CAD/CAM System to Fabricate Dental Prostheses —CAD for Bridge Restoration—

Taiji SOHMURA and Junzo TAKAHASHI

Department of Dental Materials Science and Technology,
Faculty of Dentistry, Osaka University
1-8 Yamadaoka, Suita Osaka 565, Japan

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An original CAD process for bridge restoration was developed, and CAD for a maxillary left three unit bridge was attempted. The measured shape data of the standard crown of a second premolar and molar were deformed, and were applied on the dies. The measured pontic data were inserted between two molars. Here, bite data of the opposing teeth were introduced, and the occlusal relationship with the applied molars was adjusted. The bite data were then replaced by the FGP data, and the occlusal surface interference with FGP data was eliminated. Connection processes were then carried out. The clearances between the pontic and molars were filled with interpolation, and the ends of the applied second molar and premolar were connected with the margin of each die. Finally, the data above the margin of each die were extracted, and used as the inner crown data for the bridge. The whole bridge was designed using a newly developed computer program.

Key words : CAD/CAM, Bridge, Computer

INTRODUCTION

Recently there have been many efforts to supplant traditional processes by using computer-aided design/manufacturing (CAD/CAM) systems^{1–14}, some of which have been successful. The authors developed a trial CAD/CAM system^{5–10} composed of a stone model shape measurement system, a CAD system to design the restoration and a CAM system to mill the prostheses by the CAD data using a personal computer. Using this system crowns and laminate veneers were fabricated^{6–10}.

In the present paper the development of an original CAD process for bridge restoration was attempted by extending the method of CAD for crowns. The design of the pontic and connection of the pontic with adjacent molars were difficult in comparison with the CAD for crowns, and some original ideas and methods were devised.

MATERIALS AND METHODS

A laser displacement meter with spot emitted beam and double sensors (MDD1211-40, Mitsubishi Electric Co., Ltd., Osaka, Japan) was used to measure the height of the stone casts as mentioned in previous papers^{5,10}. Two sensors were used to compensate for individual blind spots. A personal computer controlled three-dimensional (3D) modeling machine (CAMM-3, Roland D. G. Corp., Tokyo, Japan) was used to scan

Fig. 1 a) Photograph of the stone model used. Upper left second premolar and molar are prepared for dies. The first molar is missing.
 b) Photograph of the standard pontic for the first molar.
 c) CG drawing of the measured stone model drawn from nearly the same angle as a). Two circuits are the determined margin of the dies.

the tooth model automatically. The cast is shown in Fig. 1 a). This is a standard study model for three unit bridge, where the maxillary left second premolar and second molar were prepared for the dies. The first molar was missing. To obtain the 3D shape data of the pontic for the maxillary left first molar, a standard pontic model of a sanitary type shown in Fig. 1 b) was curved manually.

To adjust the occlusion with the opposing tooth, the maxillary and mandibular model were set on the average value articulator (Handy Articulator, Shofu, Kyoto, Japan), and the bite of the mandibular teeth was obtained by silicone impression (FLEXICON, GC, Tokyo, Japan). In addition, a functionally generated path (FGP) record was obtained¹⁵⁾ by using bite wax (Hi-Fi bite wax, J. F. Jelenko & Co., New York, U.S.A.). The bite of the mandibular model was marked initially, and the maxillary model was translated laterally and protrusively on the articulator, and the trace of the occlusal excursion of opposing teeth was recorded. This was used to consider the excursion of opposing teeth.

Measurement

Initially, the shapes of the die and adjacent teeth were measured with 0.2 mm pitch in x (buccal-lingual) direction and stepped in y (distal-mesial) direction using the system mentioned above. The bite impression was placed on the die, and measured to establish the relative position between the die and the record. The FGP record was also set on the die and measured. The study models of the second premolar and second molar were measured, and the data almost to the height of the contour were extracted and used as the standard data for restoration.

Regarding the pontic, the whole shape data including those of the bottom were required. The occlusal surface almost to the contour of the model shown in Fig. 1 b)

was measured initially, and then the model was turned over on the goniometer and the bottom data were measured. The time required for the measurement of die, bite, FGP and pontic was about 20 minutes for each; in total about 80 minutes.

Data processing

To accomplish the computer aided design for bridge restoration, several CAD programs were devised. C language (Borland C++ V3.1, Borland International, Tokyo, Japan) was used for the programming. A 32 bit personal computer with i486-DX4 CPU (PC-9821 Xn, NEC Corp., Tokyo, Japan) was used for the programming and data processing.

RESULTS

Process of CAD

The CAD process was based on that for crowns. The chart of the process is shown in Table 1. A brief explanation of the process in this table is as follows ;

- 1) Deforming the outer shape of the standard data of the second premolar and second molar similar to that of the margin of the dies and applying them.
- 2) Inserting the pontic data between the second premolar and second molar keeping a small clearance between the adjacent molars.
- 3) Introducing the bite data of opposing teeth, and modulating the position and the shape of applied molars and the pontic in order to adjust the occlusal relationship with opposing teeth.
- 4) Introducing the FGP data of opposing teeth, and trimming the interference of applied crown data with FGP data.
- 5) Connecting the occlusal clearances between the pontic and the adjacent applied crown of the molar.
- 6) Connecting the end of the applied premolar and molar with the margin of the dies.
- 7) Connecting the bottom clearance between the pontic and adjacent applied crown.
- 8) Extracting the data of the die above the margin, and using it for the inner data

Table 1 Flow chart of the process for bridge restoration by CAD.

of the crown, and completing the CAD for the bridge. Detailed procedures are mentioned in the following section.

Primary application of standard crown and pontic data

The computer graphics (CG) of the measured molar die and the adjacent teeth are shown in Fig. 1 c) by the wire frame model from nearly the same perspective drawing angle as in Fig. 1 a). In the figure, the margins of the second premolar and second molar are shown in circuitous curves. They were determined by calculating the gradients between adjacent data in each wire frame line of the die in Fig. 1 c). Detail procedures were mentioned in a previous paper¹⁰⁾. The measured standard data of the second premolar and second molar are shown in Fig. 2 a) and b). The pontic data were divided to two parts; occlusal and bottom are shown in Fig. 2 c) and d) respectively.

The primary CAD process to adjust and apply the measured standard data on the die was carried out on the CG drawn from three directions as shown in Fig. 3. In the application of the second premolar and second molar on the dies, the outer shapes of these molars were initially deformed to be similar to the margin of each die, and applied according to the method developed in the CAD for crowns¹⁰⁾. For the pontic, the measured standard data were inserted between two adjacent molars. The position, size and shape of the applied molars and pontic could be changed arbitrarily by eleven adjusting parameters including expansion, shift, shearing and swelling as in the case of CAD for crowns, and set correctly considering the relative position with adjacent teeth.

The connection between the pontic and the adjacent two molars was not com-

Fig. 2 CG drawings of the standard shape data measured.

- a) second premolar
- b) second molar
- c) upper half pontic
- d) lower half pontic

Fig. 3 Primary application of the standard molars and pontic on the die. CG drawing from the buccal, occlusal and mesial view.

Fig. 4 The bite data introduced to the primary application of the standard molars and pontic for the adjustment of the occlusion.

Fig. 5 The FGP data introduced to the primary application of the standard molars and pontic for the modulation of the occlusal surface considering the excursion of the opposing teeth.

Fig. 6 a) Connection of the clearances between the pontic and molars on the occlusal surface.

Fig. 6 b) Connection of the clearances between the pontic and molars on the bottom surface.

pleted at this stage, and a clearance of less than 1.0 mm was left between them.

Adjustment of centric occlusion with opposing teeth

According to the process mentioned above, the standard data were applied, but the occlusion with the opposing teeth was not considered at this stage. The opposing tooth data which were the measured bite data were then indicated in the CG as in Fig. 4, as yellow lines or dots. In the occlusal view only the cusps of the opposing mandibular molar were shown in order to recognize the occlusal condition with the applied molar. In this CG the interfered region of the applied molar or pontic with the bite data was shown by blue areas as indicated by the arrows in the occlusal view. According to the initial adjusting parameters used in Fig. 3, the interference of the second molar with the bite was found to be prominent. Therefore, as shown in Fig. 4, the position of the second molar was depressed by 0.50 mm. Even in this condition, interference at the maximum depth of 0.35 mm was still observed. In order to obtain better occlusion, further depression in the position was expected, however, interference with the die occurred since the minimum clearance between the die and the applied second molar was only 0.40 mm. These numerical values of clearance and interference were shown in the CG. The process of adjustment to obtain better occlusion is discussed later. In this case the interference was left especially at the buccal side of the second molar, and was eliminated by the next step of occlusal surface modulation by FGP data .

Occlusal surface modulation by FGP data

After adjustment with the opposing teeth, the bite data were replaced by the FGP data, as shown in Fig. 5. In comparison with Fig. 4, the blue areas increased and were observed even on the lingual side of the second premolar, meaning a further increase in interference, which threatened excursion during mastication. Accordingly, the interfered areas in the applied data were trimmed by replacing them with the corresponding data of FGP records. Thus, the occlusal surface of the applied molar could be modified and saved.

Occlusal surface connection between applied molar and pontic

In the primary application process of the standard crown and pontic, the connection between pontic and adjacent molars was left incomplete. Fig. 6 a) shows the connecting process of the occlusal surface. Using two graphics of the occlusal and mesial view, two proper lines for connection were selected near the contact points as indicated by the arrows, one was in the pontic and another was in the molar as shown by the yellow lines in the mesial view. Some bucco-lingual data lines could then be generated automatically by interpolation calculation as shown by the green line data.

This procedure was carried out in both clearances in the second premolar-pontic and pontic-second molar. The CG after the occlusal surface connection is shown in Fig. 7. The clearances could be smoothly filled. Other notable points are the areas indicated by the arrows. As mentioned in the previous section, these were trimmed

Fig. 7 CG drawing of the connected occlusal surface of the bridge.

Fig. 8 Connection of the ends of the applied second molar with their margin.

by the FGP data to avoid interference by occlusal movement.

Connection between end of applied molar and margin of die

In the application of the standard molars, only the occlusal surface data were used so that the data could apply to the various shapes of dies. To design the entire bridge restoration, it was necessary to connect the end of the applied molar with the margin of the die. This was carried out by improving the CAD program for crowns, and the successive operation of connection in the second premolar and that of the molar were accomplished. Fig. 8 shows the connection in the case of the second molar. The left illustration is a distal view and the right, a mesial view. As for CAD for crowns, the data lines of the applied molar near the distal and mesial contacts with undercut were supplied by the arcs by specifying four appropriate data points manually in the CG using a mouse, and linking them by the third order B-Spline function. Other lines were automatically connected by the parabolic function between corresponding two

Fig. 9 CG drawing of the restored bridge based on the data of the stone model.

Fig. 10 CG drawing of the bridge completed by CAD.

points at the end of the applied molar and margin of the die.

Bottom surface connection between applied molar and pontic

The connection of the bottom surface between the applied molar and pontic was carried out as shown in Fig. 6 b). The same program used in Fig. 6 a) was available by rewriting the drawing condition. As in the case of the surface, a couple of data lines of the adjacent molar and pontic were selected by the mouse, and then data lines to fill the clearance were generated by the calculation. This procedure could not be accomplished in the former connection of occlusal surface in Fig. 6 a) since the data lines of the molar to be selected were generated by the process of connection between the end of the applied molar and the margin of the die in Fig. 8.

Presentation of restored bridge and subtraction of whole data of bridge

The bridge was restored by the above mentioned application and connection, and the resulting CG is shown in Fig. 9. In this program, the die data above the marginal line of the second molar and premolar were subtracted, and were used as the inner shape of the bridge data. They were linked with the applied molar data through the connective data and composed the whole data for the CAD bridge. The CG of the designed bridge is shown in Fig. 10 in the mesio-buccal view. Thus, bridge restoration was accomplished by an originally developed CAD program.

DISCUSSION

The shape and the deformation parameter of the pontic

Several types of the pontic are used clinically. In the present case, the sanitary type which was simple and the most popular was selected, and the whole shape of the

Fig. 11 The earlier version of primary application of the standard molars and pontic on the die. Additional protrusions were situated on the mesial and distal contact points in the pontic to connect with the adjacent molar.

pontic which was composed of the occlusal and the bottom surfaces were measured. In the primary application process these data were used as a couple, and the shape shift and deformation parameters of both sets of data were operated identically. The enlarged parameter in the z direction could be adjusted independently since the occlusal surface data could be adjusted with bite or FGP data while the bottom data were adjusted with the alveolar ridge.

Primary application and bite adjustment

In the primary application of molar and bite adjustment in Figs. 3 and 4, the numerical values of minimum clearance between the applied molar and die or bite were indicated in the CG, to help determine their relative position in the design process. By referring to these values, bite adjustment was carried out as shown in Fig. 4, but even in this upmost condition, the interference of the occlusal surface with the bite maximum of 0.35 mm was observed on the buccal cusps.

In the present program eleven parameters including expansion, shift, shearing and swelling were prepared to deform the applied molar, but they operated and deformed the shape data as a whole, and could not shift or deform the selected interfered cusp only. To obtain a better occlusal relationship with the bite, the shift or deformation in the selected cusp of the applied molar or pontic should be carried out. This will also reduce the amount of the occlusal surface to be trimmed by FGP data, however, in the present case, several hollows existed as shown by the arrows in Fig. 7. Improvement in the program concerning the cusp deformation process which indicates the region of the cusp and which can be dragged by the mouse is under development, and will be reported at a later date.

Connection between applied pontic and molar

This will be the most complicated and distinctive process in the present CAD for bridge restoration. In the earlier version we put two additional protrusions in the mesial and distal contact points of the pontic model to utilize connection with the adjacent molar. These data were applied and connection with the molar was attempted as shown in Fig. 11. However, the position of the protrusions were not always located in the suitable contact point in the adjacent molar, and it was inconvenient to change their size or position independently since they were part of the pontic data and were deformed together with the pontic data.

Therefore, the protrusions were removed, and clearance was situated in the primary application process. After the shape and the relative position of the applied molar and pontic were determined by adjustment with the bite and FGP data, the clearances were filled by the interpolation calculation. This method is a more flexible and is applicable way in making connection.

In the present CAD for bridge restoration, many manual operations are still required. Their replacement by automatic process as much as possible is under consideration, and a CAM process to fabricate the bridge using present CAD data is also in progress.

CONCLUSION

The original CAD process for bridge restoration was developed. The shape data of the standard crown of a second premolar and a second molar were deformed similar to the shape of each margin, and was applied on the dies. The pontic data were inserted between the molars. The bite data were introduced, and the occlusal relationship with the applied molars were adjusted. The bite data were replaced by the FGP data, and the occlusal surface interfering with FGP data were eliminated. The connection process was then undertaken. The clearances between the pontic and molars were connected, and in addition, the ends of the applied second molar and premolar were connected with the margin of each die. Finally, the data above the margin of each die were extracted and used as the inner crown data of the bridge.

Thus, the entire bridge was designed using an originally developed computer program.

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REFERENCES

- 1) Duret F., Bloulin J. L. and Duret B.: CAD-CAM in dentistry, *JADA* 117(11): 715-720, 1988.
- 2) Rekow E. D.: Dental CAD/CAM systems, *JADA* 122(12): 43-48, 1991.
- 3) Moermann W. H., Brandestini M., Lutz F. and Barbakow F.: Chairside computer-aided direct ceramic inlays, *Quintessence Int* 20(5): 329-339, 1989.
- 4) Andersson M., Bergman B., Bessing C., Ericson G., Lundquist P. and Nilson H.: Clinical results with titanium crowns fabricated with machine duplication and spark erosion, *Acta Odontol Scand* 47: 279-286, 1989.
- 5) Kimura H., Sohmura T. and Watanabe T.: Three dimensional shape measurement of teeth (Part 3) On the measurement by the newly developed laser displacement meter with double sensors, *J Osaka Univ Dent Sch* 30: 31-37, 1990.
- 6) Kimura H. and Sohmura T.: Three dimensional shape measurement of teeth (Part 7) —CAD of crown prosthesis by using the data measured—, *J J Dent Mat Dev* 9(6): 806-811, 1990. (in Japanese)
- 7) Akao T., Takahashi J., Sohmura T., Kimura H., Nakamura T. and Maruyama T.: A study of dental CAD/CAM for laminate veneer restoration, *Advanced Prosth World-wide*: 476-477, 1991.
- 8) Sohmura T., Takahashi J.: Improvement of CAD to produce crown by considering occlusion, *Dent Mater J* 12(2): 190-195, 1993.
- 9) Sohmura T., Takahashi J.: CAD/CAM fabrication of dental prostheses —Fabrication of a crown by CAM—, *J J Dent Mat Dev* 13(1): 61-66, 1994. (in Japanese)
- 10) Sohmura T., Takahashi J.: Use of CAD/CAM system to fabricate dental prostheses. Part 1: CAD for a clinical crown restoration, *Int J Prosthodont* 8(3): 252-258, 1995.
- 11) Maeda Y., Minoura M., Tsutsumi S., Okada M. and Nokubi T.: A CAD/CAM system for removal denture. Part 1: Fabrication of complete dentures, *Int J Proth* 7(1): 17-21, 1994.
- 12) Hotta Y.: Fabrication of titanium coping using the CAD/CAM process, *J J Dent Mat Dev* 11(1): 169-178, 1992. (in Japanese)
- 13) Ueda Y., Hikita K., Uchiyama Y. and Kawai M.: The study on CAD system for crown fabrication, *J Jpn Prothodont Soc* 36 (87th Special issue): 165, 1992. (in Japanese)
- 14) Fukase A., Fujita T., Aoki H., Tamaki K., Yamamura M., Yamada S., Watanabe H., Morishige M., Kanematsu K. and Endo Y.: A study of design for coronal morphology by means of CAD. *J Jpn Prothodont Soc.* 36(5): 1092-1101, 1992. (in Japanese)
- 15) Pankey L. D., Mann A. W. and Schuyler C. H.: The teaching manual for the Pankey-Mann-Schuyler philosophy of occlusal rehabilitation; The occlusal rehabilitation seminar (4th ed.), 1969.

本号掲載論文の和文抄録

各種コラーゲン強化法のコラーゲン薄膜の 機械的強さに及ぼす影響について

小出 武, 大東道治

大阪歯科大学小児歯科学講座

各種コラーゲン強化法と象牙質強化との関連性を検討している。本研究ではI型コラーゲンを主成分としたコラーゲン薄膜を用い、紫外線照射、タンニン酸およびグルタルアルデヒド溶液浸漬後、引張試験、膨潤性試験および抗酵素性試験を実施した。作用時間の延長とともに

に引張弾性率は大きくなったが、引張破壊伸びは小さくなり、脆くなった。この傾向は紫外線照射で著明であった。また、タンニン酸は、他の2方法と比べると架橋の進行速度は遅かった。抗酵素性はタンニン酸およびグルタルアルデヒド作用で著明に上昇した。

歯科修復物製作用 CAD/CAM システム —ブリッジ修復用の CAD について—

莊村泰治, 高橋純造

大阪大学歯学部歯科理工学講座

ブリッジ修復用の CAD プロセスを開発し、それを用いて上顎の3本ブリッジの CAD による修復を試みた。

まず、標準的な第二小白歯および大白歯の三次元形状計測データを変形して支台歯に試適させた。ついで計測したポンティックのデータをその間に挿入した。ここに対合歯バイトデータを取り込んで、試適した歯冠データとの咬合関係を調整した。その後、バイトデータを FGP データに取り替え、FGP データと干渉する歯冠の部分は取り除いた。

次いで、連結プロセスを行った。つまり、ポンティックと隣接歯冠の隙間をデータ補間によって連結した。そして試適した第二小白歯と大白歯クラウンの端部と各々の支台歯のマージンとを連結した。

最後に各々の支台歯のマージンより上部を抽出して、ブリッジのクラウン内冠部のデータとして用いた。

このようにして今回開発したプログラムでブリッジ全体の設計が行えるようになった。

疎水性メタクリレートモノマーを応用した新規床用レジン基礎的研究

楳本貢三, 倉田茂昭¹

神奈川歯科大学歯科理工学教室

¹神奈川歯科大学歯科生体工学教室

PMMA レジン材料の臨床上の欠点である吸水性を改善するために、ノルボルニル基 (NBMA) やフェニル基 (PHMA) をもつ新規疎水性モノマーを用い、MMA との共重合により、ポリマーの主鎖中へ疎水性

基を導入し、レジンの機械的強さを損なうことなく、吸水性を低下 (制御) する可能性を検討した。その結果、これらコポリマーの吸水量は疎水性モノマーの添加量と共に大幅に減少した。また、圧縮および曲げ強さは