A Comparison Between the Occlusal Morphology of Virtually Reconstructed Posterior Crowns and Natural Molars

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This study was performed to evaluate the occlusal morphologic similarities between virtually reconstructed full crowns and original natural teeth. A total of 40 stone cast sets with untreated first molars (22 maxillary and 18 mandibular) were scanned and saved as three-dimensional virtual models. The 40 first molars on the stone casts were prepared for all-ceramic restorations, scanned again, and virtually restored with a full veneer crown using a biogeneric tooth algorithm. For comparison of original and virtually restored teeth, orthographic measurements were performed on the cusp tip configurations from the central pits. The measurements were compared using the concordance correlation coefficient (CCC). For maxillary molars, the ranges of CCC were 0.040 to 0.566 in linear, 0.127 to 0.509 in area, and –0.114 to 0.327 in angular measurements. For mandibular molars, the ranges of CCC were 0.104 to 0.555 in linear, 0.183 to 0.597 in area, and 0.030 to 0.396 in angular measurements. The reproducibility of automatic occlusal construction was relatively low. There is a need for improvement in the biogeneric tooth algorithms to enhance the accuracy of restoring to the original occlusal tooth form in cases of full veneer crown preparation. (Int J Periodontics Restorative Dent 2014;34:e73–e78. doi: 10.11607/prd.1936)

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The primary objective of restorative dentistry in reconstructing occlusion is to improve stomatognathic function.[1] In order to fulfill this purpose, it is widely agreed that the occlusal design of restorations should be harmonious with the remaining dentition and reproduce the natural morphology of the tooth,[2] although there is some controversy regarding occlusion concepts.[3]

In conventional restorative procedures, the design of occlusal morphology usually has been performed through the manual work of humans such as dental technicians. Therefore, it is not surprising that the design of occlusal morphology differs on a case-by-case basis due to the different level of dexterity, experience, condition, and even artistry of each dental technician. Recently, there has been a gradual shift from manual to computerized fabrication of restorations by means of computer-aided design/computer-assisted manufacture (CAD/CAM).[4] One of the many advantages of computerized fabrication is that clinicians can deliver restorations on the spot without delay.[5] However, it is time consuming, cumbersome at some steps,[6] and still requires subjective input from dental technicians during the process. Therefore, studies have been conducted to develop processes that could reduce variations from the human factor. One such attempt, the biogeneric tooth model, has been introduced recently.[7]

This algorithm of the biogeneric tooth model mathematically describes occlusal tooth surfaces while taking their natural variations into consideration.[8] The information is based on a three-dimensional (3D) data library of several hundred scans of the teeth of Western European children with intact natural and caries-free occlusal surfaces.[9] Comparative studies of fully automatic CAD designs generated by biogeneric tooth algorithms with waxed-up design and natural morphology in partial and full occlusal surfaces have been recently reported.[6,10,11] These reports showed promising results and concluded that this system was superior or at least comparable to wax up or conventional interactive software in reproducing occlusal morphology.

To date, many different methods have been described to assess the discrepancies between original tooth morphology and CAD reconstruction, including subjective questionnaires, vertical increases, and professional ratings based on fissure lines and occlusal contact point patterns.[6,12–15] Two of the studies mentioned above[10,11] used mathematic approaches with matching software to superimpose the two data sets with a least square fitting routine. However, it is not clear how well their quantitative assessment reflected the similarity of the 3D morphologic characteristics since there were innate and unresolved difficulties in the comparison of 3D morphology.[16,17]

Another issue concerning the biogeneric tooth algorithms that should be addressed is the fact that the library scans of teeth are from limited ethnic populations. To the best of the authors' knowledge, there has been no report comparing teeth samples from Asian populations. Therefore, the design of biogeneric teeth and their similarity to natural tooth morphology from different ethnic populations has yet to be evaluated.

The present investigation aims to evaluate how much of a discrepancy exists between natural occlusal morphology and its biogeneric reconstruction in Korean adults. Therefore, the null hypothesis of this study is that there is no significant statistical difference between the original occlusal anatomy and its restored version. We anticipate the results of this study may be used to guide further improvement of the biogeneric algorithm in reconstructive dentistry.

Method and materials

Type IV gypsum (Neoprimestone, Mutsumi Chemical Industries) cast sets were prepared following alginate impressions of 100 first-year students at the School of Dentistry, Seoul National University, Korea. From these impressions, any casts with missing teeth other than third molars or more than 3 mm of crowding were excluded from the study. Casts that had any type of restorations or caries defects in the posterior segment, including the second premolar, first molar, and second molar on either the preparation side or antagonist side, were also excluded. Then, a total of 40 cast sets, which all were judged to have clinically stable occlusions, were included in the study. The ages of the participants ranged from 23 to 26 years with a mean age of 24.7 years. All participants provided written informed consent. This study was approved by the institutional review board of the College of Dentistry, Seoul National University.

From the selected cast sets, only one quadrant was randomly selected in this experiment; therefore, a total of 40 first molars (22 from the maxilla and 18 from the mandible) were chosen for preparation. Prior to preparation, the selected quadrants were scanned with a CEREC Bluecam (Sirona) according to the manufacturer's recommended protocol by one of the authors with sufficient experience (W-JS). The scans were performed perpendicular to the occlusal plane. The scanned casts were saved as original casts in 3D for comparison after the preparation. Following this procedure, the selected 40 first molars in the original stone casts were chosen for real preparation. The preparations for all-ceramic full veneer crowns were performed by six dental residents of conservative dentistry who had completed 1 month of training in cavity preparations for CAD/CAM restorations. They were instructed

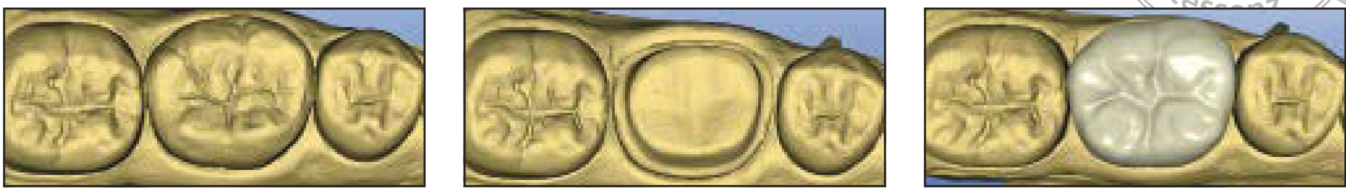

Fig 1 *Comparison of automatic reconstruction of full crown and original tooth.*

to follow the general guidelines for CAD/CAM restoration for the preparations,[18] and all of their preparations were meticulously checked by a single expert clinician (W-JS).

After the preparations, the casts were scanned again in the same manner by the same author (W-JS). At least one adjacent mesial and distal tooth was included in both the prepared and antagonist sides. Bite registrations were made in clinically stable occlusion with both casts. The 3D casts after the preparations were virtually trimmed, and the margins of the dies were automatically determined, followed by detailed manual determination. After checking the proper occlusal thickness, the restorations were constructed using a biogeneric function. Manual adjustments were completed only on the buccal, lingual, and proximal contact surfaces as needed but not on the occlusal surfaces (Fig 1).

All cusp tips and central pits of the occlusal surfaces of the teeth were identified as reference points. Since the software for decrypting the proprietary format into an .stl file format was unavailable, the cursor option of the program was switched on to detect the 3D coordinates of those points. The height value of the cursor windows was converted to pixel values by a conversion factor of 40, which corresponds to the z-coordinate. In order to enhance the reproducibility and reliability of identifying the reference points, one observer was trained for 2 weeks prior to the actual measurements. Measurements of each cast were taken three separate times by a single observer over a 3-week period.

For orthographic measurements, each reference point (five in the maxillary molar and six in the mandibular molar) was redesignated as the foot of the perpendicular onto the occlusal plane, which was made from four cusp tips in maxillary molars and five cusp tips in the mandibular molars using the least-squares algorithm by Matlab v. R2012a (Mathworks). The following measurements were calculated from the coordinates: the distance from the central pit to each cusp tip, the length of the periphery of the polygon created by the cusp tips, the area of the triangle made by the central pit and adjacent cusp tips, and the vertex angle of the triangle formed by the central pit and the adjacent cusp tips, where vertex was the central pit (Fig 2).

To test the reliability of the measurements, 10 3D scans were randomly selected and measured again 2 months after the initial measurement. All the measurements were recorded in an Excel 2010 spreadsheet (Microsoft), and statistical analysis was performed using the language R. To evaluate the level of agreement between the measurements of the original teeth and the reconstructed teeth, the concordance correlation coefficient (CCC) was calculated. In addition, a paired-samples *t* test was performed. Scatterplots and Bland-Altman plots were constructed to compare the two occlusal configurations.

Results

The intraexaminer reliability coefficients ranged from 0.964 to 0.989. In terms of root mean squares, the random errors of estimation were lower than the 0.07 mm in linear measurements. There were no statistically significant differences between the test-retest measurements for any of the variables.

The reproducibility of automatic occlusal construction was relatively low for both the maxillary and mandibular first molars. For maxillary molars, the ranges of CCC were 0.040 to 0.566 in linear measurements, 0.127 to 0.509 in area

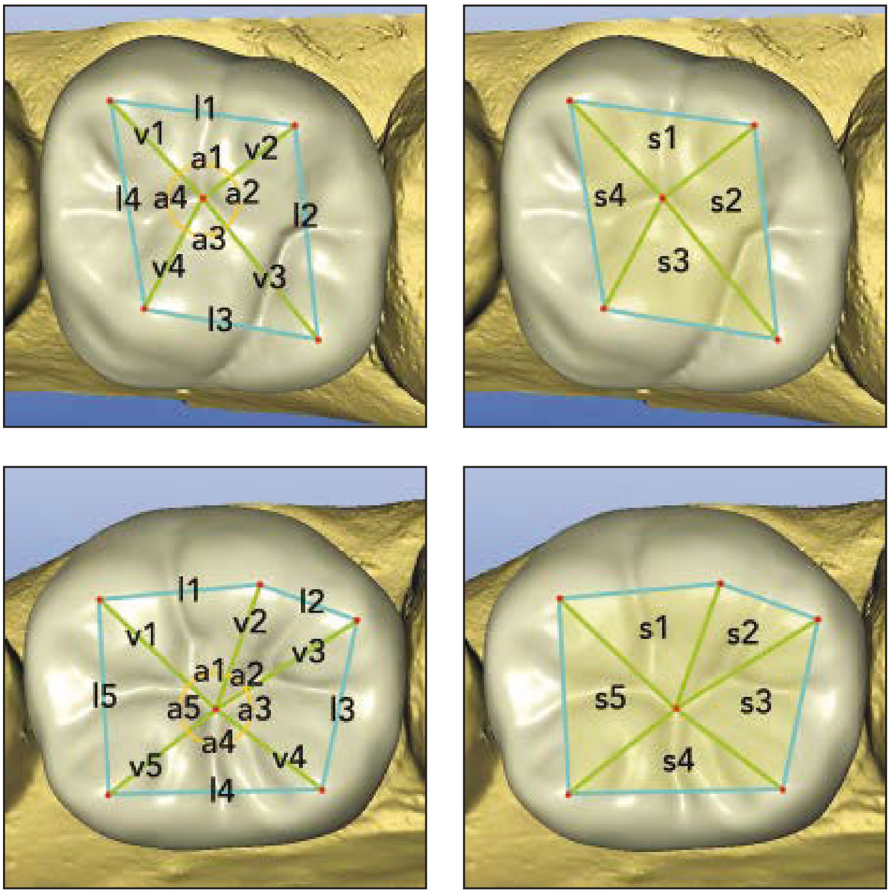

Fig 2 *Measured variables. l and v = point-to-point distance; a = angle; s = area.*

measurements, and –0.114 to 0.327 in angular measurements. For mandibular molars, the ranges of CCC were 0.104 to 0.555 in linear measurements, 0.183 to 0.597 in area measurements, and 0.030 to 0.396 in angular measurements. Some of the measurements exhibited statistically significant differences according to the paired-samples *t* test in both the maxillary and mandibular teeth. The detailed results are summarized in Tables 1 and 2.

Discussion

The assumption that good function can be achieved by providing good morphology is logical only if there is a close positive relationship between the morphology and function.[1] Since current restorative treatment is focused on improving debilitated morphology and function, it is important to know what ideal morphology is. While restoring the untreated original morphology is generally thought to be good, simplified occlusal design has been advocated in contrast to traditional schemes, although controversy lingers regarding this approach.[3] Under certain circumstances, such as in patients who need extensive rehabilitation or who have a bruxism habit, artificial morphology should be created for the purpose of the treatment. However, in cases of single restorations, the chances of success are high when the original morphology is successfully restored if the surrounding environment is not altered. In addition, duplication must reflect the original as accurately as possible to reduce the time-consuming adjustment procedures. In fact, this is one of the objectives of the automatic occlusal reconstruction algorithms.

Comparing the 3D shape of teeth is difficult, and none of the presented methods could satisfactorily explain the shape differences. Therefore, better methodologies are still sought after and suggested continually. A recently introduced mathematic superimpositioning method has many advantages over the conventional approaches.[10,11] However, the superimpositioning method cannot metrically indicate which areas of the two surfaces are coincident or not. In this respect, the authors of the current study focused on comparing the cusp configuration from the occlusal point of view rather than the total volumetric difference because it is important to know the precise location of incongruent results. With sufficient improvement in accuracy of the biogeneric algorithms, a single crown restoration procedure may become more efficient and have greater predictability.

Another obstacle for evaluating the virtually reconstructed occlusal surface was the proprietary file format, which cannot be measured in universal 3D software without a customized conversion program.

For this reason, in the present study the authors detected the 3D coordinates of the reference points and then calculated the measurements instead of directly measuring with the program.

Agreement between the original and reconstructed occlusal surface was evaluated by calculating the CCC[19,20] and the means with standard deviations of the difference between measurements. The CCC was first introduced in 1989[19] and readily became one of the most used indexes for assessing agreement. It provides an estimate of the agreement between two variables and can provide an indication of excellent agreement. The CCC was used in this study because the intraclass correlation coefficient (ICC) measures reliability under the model of equal marginal distributions. However, when the marginal distributions are unequal, the ICC captures the deviations and may erroneously consider them unreliable.[21] Furthermore, the commonly used Pearson correlation coefficient provides only an expression of the linearity between values for repeated measurements while providing little information on the inaccuracy component. In contrast, CCC can be used to distinguish inaccuracy from unreliability in data.[22]

In contrast to the promising results of previous studies, relatively poor agreements were observed between the original and reconstructed occlusal shape parameters in this study, even though some measurements did not show statistical difference in the paired *t* test. In particular, the authors excluded

Table 1 Reproducibility of maxillary first molars

Variables	CCC	95% CI lower limit	95% CI upper limit	Mean Δ ± SD
v1*	0.159	0.012	0.300	−0.424 ± 0.247
v2	0.040	−0.334	0.403	−0.071 ± 0.365
v3	0.430	0.067	0.692	−0.071 ± 0375
v4	0.404	0.131	0.621	0.163 ± 0.488
l1	0.420	0.085	0.670	−0.085 ± 0.469
l2	0.566	0.203	0.792	0.003 ± 0.487
l3*	0.246	−0.063	0.512	−0.222 ± 0.435
l4*	0.492	0.183	0.713	−0.283 ± 0.452
s1*	0.127	−0.137	0.375	−0.869 ± 1.189
s2	0.509	0.156	0.746	0.140 ± 1.300
s3	0.351	0.018	0.614	0.041 ± 1.421
s4*	0.265	0.007	0.490	−0.832 ± 1.259
a1*	−0.114	−0.383	0.173	6.304 ± 10.056
a2	0.327	−0.079	0.640	−2.271 ± 8.301
a3*	0.187	0.013	0.350	−6.493 ± 7.666
a4	0.139	−0.089	0.353	2.460 ± 7.918

CI = confidence interval; l and v = point-to-point distance; a = angle; s = area.
*Statistically significant difference (P < .05).

Table 2 Reproducibility of mandibular first molars

Variables	CCC	95% CI lower limit	95% CI upper limit	Mean Δ ± SD
v1*	0.104	−0.099	0.299	−0.415 ± 0.327
v2*	0.365	0.100	0.582	−0.515 ± 0.370
v3*	0.555	0.183	0.788	−0.199 ± 0.395
v4*	0.229	−0.111	0.521	−0.185 ± 0.300
v5	0.509	0.108	0.767	0.125 ± 0.435
l1*	0.217	0.042	0.380	−0.519 ± 0.246
l2*	0.360	0.066	0.597	−0.328 ± 0.322
l3*	0.551	0.208	0.773	−0.300 ± 0.441
l4	0.420	0.046	0.690	0.063 ± 0.453
l5	0.264	−0.164	0.609	−0.158 ± 0.383
s1*	0.183	0.012	0.344	−2.054 ± 1.021
s2*	0.417	0.133	0.637	−1.327 ± 0.991
s3*	0.597	0.235	0.813	−0.614 ± 1.154
s4	0.402	−0.039	0.712	−0.156 ± 1.158
s5*	0.455	0.114	0.700	−0.747 ± 1.049
a1	0.352	−0.096	0.681	−0.954 ± 8.186
a2	0.338	−0.101	0.667	0.155 ± 10.211
a3	0.396	−0.052	0.712	−0.503 ± 8.088
a4	0.202	−0.265	0.593	−1.757 ± 13.812
a5	0.030	−0.383	0.433	3.060 ± 9.249

CI = confidence interval; l and v = point-to-point distance; a = angle; s = area.
*Statistically significant difference (P < .05).

two mandibular molars from evaluation because their cusp numbers were different between the reconstructed and original teeth, being 5 versus 4, respectively. The reason may be twofold. First, the biogeneric algorithms may not reflect the characteristics of teeth of Korean origin since it is based on data from a different ethnic population. In this case, an experiment identical with this study should be performed with the data set from European populations. Second, the biogeneric algorithms provide the form of restorations primarily based on the adjacent tooth. The inferential capability for the missing tooth still has room for improvement or refinement, especially in cases of full crowns. A tendency for the reconstructed first molars to look similar to second molars by visual inspection was observed.

The perfect duplication of original teeth may not be the goal for clinical restorative treatment, and modification of the original shape is sometimes required. However, the inferential capability of automatic occlusal construction programs is important in most clinical situations, and human intervention could be dramatically reduced with the development of automatic occlusion construction capability with sufficiently high precision. In addition, the component of a virtual articulator would be beneficial for this purpose. Research on the prediction of lost tooth structure should be performed further to improve the function of this application.

Acknowledgments

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Science, ICT & Future Planning (NRF-2012R1A1A1001758). The authors reported no conflicts of interest related to this study.

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