Three Dimensional Shape Measurement of Teeth (Part 11)
— CAD to Produce Crown Considering Occlusion —

Hiroshi KIMURA, Taiji SOHMURA and Junzo TAKAHASHI
Department of Dental Technology, Osaka University, Faculty of Dentistry, 1-8 Yamadaoka, Suita, Osaka 565, Japan

Received on January 31, 1992.
Accepted on March 3, 1992.

Use of a CAD program to design the shape of a crown, restoration of 6 molar was studied. Stone models of 5 to 7 molars with 6 prepared die for crown and a complete 6 crown which was applied for restoration were measured. The 6 crown data were adapted on the 6 die, and adjusted with 5 and 7 proximal teeth. The coordinates of the data of 6 were then transferred to that of the 6 die. The ends of the adapted crown data were linked with the margin of 6 die.

Further the occlusal condition with antagonistic tooth was adjusted by applying the FGP (functionally generated path) technique. FGP was recorded on bite wax and measured. Comparing FGP record and adapted crown, modulation of the occlusal surface was accomplished.

Key words: CAD/CAM, Crown prosthesis, Computer

INTRODUCTION

Recently, there have been many efforts to replace the present complicated process of producing prostheses by casting with a CAD/CAM system1-8). As reported in our previous paper, we assembled a personal computer-controlled three dimensional shape measurement system composed of a laser displacement meter with double sensors and a stone model scanning machine4-6). With this system, we have measured the shape of tooth models and attempted to develop a CAD/CAM system to produce a crown.

In the present paper, stone models of 5 to 7 molars with 6 prepared die for crown, and a complete 6 crown which was used for restoration were measured. The 6 crown data were adapted on the 5 die, adjusting the size and contact points with the proximal teeth. Further, on the occlusal condition of the designed crown with antagonistic tooth, application of a functionally generated path (FGP) technique was attempted.

MATERIALS AND METHODS

1. Apparatus for Measurement

The system is composed of the following apparatus4).

(1) Laser displacement meter with double sensors*; Measures the height of a stone model tooth. The sensors are equipped so that they can compensate for each others blind spot. The accuracy of measurement on a flat stone surface is about 10 µm.

* MDD1211-40, Mitsubishi Electric Co. Ltd., Osaka, Japan
(2) Tooth model scanning machine**: A personal computer-controlled three dimensional modeling machine was used to drive the model tooth automatically.
(3) Personal computer***; Controls the scanning of the working stage of the CAMM-3, and stores and analyzes the data.
(4) Articulator****; An average value condyle type articulator was used to record the functional movement of antagonistic teeth on occlusion.

2. Procedures of Measurement and Data Processing
(1) Measurement
A gonion stage with model teeth was fixed to the working stage of the CAMM-3. The working stage was scanned along the X and Y axes in steps of 0.2 mm, and the height of the model tooth was measured by the displacement meter. Precise procedures were explained in the previous paper⁴.
(2) Data processing
In order to perform CAD for crown restoration, several programs mentioned in the following section were written. The C language***** was used for programming.

RESULTS AND DISCUSSIONS

1. Adaptation of 6 Crown Data on the 6 Die
The stone model of 5 to 7 molars with 6 prepared die for crown are shown in Fig. 1 a). The shape of this model was measured and is shown in Fig. 1 b) by CG (Computer Graphics). The gradient of each line of 6 die data was calculated as mentioned in the previous paper, and the margin was recognized and linked around the tooth as shown by the arrow⁶. The shape of the complete 6 molar was measured and its crown part extracted as

![Fig. 1](image_url)

Fig. 1  a) Photograph of 5/7 stone model.
b) CG drawing of 5/7 measured. Margin line of 6 die is linked.

---

** CAMM-3, Roland D. G. Co. Ltd., Hamamatsu, Japan
*** PC-9801 RA21, NEC Corp., Tokyo, Japan
**** Spacy A, Yamaura Co. Ltd., Tokyo, Japan
***** Turbo C V2.0C, Micro Software Associates Co. Ltd, Tokyo, Japan
shown in Fig. 2. These data were adapted on the 6 die. In this program, CG of measurements from three directions X (mesial), Y (lingual) and Z (occlusal) are taken. From these CG data, the size, position, tilt and rotation of 6 crown were varied so that the appropriate adjustments with proximal 5 and 7 teeth were obtained. The results are shown in Fig. 3 a) and b) by CG images from the X and Z directions respectively. In this case 6 data were reduced 0.98 times in X direction, and magnified 1.05 times in Y direction, and rotated 2°, -2° and -2° around X, Y and Z axes. By this modification, the pitch and array of 6 data were distorted from those of 6 die as can be seen by careful inspection of the figure. This illustrates the complication in data analysis.

In the previous paper, the main coordinate was changed from die data to 6 adapted crown data and linkage between crown and die was accomplished. In this procedure, however, the distortion of data between them remained unresolved, creating problems in producing the shape of the crown by CAM.

Accordingly, in the present study, the distorted crown data were rearranged and interpolated so that the data pitch and coordinate coincide with those of 6 die data. A program to accomplish it was written, and the distorted 6 crown data shown in Fig. 3 were restored along the coordinates of 6 die data as shown in Fig. 4, although the amount of correction may too subtle to observe. The restored 6 crown data were applied to the 6 die again as shown in Fig. 5 a) and b) from the X and Z directions. With very careful observation, the coincidence of data pitch and coordinates will be confirmed. Thus, the adaptation of 6 crown data on 6 die was accomplished. In the next step, connection between the end of the adapted crown and margin of the abutment was carried out. As shown in Fig. 6 a) from the mesial view, the ends of the wire frame line of the crown were extended smoothly by using

---

**Fig. 2** CG drawing of the 6 crown measured for data base.

**Fig. 3** CAD process to adapt the crown on the 6 die and adjust.

a) Buccal (y-axis) view

b) Occlusal (z-axis) view

**Fig. 4** After coordinate transformation of crown data.

---
a third order B-Spline function connected with the margin by the same Y-value as indicated by arrow A. In this case, however, four or five lines near the contact point could not meet the margin using extension of the same Y-value, because of undercutting around the contacts. Accordingly, both ends of the line were connected in a closed circuit by specifying some data points manually by mouse and linking them to the third order B-Spline function as shown by arrow B.

Thus, the connection between the ends of the crown and the margin of the die was completed and is shown in Fig. 6 b).

2. Modification of Occlusal Surface by Applying the FGP Technique

As described, the adaptation of the crown data was accomplished, but the shape of the occlusal surface was transferred from the $\overline{6}$ crown without considering occlusion with antagonistic teeth. This is one of the most difficult problems in the dental CAD/CAM system.

In the present study, application of the FGP technique was attempted. Since this technique records the three dimensional information of occlusion, it allows spatial modification to be performed easily. In clinic application, an FGP record is obtained directly from the mouth of patient. However, in the present study, it was done on an average value condyle type articulator, since an ordinal study stone model was used for the measurement. Initially,
maxillary and mandibular stone models were set on the articulator by the conventional method, and bite wax was placed on the $5-7$ molars and bitten to measure centric occlusion. The wax was then fixed to the mandibular stone model so that it did not move after recording the FGP. The maxillary model was then translated by the protrusive and lateral movement and an FGP record was obtained as shown in Fig. 7 a). The bite wax was then removed carefully, and the shape of the recorded pattern was measured. Position matching between the FGP recorded pattern and $5-7$ stone model is extremely important. Therefore, $5-7$ stone model was kept in the same position on the gonion stage of CAMM -3 as when initially measured. The FGP record was placed on it and measured. Thus, the coordinates between the FGP record and $5-7$ stone model coincided. The CG model of the FGP record is shown in Fig. 7 b) including the molars $5$ and $7$. Since this is a record of the functional movement of teeth antagonistic to $6$, the restored $6$ crown should not interfere with this movement. Accordingly, the three dimensional shape of the FGP record was compared with the $6$ adapted crown data.

Two significant points exist. One is the coincidence of coordinates between the adapted crown data and the FGP record. This has already been accomplished. The coincidence between the adapted crown data and the $5-7$ molar data, and the coincidence between $5-7$ molar data and the FGP record was accomplished in the procedures described above. The other is how to visually recognize the interference of the adapted crown data with the FGP record on the CG model. This was accomplished by applying the hidden line removal technique developed in the previous study of occlusion simulation$^5$, that is, by initially drawing the data of the adapted crown using the hidden line removal treatment and secondarily drawing the data of the FGP record with the same Y-value, and so on. By this technique, the higher part, in other words, the interfering part of the adapted crown remains behind, and is easily recognized as shown in Fig. 8 a). In colored CG model, interfering portions are easily recognized, but in this monochromatic figure, they are marked by a mesh pattern in the distolingual cusp of the crown as shown by arrows.

According to this procedure, the modification of the occlusal surface of the adapted

![Fig. 7](image)

**Fig. 7** The application of FGP technique.

a) Recording of FGP on the articulator

b) CG drawing of the FGP record
crown was possible. The $Z$-value between the adapted crown data and the FGP record with the same X and Y coordinates was compared, and the higher data of the crown were exchanged with that of the FGP record. Thus, the modification of the occlusal surface which should not interfere with the FGP of antagonistic teeth was accomplished. The CG model is shown in Fig. 8 b). In comparison with the CG model in Fig. 4) before modification, a slight depression is observed on distolingual cusp of crown. These crown data were restored on the $6^i$ die as shown in Fig. 9. A total view of crown adaptation with modified occlusal surface is observed.

At present, the FGP record was obtained on the articulator, but in practical application, this will be obtained directly in the mouth. The present method enables the spatial correction of the occlusal surface. Other methods, such as detecting the movement of the mandible by pantograph or sirognathograph may be possible, but transformation of their linear data into spatial modification on the occlusal surface will be complicated.

In the present study, the removal of interfering surface became possible, but the clearance between the FGP record should also be considered, since the position of the adapted crown with least correction of removal and clearance between FGP data is desirable. This will also satisfy the centric occlusal relation which is the starting point of the functionally generated path of antagonistic teeth.

![Fig. 8](image1.png)

Fig. 8 a) CG drawing of combined data of crown and FGP record.  
b) Crown data after modulation of occlusal surface.

![Fig. 9](image2.png)

Fig. 9 The CG drawing of the total sight of modulated crown adaptation.
At present, the position of the adapted crown was initially determined considering the relative location between proximal teeth and only. A program which facilitates shifting the adapted crown to a position with the least clearance and removal of occlusal surface between FGP record should be developed.

Further improvement will be attempted.

CONCLUSION

Application of the CAD process to design the shape of a crown restoration of molar was studied. Stone models of to molars with prepared die for crown, and a complete crown which was applied for restoration were measured. The crown data were adapted on the die, and adjusted with proximal teeth. The coordinates of the data from were then transferred to those of the die. The ends of the adapted crown data were linked with the margin of the die. The occlusal condition with the antagonistic tooth was adjusted by applying the FGP technique. FGP was recorded on bite wax and measured. Comparing the FGP record and adapted crown, modulation of the occlusal surface was accomplished.

ACKNOWLEDGMENT

The authors wish to express their thanks to Kashimura Co. Ltd, Wada Precision Dental Co., Ltd, Mitsubishi Electric Co. Ltd and Roland D. G. Corporation for their kind advice and support the experiment.

REFERENCES

歯科用接着性モノマー（N-methacroyloxyloy-5-aminosalicylic acid, MASA）の
溶血性及びりん脂質リポソームとの相互作用のNMR，DSC研究

藤沢穂一郎*，藤田泰夫**，門磨義則**
*東京医科歯科大学歯学部総合診断部
**東京医科歯科大学歯科医器研究部

MASAとは接着性プライマーとしてレジン修復システムに用いられている。MASAの生物学的活性をモニタするため、アルブミン及びコラーゲン存在下ジパルミトイルホスファチジルコリン（DPPC）/MASAリポソーム系のNMR及DSC相転移温度（Tm）を研究した。その結果、蛋白の存在はリポソームのTm及びDSCに変化を与えない。また

コンポジットレジン修復時に生ずる窩縁部エナメル質微小亀裂に及ぼす
臨床的因子に関する研究

韓　臨麟，岡本　明，岩久正明
新潟大学歯学部歯科保存学第一教室

本研究では、コンポジットレジン修復時に生ずるエナメル質微小亀裂を、歯牙表面及び裏側面において、実体顕微鏡及びSEMを用いて観察した。さらに、エナメル質微小亀裂の発生に及ぼす臨床的因子、すなわち、重合方法、窩縁形態及び研磨時期の影響について検討した。エナメル質微小亀裂は、ベルを付与せず充満直後に研磨を行った1級及び5級の光重合型コンポジットレジン修復物において、全例に観察された。エナメル質微小亀裂

歯の形状の三次元計測（第11報）
—咬合を考慮したクラウン形状設計のためのCADについて—

木村　博，荘村泰治，高橋純造
大阪大学歯学部歯科理工学講座

「6」臼歯のクラウン補綴のための形状設計のCAD化につき研究した。「6」にクラウン用の支台歯形成がされている。「5」〜「7」臼歯の石膏模型と、修復用に用いる「6」完全歯の計測を行った。

クラウンデバイスは「6」の支台歯に適合し「5」〜「7」の隣接歯との調整を行った。その後、「6」のデータの座標は「6」支台歯のそれに変換した。適合したクラウンの端部は、「6」支台歯の辺縁と結合した。

さらに、対合歯との咬合関係をFGP法を応用して調整した。FGPは、パイトワックスに記録し計測した。