# Computer modeling of occlusal surfaces of posterior teeth with the CICERO CAD/CAM system

**Lambert W. Olthoff, PhD, DDS,[a] Jef M. van der Zel, PhD,[b] William J. de Ruiter,[c] Simon T. Vlaar,[d] and Frederik Bosman, PhD[e]**
University of Utrecht and Cicero Dental Systems, Hoorn, The Netherlands

Statement of problem. Static and dynamic occlusal interference frequently needs to be corrected by selective grinding of the occlusal surface of conventional cast and ceramic-fused-to-metal restorations. CAD/CAM techniques allow control of the dimensional contours of these restorations. However, parameters responsible for the occlusal form need to be determined. In most articulators, these parameters are set as default values. Which technique is best for minimizing the introduction of occlusal interference in restorations has not been determined.

Purpose. This study investigated differences in crown structure of a crown designed in static occlusion (STA) with designs adapted for dynamic occlusal interferences. Therefore, values from an optoelectronic registration system (String-Condylocomp, KAVO), an occlusal generated path (OGP) technique and default settings (DEF) were used in the CICERO CAD/CAM system.

Material and methods. Morphology of CON, DEF, and OGP crowns was compared with that of the STA crown with respect to differences in a buccolingual section and frequency of occlusal distances in an interocclusal range of 1 mm, measured from the occlusal surface of the crown.

Results. All crown types fulfilled the esthetic and morphologic criteria for restorations in clinical dentistry. Difference in the morphology of the OGP crown, compared with that of the STA crown, was greater than that for the CON and DEF crowns. These differences were seen especially in the distobuccal part of the occlusal surface; however, the number of occlusal contacts was considered sufficient to stabilize occlusion.

Conclusion. Functional occlusion, adapted to dynamic occlusion in a CICERO crown for the first mandibular molar, can be obtained using data acquired with the String-Condylocomp registration system. The OGP technique was preferred to other techniques because of the simplicity of the technique for eliminating potential problems with opposing teeth during motion. However, this is achieved at the cost of fewer points of contact during occlusion than with the CON crown. (J Prosthet Dent 2000;84:154-62.)

CLINICAL IMPLICATIONS

*In this study, the data from optoelectronic registrations (Condylocomp-KAVO) and computer-generated occlusal paths (OGP) were used to design CICERO CAD/CAM crowns, which are free of dynamic occlusal interferences.*

Clinical experience has shown that factors that affect occlusion in crowns prepared by conventional indirect techniques are difficult to control.[1] Even after careful use of impression techniques, registration of jaw movements, and optimal technical procedures, disturbances of occlusion are common. When there is a tight contact of the front teeth in centric occlusion, this condition will dictate disclusion of the lateral teeth during any of the jaw movements. However, a dynamic occlusion classified as unilateral guidance or group function exists without a tight contact of the antagonistic anterior teeth.[2] In the latter type of occlusion, combined with some degree of horizontal overjet, dynamic interferences may easily be introduced during restorative procedures. This means that, in clinical practice, the restoration has to be corrected by grinding at the time of insertion, which affects the quality of the material, especially when porcelain is used on the occlusal surface of dental restorations.

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[a]Assistant Professor of Gnathology and Oral Pathophysiology, Department of Oral-Maxillofacial Surgery, Prosthodontics and Special Dental Care, University of Utrecht.
[b]Chair, Elephant Industries, Cicero Dental Systems.
[c]IT Engineer, Cicero Dental Systems.
[d]IT Engineer, Cicero Dental Systems.
[5] Professor of Oral Pathophysiology, Department of Oral-Maxillofacial Surgery, Prosthodontics and Special Dental Care, University of Utrecht.

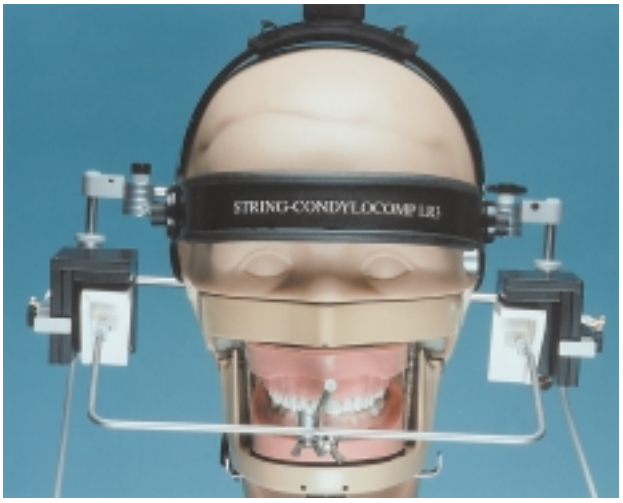


**Fig. 1.** Sensors (Dentron-Condylocomp registration apparatus) positioned near condylar heads of KAVO patient simulator.

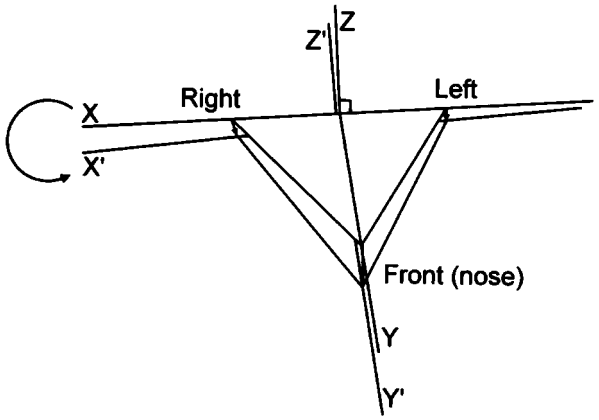


**Fig. 2.** Movements of right and left condyles were recorded. Rotational values from plane determined by left and right condyle and inferior incisal point with respect to rotational intercondylar axis were also recorded. Positions of both condyles and mandibular incisal point are expressed with reference to Cartesian axis system.

Different types of articulators have been developed to copy the individual 3-dimensional movements of the mandible to improve dental restorative procedures. Default values for the angles of the right and left sagittal condylar path, the Bennett movement, and the incisal guide are usually used with semiadjustable articulators to simulate the individual movement patterns of opposing tooth surfaces during occlusion[3-6]; however, the use of such average settings is not likely to result in sufficiently accurate modeling of the individual's dynamic movement pattern, which is a prerequisite for successful restoration of the occlusal surface of posterior teeth. This is also true of crowns made according to CAD / CAM techniques using average default values.[7-9]

The software of the CICERO[7] system (Cicero Dental Systems, Hoorn, The Netherlands) can use various input parameters to design a functional restoration by simulating 3-dimensional maxillomandibular movement patterns on the basis of data on the protrusive, laterotrusive, and mediotrusive pathways of interocclusal contact movements. These data are acquired for 6 independent coordinates corresponding to the 6 degrees of freedom.[10-12] The 6 degrees of freedom of the mandible are established using a head-related coordinate system, because movements of the head are normal phenomena during registration procedures. After the application of these values, the individual locations of the supporting cusp tips can be computed using CAD software.

A new optoelectronic registration apparatus (String Condylocomp, Kavo EWL, Leutkirch, Germany) has been recently developed for clinical practice. With this apparatus, the origin of the coordinate system is attached to the moving head, so that the coordinates of the mandibular intercondylar axis are relative to the position of the head. According to the manufacturer (Kavo, Dentron), the precision of this instrument is 0.01 mm, and the error at 10 to 12 mm from the axis is 5%. In this study, we used data acquired with the String-Condylocomp to simulate mandibular contact movements with the Cicero system. However, because these head-related 3-dimensional registration systems are laborious and time-consuming in practice, we also used a computer-generated occlusal path (OGP) technique. The computer software detects and registers stepwise forward and lateral right- and left-directed "occlusal generated" contact movements and the incidence of contact between opposing teeth. In this way, the outline of the surface of the opposing teeth can be "digitized" to provide the outer occlusal boundaries for the contour of the restoration so that it can function without interference.

The CICERO CAD / CAM software also provides the possibility to introduce other constraints that may influence the outline boundaries of the antagonistic surface, for example, the amount of horizontal overjet of the front teeth, the incisal inclination, and the values for long or wide centric articulation. In restorative procedures using the OGP technique, enough teeth should remain to direct the occlusal contact movements from centric occlusion in a proal, lateral right, and lateral left contact movement to define the antagonistic surface.

The purpose of this article was to investigate the extent to which CICERO CAD / CAM crowns (for the first mandibular molar) designed on the basis of data for dynamic occlusion (default values and values obtained

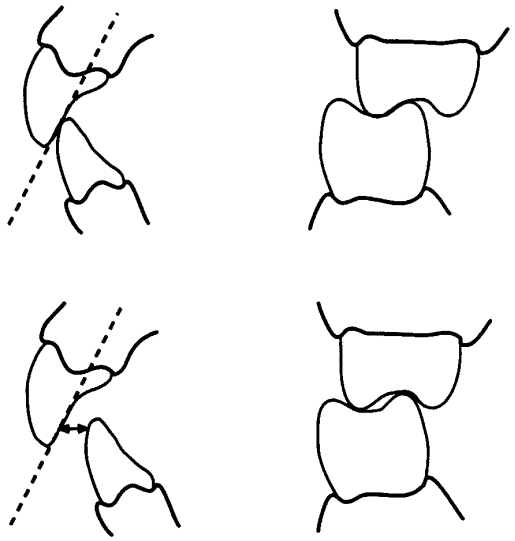

**Fig. 3.** Two conditions set for OGP crown fabrication. 1. OGP-, contact of front teeth; 2. OGP+, long centric occlusion of 1 mm. Incisal angle was set at 60 degrees.

using the OGP or String-Condylocomp techniques) differed from a crown designed for static occlusion.

## MATERIAL AND METHODS

Fourteen acrylic resin dental elements were placed in the upper and lower jaws of a model of a human head (Patient Simulator, Kavo EWL). The relation between the maxilla and mandibular could be classified as Angle Class I with a sagittal overjet of 1 mm. The dental arches were fixed in the head and connected via a mechanical temporomandibular joint (TMJ). The inclination of the condylar path of the TMJ has been preset by the manufacturer. The contact movements of both jaws are guided manually by the operator. The movement patterns of the mandible are limited by the mechanical constraints of the artificial TMJ and by the maxillary and mandibular elements. Jaw movements were recorded by using the KAVO model after preparation of first mandibular molar for a restoration with a CICERO porcelain crown. Diamond burs with rounded heads were used to obtain a rounded shoulder restoration. This form is easier to cut than sharp or rectangular angles during the CICERO CAM procedure. A silicone-rubber impression was made of the preparation and the other elements of the mandible. The impression of the antagonist was incorporated in the check bite. The gypsum casts of the prepared tooth and adjacent teeth, and of the opposing teeth, were digitized.[7]

### Static crown

The crown was modeled from the anatomic form of the first mandibular molar stored in a "library" of tooth

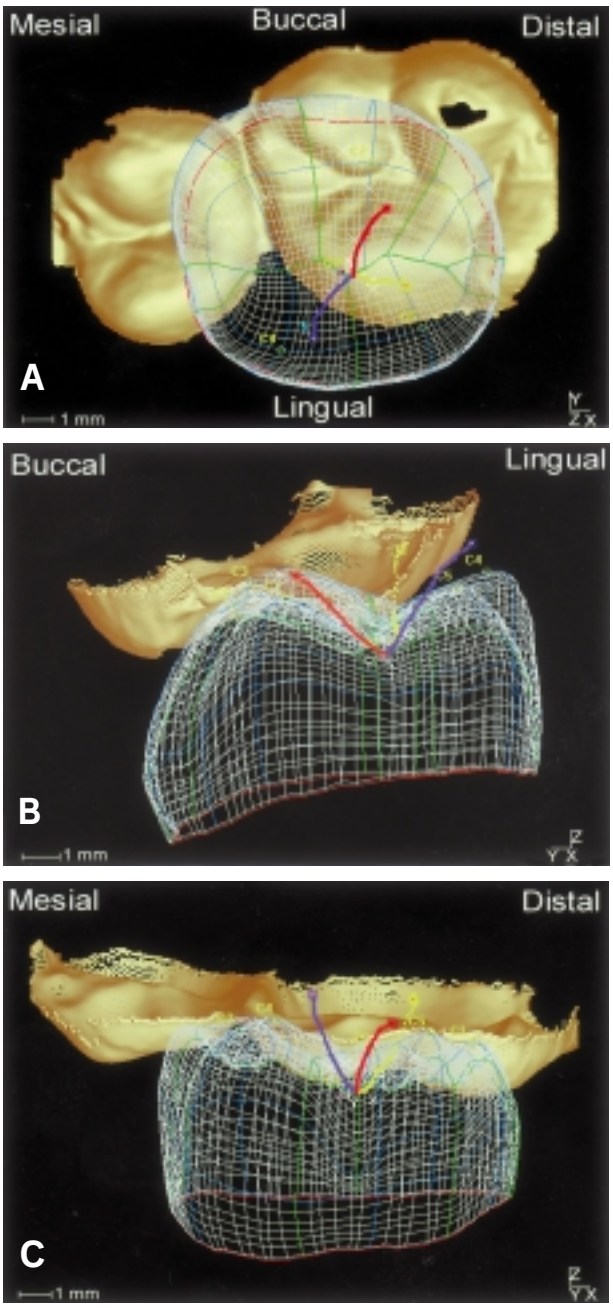


**Fig. 4.** Result of translations and rotations calculated for position of T46, illustrated as pathways from maximal occlusion in mediotrusive (red), laterotrusive (blue), and protrusive (yellow) direction in occlusal (**A**), buccolingual (**B**), and mesiodistal (**C**) view. C1-C5 indicate cusp positions. Discontinuity in surface of disto-occlusal surface of antagonist is shadow missed in scanning procedure, which is not in contact with T46 during function.

forms. This form was adapted to the form of the adjacent molars and opposing teeth[7] in static occlusion. This type of "static" crown (STA crown) usually gives rise to disturbances during dynamic occlusion. Three procedures for eliminating these distur-

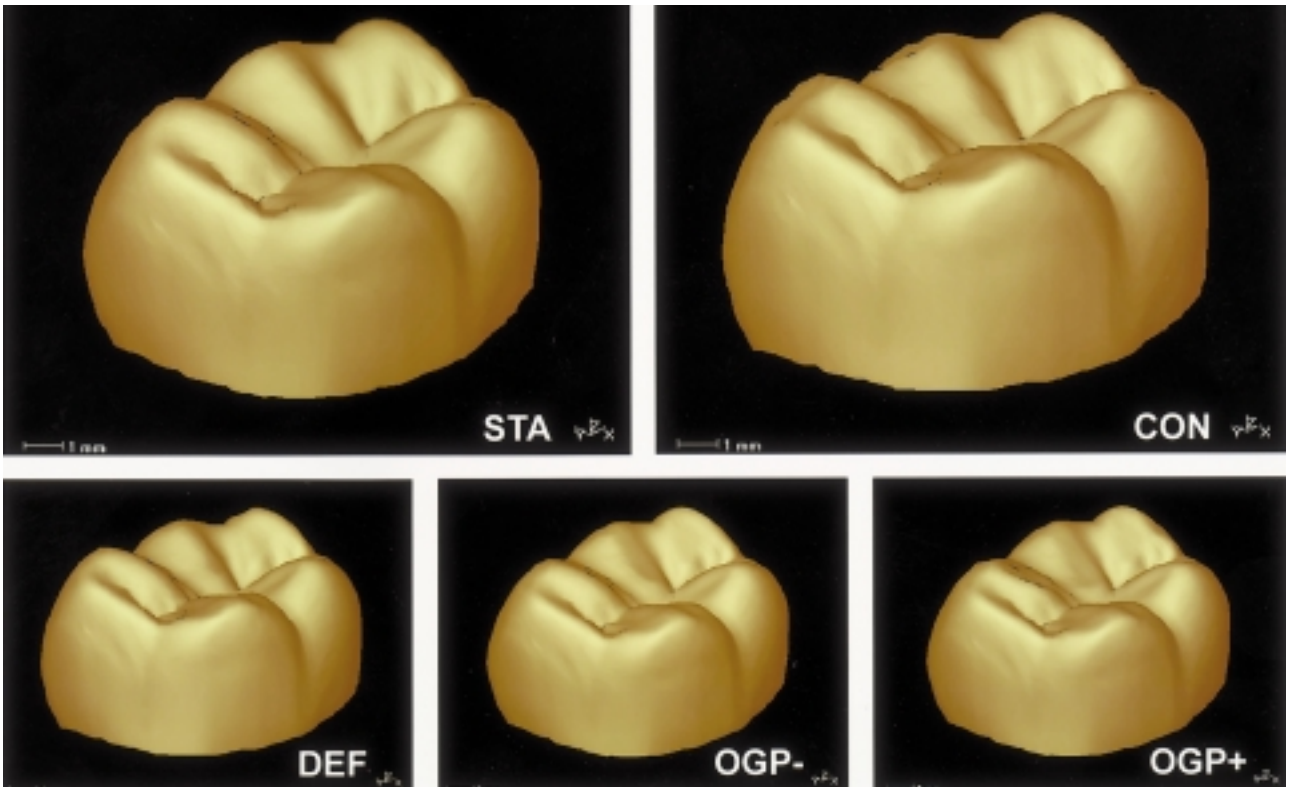


**Fig. 5.** STA, CON, DEF, and OGP+ and OGP– crowns of first mandibular molar. Most striking differences were seen in distobuccal parts of these crowns, namely, flattening of this part of first mandibular molar in combination with less dented ridge alignment.

bances were evaluated by modifying the crown design.

## String-Condylocomp registration technique

The String-Condylocomp LR3 is a computerized jaw movement registration apparatus. Rotational and translational movements of a reflector connected to the mandible and positioned laterally of the right and left TMJ are measured by a head-related device (Fig. 1). The reflector is connected to the mandible via a clutch fixed on the labial surfaces of the lower front elements. The frame is positioned according to the intercondylar hinge axis, Camper plane, and centric occlusion position. The protrusive and the left and right lateral-guided contact movements are registered.

Individual movements are determined from the X, Y, and Z coordinates of the left and right end points near the condyle of the axis and from the rotation around this axis. Movements of both condyles were described in the medial, proal, and caudal direction. The rotational values from the plane determined by the left and right condyle and the inferior incisor and the rotational intercondylar axis were recorded. The data obtained from the Condylocomp registration in 3 directions are given in reference to a Cartesian axis system (Fig. 2). These data were fed into the CICERO system and transformed to fit the position of the first mandibular molar. The CICERO CAD procedure was then used to design the String-Condylocomp (CON) crown.[7]

## DEF setting

In the default (DEF) mode, the STA crown was adapted according to the default settings commonly used by dental technicians to adjust dental articulators. The values for the angles of the sagittal condyle, the lateral Bennett angle, and the incisal path were chosen as 30, 20, and 30 degrees, respectively. The values were fed into the CICERO system. The CICERO system was then used to design the DEF crown.

## OGP technique

With this technique, lateral and forward movements of the STA crown are simulated under different conditions. Two conditions were used to illustrate some of the possibilities of the CICERO system (Fig. 3). In the first condition, OGP–, the occlusal contact of opposing teeth during lateral and proal movements was monitored in steps of 50 μm. In addition, incisal guidance was set at 60 degrees, immediately from centric occlusion. In the second condition, OGP+, the occlusal

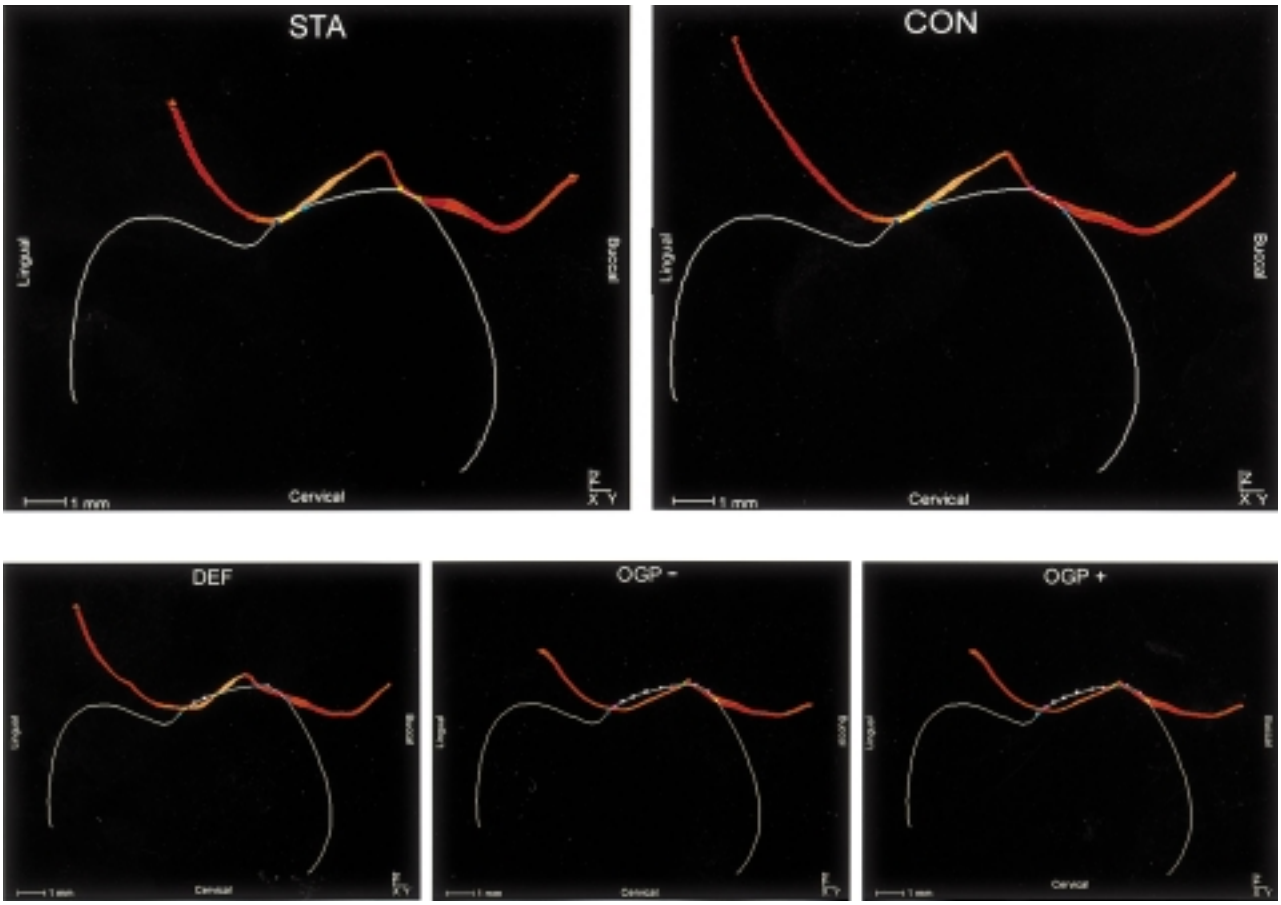


**Fig. 6.** Buccolingual sections of CON, DEF, and OGP– and OGP+ crowns at same mesiodistal position, compared with STA crown. Static (STA) crown was starting point for designs of CON, DEF, and OGP crowns in dynamic occlusion. Overlapping contours of OGP crown compared with DEF and CON crowns show that more correction of the STA design is needed for the OGP crown designs to function without interference in OGP setting. Color of points in overlapping contour indicate various interocclusal positions: Pink = disturbance, yellow = contact, and blue = no-contact. At level of section, hardly any differences can be found between OGP+ and OGP– designs because these differences exist mainly at distobuccally oriented ridges of occlusal surface.

contact of opposing teeth during lateral and proal movements was again monitored in steps of 50 μm, but after centric occlusion was shifted forward horizontally by 1 mm (long centric articulation). Under both conditions, no other lateral guidance parameters (Bennett angle or immediate side shift) were used, apart from the lateral guidance as derived from the OGP procedure.

The region from the second molars to the first premolar on the side of the fabricated crown was monitored. We used 3 approaches to highlight the differences in the occlusal surface of the CON, the DEF, and the OGP, compared with that of the STA crown. First, we compared the buccolingual sections of the opposing right-sided first maxillar and mandibular molar teeth for the 4 crowns (STA, CON, DEF, and OGP). Second, structure of these crowns was compared in different dimensions using the Cicero system. Third, the number of interocclusal distances in an interocclusal range of 1 mm were compared, measured from the occlusal surface of the crown.

## RESULTS

Trajectories in mediotrusive, laterotrusive, and protrusive direction as obtained from the border movements in the KAVO simulator are shown on a projection of the STA design of the first mandibular molar in the occlusal, the buccolingual, and the mesiodistal view, respectively (Fig. 4, *A* through *C*). The perspective view of the CON, DEF, OGP, and STA crowns are illustrated in Figure 5. The differences between the CON, DEF, OGP, and STA crowns mainly exist in the distobuccal part of the crown. This difference was such that

dynamic occlusion would be disturbed if the STA crown was not adapted. The amount of interference could be assessed from buccolingual sections of the opposing right maxillar and mandibular molar teeth (Fig. 6). In the STA crown, these molar teeth made contact because the crown was developed on the basis of teeth alignment during static occlusion. However, the occlusal surface of the STA crown needed to be corrected for the dynamics of occlusion. The CICERO system used the CON values, the DEF settings, and the OGP values to determine new occlusal configurations so that the crown would function without disrupting the harmonious movements of the stomatognathic system. The changes made to the STA crown are indicated by the overlapping contours of the CON, DEF, and OGP crowns. From Figure 6, it can be seen that the OGP crown needed to be adjusted the most to fit the structure of the STA crown, the DEF crown slightly, and the CON crown the least.

The differences between the OGP crowns manufactured without (OGP–) and with (OGP+) adjustment for long centric articulation can not be detected in Figure 6 because the main differences existed in the distobuccal ridge contour, which is not shown in this view. The frequency of interocclusal distances up to 1 mm in steps of 50 μm are depicted in Figures 7 and 8 and Table I. Apart from the STA crown, only the CON crown made contact with the antagonistic teeth (distance 0.00). With the OGP and DEF crowns, the distance between the crown and opposing tooth was always larger than 50 μm.

**Table I.** Interocclusal intervals of 50 μm calculated from the occlusal surface up to a distance of 1 mm versus the frequency of these intervals for the STA, CON, DEF, and OGP– and OGP+ designs

| d | OGP– | OGP+ | STA | DEF | CON |
|---|---|---|---|---|---|
| 0.00 | 0 | 0 | 14 | 0 | 11 |
| 0.05 | 3 | 1 | 15 | 4 | 15 |
| 0.10 | 6 | 7 | 17 | 7 | 17 |
| 0.15 | 15 | 14 | 22 | 28 | 25 |
| 0.20 | 26 | 24 | 21 | 28 | 21 |
| 0.25 | 31 | 31 | 25 | 33 | 25 |
| 0.30 | 29 | 31 | 31 | 31 | 31 |
| 0.35 | 46 | 46 | 35 | 35 | 35 |
| 0.40 | 33 | 32 | 23 | 29 | 23 |
| 0.45 | 39 | 37 | 32 | 38 | 32 |
| 0.50 | 32 | 30 | 28 | 29 | 28 |
| 0.55 | 35 | 37 | 37 | 38 | 37 |
| 0.60 | 46 | 41 | 45 | 45 | 45 |
| 0.65 | 37 | 38 | 37 | 37 | 37 |
| 0.70 | 42 | 42 | 41 | 41 | 41 |
| 0.75 | 40 | 43 | 40 | 40 | 40 |
| 0.80 | 35 | 35 | 33 | 33 | 33 |
| 0.85 | 38 | 39 | 39 | 39 | 39 |
| 0.90 | 44 | 41 | 42 | 42 | 42 |
| 0.95 | 30 | 33 | 30 | 30 | 30 |

## DISCUSSION

Although the strength and the esthetic demands of dental restorations can be met by automated production system,[7-9] and such systems are less time-consuming and thus will help to reduce the expenses of dental treatment, the functional properties of the restoration will determine its overall quality. For this reason, the production of crowns that do not cause interference in dynamic occlusion and in which there is optimal contact in centric occlusion will be of great value to dental practice.

In this study, the CICERO CAD/CAM procedure was used to prepare a crown in static contact (STA). Because this crown disturbs normal functional movements, 3 methods were used to design crowns that avoided these disturbances during dynamic contact movements: (1) individual data transferred from KAVO-Condylocomp registration; (2) default values often used in semiadjustable dental articulators; and (3) data obtained after registration of the individual contact movements in an occlusal-generated path technique (OGP).

### Implementation of optoelectronic registration data

Data acquired with the String-Condylocomp system was implemented in the CICERO system to produce metal-ceramic crowns. This combination makes it unnecessary to use articulators to construct the occlusal design of the crown. Furthermore, the difficulty of visualizing, in 2-dimensional projections, the contact situation of spatial movements of the opposing teeth during function and contact movements of opposing jaws in the articulator is avoided by the possibility to evaluate the designs in all dimensions on the computer screen. The String-Condylocomp registration system provided for an optimal restoration in terms of contact in centric occlusion but may be too time-consuming and troublesome to the patient for use in routine clinical practice, although this should be evaluated in larger clinical trials.

### Occlusal generated path technique

The OGP technique was introduced to overcome the time-consuming procedures of the String-Condylocomp registration system. The OGP technique can be compared with the functionally generated path (FGP) technique, which is used to register dynamic contact movements with dental registration wax.[13-17] With the FGP technique, the registration wax will reproduce the movements in the TMJ and the gliding contact movements of the front and lateral teeth. These constraints in the TMJ and dynamic front contact are not measured with the OGP technique.

Although in essence the FGP method allows the incorporation of all determinants of occlusion in the FGP wax registration procedure, this technique is not easy to perform accurately, even for trained dentists and dental

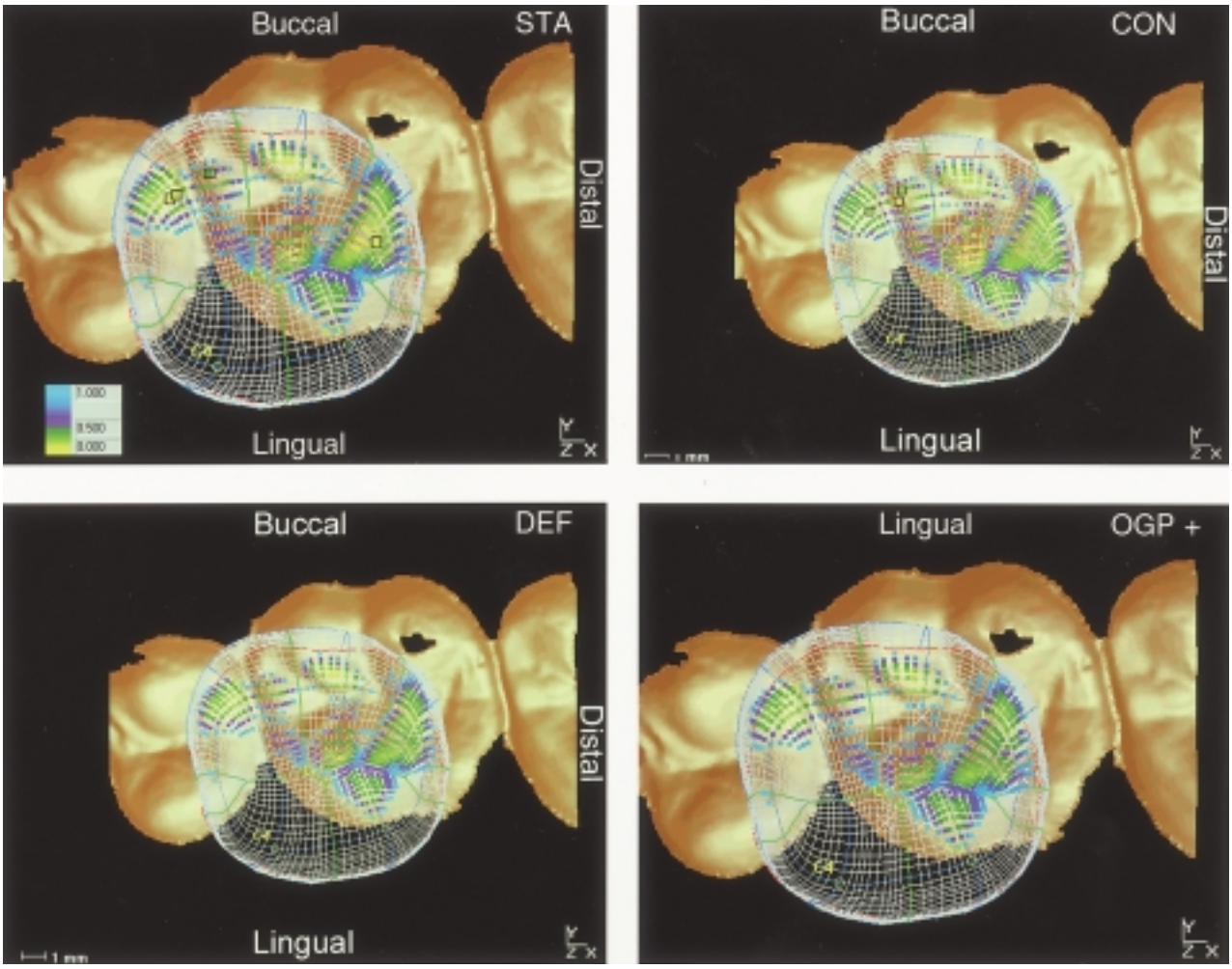


**Fig. 7.** Frequency of interocclusal distances determined in range from 0 (contact with crown surface) to 1 mm. Spatial distribution of interocclusal distances for CON, DEF, and OGP crowns are shown related to STA design. For instance, CON crown made interocclusal contact (yellow) at other positions on occlusal surface than did STA crown.

technicians.[18] For practical reasons, dentists do not favor this technique. For this reason, the OGP technique was introduced, which makes use of a computer program (CICERO). Computer calculations can now solve the practical problems of the FGP registration system.

Our results suggest that the OGP method used for the production of CICERO CAD/CAM crowns is an appropriate method for restorative procedures in which 1 or a couple of teeth are replaced. With this method, it is possible to gather information on the movements of the restoration with reference to the opposing teeth by making use of digitized models. It is generally recognized that, when it comes to restoration of the lateral teeth, the type of dynamic occlusion of the front and lateral teeth dictates the most appropriate occlusal design for the functions of the stomatognathic system. The OGP technique was tested with occlusal determinants that could be considered extreme, ie, without setting a value for the laterally directed movements. Even under these conditions, a crown with a well-modeled anatomic form could be generated.

The 4 crowns differed mainly in the distobuccal occlusal region (Fig. 5). In the CON, the DEF, and OGP crowns, these ridges had a less dented contour. Although it is known that the arcs of movement produced by cusp tips against the occlusal surfaces of opposing teeth should be considered in 3-dimensional, most studies have focused on these movements projected in the horizontal plane.[4-6] These studies showed that an increase in the angular alteration of the medial condylar path (Bennett angle) drastically changed ridge and groove direction. An increase in the Bennett angle on the nonworking side will cause a medial shift in the path of movement of the maxillary tip projected on the horizontal plan. Furthermore, this increase will permit a smaller cuspal

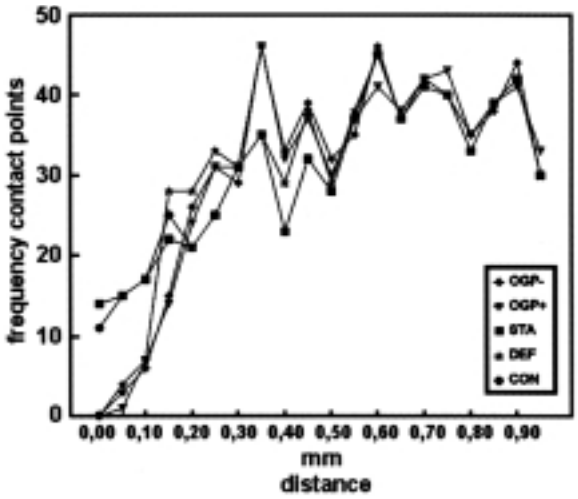


**Fig. 8.** In first 0.2 mm, number of intervals for CON and STA crowns exceeded that of DEF crown. Differences may be explained by performance of jaw movements in KAVO-head imitating border movements with KAVO-Condylocomp. STA and DEF crowns had comparable number of intervals in first 0.2 mm, whereas after about 0.3 mm hardly any differences in number of contacts existed between 3 types of crown.

height.[4-6] The change in the design of the distobuccal cusp anatomy of the OGP crown, compared with that of the STA, DEF, and CON crowns can be explained by the extremely flat lateral movement trajectory, guided by the cusps of the molar and premolars near the first molar in the OGP mode. The flattening of the disto-occlusal form of T46 can be explained by the use of long centric occlusion. Crowns made with this type of flattened laterally directed movement are less likely to disturb dynamic occlusion (Fig. 7).

In the CON, DEF, and OGP crowns, the overlapping contours seen in the buccolingual sections (Fig. 5) indicate the amount of tooth structure that needs to be removed for the crown to function without disturbing jaw movements. The OGP+ and OGP– crowns will be least likely to introduce nonworking side disturbances during dynamic occlusion. However, this is achieved at the cost of less contact between opposing teeth in static conditions. This lack of contact will cause eruption of the antagonistic elements.

## Relevance of tooth morphology

The significance of the cusps of molar teeth in dental restorative procedures has been widely discussed in the dental literature. Evolutionary,[19-21] phylogenetic and ontogenetic,[22] periodontal,[23,24] and prosthodontic[25,26] aspects of cusp morphology have been discussed. Cusps are considered to stabilize occlusion. A great variety of cusp forms can be found, and it would be wise to adapt the form of the restoration to the anatomy of well-functioning teeth.[27-29] There is no evidence that one cusp form increases chewing efficiency more than another; however, in their review, Luke and Lucas[30] concluded that conical rounded cusp forms were advantageous, given the physical properties and composition of the modern diet.

## SUMMARY

This study demonstrated that, in the near future, computer techniques may help to monitor the ideal articulation in restorative dentistry. Electronic registration devices are an essential part of these new techniques. The CICERO CAD / CAM system is well equipped to demonstrate the influence of various articulator settings on the 3-dimensional configuration of occlusal surfaces. A study to demonstrate systematically the influence of these parameters is in progress.

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*Reprint requests to:*
DR L. W. OLTHOFF
DEPARTMENT OF ORAL-MAXILLOFACIAL SURGERY, PROSTHODONTICS AND SPECIAL DENTAL CARE
PO BOX 80.037
3508 TA UTRECHT
THE NETHERLANDS
FAX: (31)30-2535537
E-MAIL: l.w.olthoff@med.uu.nl


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## Noteworthy Abstracts of the Current Literature

Topical application of capsaicin for the treatment of localized pain in the temporomandibular joint area
Winocur E, Gavish A, Halachmi M, Eli I, Gazit E. *J Orofac Pain 2000;14:31-6.*

Purpose. Capsaicin gains therapeutic effect through release of substance P and pain-related neuropeptides. This agent has topical analgesic and antiinflammatory properties and has been used for a number of clinical applications. This study attempted to determine the effectiveness of topical capsaicin cream applied to painful areas near the temporomandibular joint.

Material and methods. Thirty patients were selected to participate in a randomized, double-blind, placebo-controlled study. Patients were required to meet specific inclusion criteria, including unilateral TMJ pain of at least 3 months duration localized to a specific area, tenderness to TMJ palpation, and joint pain during function. Patients were randomly assigned to receive a topical cream containing either 0.025% capsaicin or no capsaicin. Subjects and examiners were blinded to the material although patients were aware that they would receive the test medication of a placebo. Topical applications of the cream were performed 4 times daily for 4 weeks. Subjective and objective evaluations were performed to assess outcomes. Data analysis consisted of a 2-way ANOVA to evaluate differences between groups and differences relative to time of treatment.

Results. When compared with the placebo, capsaicin cream produced no significant improvements in pain relief or in jaw movement. Pain improvement was noted relative to time for both groups but no difference was seen with the use of capsaicin.

Conclusion. During the course of this study the placebo and the test groups responded similarly with both groups reporting reduced pain intensity. Physical attention, concern from the health care team, and patient expectations may have been responsible for the therapeutic benefits. 27 References.—*SE Eckert*