to reconstruct complete occlusal surface for crown restora-

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tions. In this case, the data for biogeneric reconstruction are gathered from the distal adjacent, antagonist, or contralateral teeth.[2] While the efficiency of biogeneric tooth model in generating CAD/CAM partial crowns with natural tooth morphology has been shown by previous studies[1,3] limited knowledge still exists on the design and occlusal contacts of biogeneric mode even when the whole occlusal surface has been lost.

In restorative dentistry, understanding the nature of occlusal contacts of the natural dentition and reproducing the contacts on the restoration is important for durability of teeth as well for stabilization of mandible.[10,11] From the clinical point of view, the goal is achieving a restoration which is optimally integrated into the stomatognathic system, biologically compatible, esthetically pleasant, and requiring reduced time expenditure in insertion of the restoration without clinical adjustments. Therefore, designing a restoration with natural occlusal morphology as well as accurately reproducing clinical contacts is expected from CAD/CAM software.

The aim of this study was to evaluate the accuracy of digital occlusal contacts virtually generated by 3 different biogeneric design modes - biogeneric individual (BI), biogeneric copy (BC), biogeneric reference (BR) - of Cerec (Cerec, Sirona Dental Systems, Bensheim, Germany) CAD/CAM system and to subjectively assess their efficiency in designing natural morphology of a crown.

MATERIALS AND METHODS

Ten pairs of maxillary and mandibular stone casts (Die Keen, HeraeusKulzer, Armonk, NY, USA) with full dentition, representing clinically stable interocclusal relationships, no prosthetic or orthodontic appliances and minimal or no occlusal wear were obtained from subjects ranging in age from 18 to 29. All participants agreed to participate in the study by written informed consent. The study was approved by the Ethics Committee of the University of Ankara. The casts were mounted in semi-adjustable articulators (Stratos 100, IvoclarVivadent, Schaan, Liechtenstein) in maximum intercuspal position to serve as patient simulation models. One articulator was provided for each pair of casts and the casts were not removed during the study.

Identification of occlusal contacts of casts in maximum intercuspal position was performed with 8 μm articulating paper (Arti-Fol BK 25 Red, Dr. Jean Baush, Cologne, Germany). All ceramic crown preparation was performed on the left mandibular first molar tooth of each casts. All teeth were prepared with an occlusal reduction of 2 mm, an axial reduction of 1 mm, and a finish line located below the supragingival field. Three digital impressions were taken from each cast using an intraoral scanner (CEREC Omnicam, Sirona Dental Systems, Bensheim, Germany). First digital impressions were taken from left one-half the mandibular casts to obtain unprepared tooth morphology and original occlusal contacts of the left first molar teeth. Screenshot images of the virtual casts with the indicated occlusal contacts were saved as JPEG files. Second digital impressions were taken from left one-half the mandibular and maxillary casts, and buccal bite image was taken covering the second premolars and first molars when the articulator was closed into maximum intercuspal position. Virtual 3D models of each cast pair were generated by the CAD software (inLab SW 4.2, Sirona Dental Systems, Bensheim, Germany) on the computer screen. Using the buccal image, the software calculated maximum intercuspal position. The virtual contacts calculated by the software were visualized on the screen. Screenshot images of the virtual casts with the virtual occlusal contacts were saved as JPEG files.

Third digital impressions were taken from left one-half the mandibular casts including prepared first molar, left one-half the maxillary casts, and buccal side of the casts when they were set into maximum intercuspal position. After virtual 3D models of each cast pair were generated by the CAD software, their maximum intercuspal position were calculated using buccal images, the model axis were set, and restoration margins were determined. For each virtual model, three crowns were designed using biogeneric individual (BI), biogeneric copy (BC), biogeneric reference (BR) design modes of the software. Manual adjustments were not made on the designs which were suggested by the software. Screenshot images of the virtual casts with the virtual occlusal contacts were saved as JPEG files. Also, screenshot images of the virtual casts without the virtual occlusal contacts were saved as JPEG files.

In order to analyze the congruence of the indicated contacts of the gypsum casts with the virtual occlusal contacts of the virtual casts aligned into maximum intercuspal position by the CAD software before tooth preparation, the screenshot images of the virtual casts were superimposed onto the screenshot images of the casts with the indicated occlusal contacts in a transparent manner using the an image processing program (Adobe Photoshop CS4, Adobe systems, San Cos, CA, USA) as described previously.[12] The number of the contacts of the virtual mandibular first molar that were identical with the contacts of the gypsum casts was determined. Also, in order to analyze the congruence of virtual occlusal contacts of the designed crowns using BI, BR, and BC design modes with the contacts of unprepared tooth, the screenshot images of the virtual crown was superimposed onto the screenshot images of the virtual casts with the indicated occlusal contacts. The number of the contacts of the designed mandibular first molar crowns that were identical with the contacts of the gypsum casts was determined and calculated as percentages in relation to the gypsum cast contacts to analyze the congruence.

After obtaining the screenshot images of the designed crowns with occlusal contacts, the occlusal contacts were made imperceptible using "display object" tool of the software and screenshot images were saved as JPEG files. Three designs of each prepared tooth were displayed on the screen. To assess naturalness of the morphology, three designs were evaluated by visual judgment in a double-blind

test. For this purpose, three crown designs were displayed in one monitor adjacently (A, B, and C) (Fig. 1). Each crown design was presented with all three designs. No exterior clue was given with respect to the type of design as seen in Fig. 1. Twenty one postgraduate students and 50 final year undergraduate students of dental school compared the naturalness of the morphology of each restoration by answering the questionnaire shown in Fig. 2.

Spearman rank correlation coefficient were estimated to determine the relationship between number of occlusal contacts identified on original gypsum cast and occlusal contacts of virtual models for the left mandibular first molar tooth.

Repeated measurements of Analysis of Variance (ANOVA) test was used to compare the number of virtual contacts of BI, BR, and BC crowns which were identical to the contacts of original gypsum cast. Duncan multiple range test was used to determine any significant differences among the groups. *P* values less than 0.05 were considered to be statistically significant in all tests.

The frequency distribution of the responses to the questionnaires for naturalness of fissure morphology, cusp shape and cusp tip position, and overall occlusal morphology was calculated. For all statistical tests, SPSS Statistics for Windows Version 19.0 (IBM Corp., Armonk, NY, USA) was used.

RESULTS

There was a significant difference between the number of occlusal contacts identified on original gypsum cast and occlusal contacts of virtual models of the left mandibular first molar tooth ($P < 0.05$). The occlusal contacts of virtual models which were determined by CAD software showed %66 similarities with the contacts of original gypsum casts before tooth preparation.

The comparison of the percentage of virtual contacts of three crown designs performed by means of BI, BR, and BC design modes which were identical to the contacts of original gypsum cast revealed that BC group showed statistically significantly lower percentage of identical contacts compared with BI and BR groups ($P < 0.05$). The difference was not significant between BI and BR groups ($P > 0.05$). The mean and standard deviation for each design are shown in Table 1.

Table 2 and Table 3 present the results of the visual

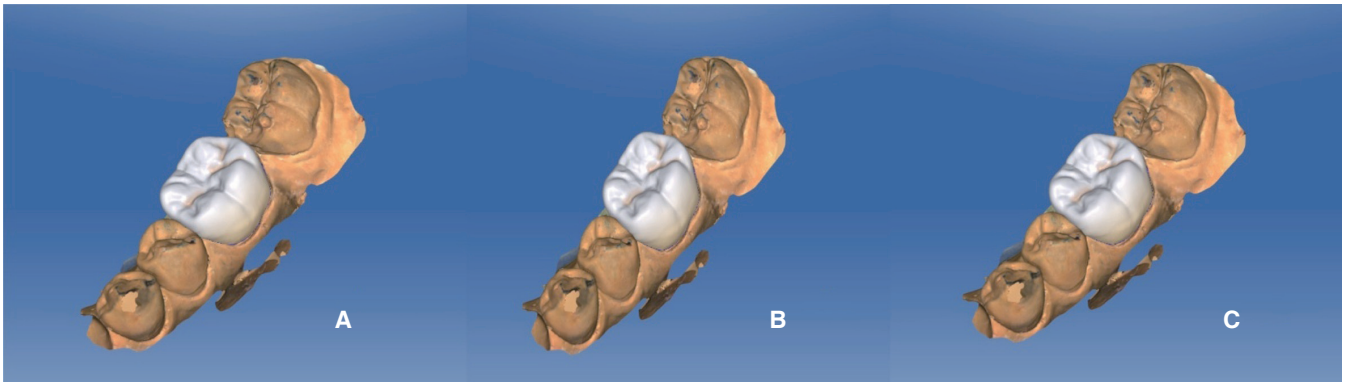

Fig. 1. Crown designs for each design mode. (A) Biogeneric individual (BI), (B) Biogeneric copy (BC), (C) Biogeneric reference (BR).

Model No	Question		A	B	C
	1. Which design offers the more natural fissure morphology?				
	2. Which design shows the more natural cusp shape and cusp tip position?				
	3. How do you asses each design's occlusal morphology?				
		Too strong			
		Too weak			
		Perfect			

Fig. 2. Questionnaire to assess the naturalness of occlusal morphology of the restoration designs.

assessment of morphology of three crown designs by postgraduate and undergraduate students. In terms of naturalness of fissure morphology, postgraduate students generally found BI designs the most natural design and followed by BR designs, while undergraduate students generally indicated BR design as the most natural followed by BI design (Table 2). Fissure morphology of BC design was not found natural both student groups.

For the question regarding naturalness of cusp shape and cusp tip position, postgraduate students found both BI and BR designs natural. Undergraduate students also reported similar results for naturalness of cusp shape and cusp tip position. BC design was not found natural by both student groups.

Table 1. The mean and standard deviation for each design of percent similarity with original cast

Design	N	Mean ± SD
BI	10	0.55 ± 0.26^{A}
BC	10	0.14 ± 0.21^{B}
BR	10	0.54 ± 0.22^{A}

Different capital letters indicate significant differences (P<.05).

The results of assessment of occlusal morphology are shown in Table 3. Postgraduate students generally found BI design "too strong" or "perfect", BC design "too weak", and BR design "perfect". Most of undergraduate students found BI design "too strong", BC design "too weak", and BR design "perfect".

DISCUSSION

An essential step in CAD/CAM fabrication of posterior full crowns is occlusal design including harmonious contacts with natural dentition and natural looking morphology. Designing such a crown in a short time is also important in a chairside treatment approach.[13] Therefore, this study evaluated occlusal contacts and naturalness and morphology of crown designs made by CAD software before any manual modification.

In the present study the number of occlusal contacts identified on original gypsum cast and occlusal contacts of virtual models of the left mandibular first molar tooth were compared to find out the ability of the software to align virtual casts into maximum intercuspal position. The occlusal contacts of virtual models showed 66% similarities with the contacts of original gypsum casts before tooth preparation. This finding suggests that algorithms for matching virtual models into maximum intercuspal position might be

Table 2. The results of the naturalness of fissure morphology and cusp shape and cusp tip position

Design	Question 1 (Naturalness of fissure morphology)			Question 2 (Naturalness of cusp shape and cusp tip position)		
	Postgraduate students (%)	Undergraduate students (%)	Total (%)	Postgraduate students (%)	Undergraduate students (%)	Total (%)
BI	0.0 - 81.0	10.0 - 66.0	7.0 - 70.4	0.0 - 81.0	16.0 - 66.0	11.3 - 70.4
BC	0.0 - 52.4	0.0 - 28.0	0.0 - 35.2	0.0 - 38.1	2.0 - 28.0	1.4 - 26.8
BR	14.3 - 90.5	28.0 - 78.0	25.4 - 81.7	19.0 - 81.0	26.0 - 76.0	25.4 - 76.1

Table 3. The results of assessment of occlusal morphology

Design		Question 3 (Assessment of occlusal morphology)		
		Too strong (%)	Too weak (%)	Perfect (%)
BI	Postgraduate students	4.8 - 66.7	0.0 - 81.0	4.8 - 66.7
	Undergraduate students	12.0 - 72.0	6.0 - 70.0	12.0 - 64.0
	Total	9.9 - 69.0	4.2 - 73.2	9.9 - 59.2
BC	Postgraduate students	0.0 - 76.2	9.5 - 100.0	0.0 - 23.8
	Undergraduate students	0.0 - 66.0	24.0 - 96.0	4.0 - 16.0
	Total	0.0 - 67.6	22.5 - 97.2	2.8 - 16.9
BR	Postgraduate students	0.0 - 42.9	4.8 - 66.7	19.0 - 81.0
	Undergraduate students	4.0 - 28.0	10.0 - 44.0	30.0 - 86.0
	Total	8.5 - 29.6	8.5 - 49.3	32.4 - 83.1

improved. However, comparing occlusal contacts of original cast and virtual cast was performed on a limited area (mandibular first molar) in this study. Further studies are needed to evaluate virtual casts generated from optical impressions and aligned into maximum intercuspal position by the matching algorithms of software in terms of simulating real contacts. The literature include limited studies on the accuracy of occlusal contacts of virtual models.[12,14,15]

One requirement for using a chair-side CAD/CAM system is fabricating the restoration in a reasonable time. Through the fabrication process, design phase can be time consuming, resulting from the provided standard morphology, which has to be adapted to the individual tooth with manual interactive design tools.[1] The tested CAD software used 3 different modes to design a restoration including BI, BR, and BC modes, each of which uses different data. BI design mode uses the data of distal, mesial and antagonist teeth to restoration to design a crown harmonious with remaining dentition, BR design mode allows the operator to copy the contralateral tooth and creates a mirror image of it on the preparation, permitting symmetrical design through the use of the mirrored twin, and BC design mode provides a design which is the same of unprepared tooth morphology.[16] In the literature, case reports which used these design modes have been published.[17,18] However, no evaluation of the crown designs performed in different ways has yet been reported. Probst and Mehl[19] reported that CAD reconstruction using the morphology of mirrored contralateral tooth is a suitable concept for CAD of anterior restorations. In the present study, three full crown designs offered by different design modes of the software which received no manual modifications were compared in terms of occlusal contacts and naturalness.

Comparison of similarity of occlusal contacts of three design modes with the original contacts revealed that the occlusal contacts of BI and BR designs had higher similarity with original cast contacts than BC design. Similarly, subjective assessment of the designs in terms of naturalness of occlusal morphology revealed BC designs the least favorable. These findings are in contrast to the expectations of the authors, because copying the existing morphology was thought to originally restore the tooth in terms occlusal contacts and morphology. The occlusal contact characteristic of the CAD design might be affected by selected restorative material in the software and occlusal reduction amount during preparation. To provide standardization, 2 mm occlusal reduction was generated in tooth preparation and a standard restorative material was chosen in the CAD software.

The subjective assessment of three different crown designs revealed that "fissure morphology" and "cusp shape and position" generally found more natural for BI and BR designs by both postgraduate and undergraduate students. Although some differences were noted after assessment of occlusal morphology, generally BI design was found "too strong", BC design was found "too weak", and BR design was found "perfect". These results may indicate that education and experience have limited effect on the results of subjective visual ratings of three different crown designs. On the contrary, Litzenburger *et al.*[3] stated that their visual comparison of CAD generated crown designs were dependent upon experience and imagination. The previous studies on evaluation of CAD generated tooth morphology were performed by comparing CAD restorations with conventional restorations waxed up by dental technicians.[1-3] These studies revealed that CAD/CAM systems can effectively produce natural tooth morphology for partial crowns.[1,3] Kollmuss *et al.*[2] evaluated CAD-constructed and waxed-up full occlusal surfaces of partial crowns and they reported that CAD software enables to design an occlusal surface that is closer to original morphology than wax-ups.

The limitations of the present study include that contact point and subjective assessments of naturalness of crown designs were performed on virtual restorations. The milled restorations might represent difference from virtual restorations; therefore further studies are needed on the milled restorations. A further limitation of this study is that proximal, buccal and lingual surfaces were not taken into consideration. An objective measurement of CAD/CAM designed and manufactured restorations to display similarities with original tooth morphology might be evaluated in a further study.

CONCLUSION

Three different biogeneric design modes (Biogeneric individual-BI, Biogeneric copy-BC, Biogeneric reference-BR) of a CAD/CAM software which were done on the same prepared tooth revealed different crown designs regarding occlusal contacts and occlusal morphology. Objective assessment of occlusal contacts revealed that BI and BR designs showed higher percentages of identical virtual contacts with the contacts of the gypsum casts compared with BC design. The subjective assessment of three different crown designs by both postgraduate and undergraduate students revealed that "fissure morphology" and "cusp shape and position" generally found more natural for BI and BR designs and "occlusal morphology" was generally found "too strong" or "perfect" for BI design, "too weak" for BC design, and "perfect" for BR design.

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