

A technique for fabricating patterns for removable partial denture frameworks using digitized casts and electronic surveying: A pilot study

R. J. Williams, BA (Hons), PhD,^a Richard Bibb, BSc (Hons), PhD,^b and Tahseen Rafik, BSc (Hons), MSc, PhD^c

Centre for Dental Technology^a, National Centre for Product Design & Development Research^b and School of Product and Engineering Design^c, University of Wales Institute, Cardiff, United Kingdom

ABSTRACT

Although computer-aided design and manufacture techniques have shown some promising applications in the fabrication of crowns, inlays, and maxillofacial and oral surgery, the field of removable prosthodontics has not embraced these technologies so far. This study developed and investigated computer-aided techniques that may eventually enable prosthodontic procedures such as surveying and the production of sacrificial patterns to be performed digitally. A 3-dimensional computer model of a conventional cast from a patient was obtained using an optical surface capture device (a scanner). The shape of a number of components of a removable partial denture framework was modelled on the 3-dimensional scan electronically using computer aided design software. A physical plastic shape of the components was produced using a Rapid Prototyping machine and used as a sacrificial pattern. Techniques to allow digital cast surveying before the production of sacrificial patterns were also developed. The results show that

digital dental surveying and machine-produced sacrificial patterns can be accomplished. The study forms a basis for further developments leading to a fully integrated approach to the computer-aided design and fabrication of removable partial denture frameworks.

INTRODUCTION

Computer Aided Design and Manufacture (CAD/CAM) techniques have been successfully introduced in the field of fixed partial dentures^{1,2} and maxillofacial technology^{3,4} over a number of years. The development^{5,6} and evaluation⁷⁻⁹ of these advances continue. Advantages of such systems have been well-documented¹⁰ and may well eventually become the 'next generation' of methods of fabrication.

To date, however, CAD/CAM production of metal removable partial denture frameworks has remained only a theoretical possibility. Yet, the potential benefits possibly exceed those noted for the field of fixed partial dentures. For example, if electronic surveying programs can be developed, digitized surveying of a 3D scanned dental cast may be almost instantaneous.

Various methods of scanning are used throughout dentistry including laser and lined light.^{11,12} The scanner used in this study was an optical system that used projected light and digital camera technology to capture approximately 140,000 points in 3D on the surface of the object, termed a 'point cloud'. The scanner can only collect data on surfaces within the line of sight. Areas on the surface that are obscured or at too great an angle to the line of sight will not appear in the scan data. Moving either the object or the scanner and repeating the process overcomes this problem. For a cast of a patient, several scans may be necessary.

Computer software was then used to create surfaces from these points. This method creates the surface of a 3D object by approximating the point cloud with a series of connected

triangular facets. These triangular faceted models, termed a stereolithography or STL file. These triangular faceted models, termed stereolithography or STL files, are commonly used in transferring CAD models to Rapid Prototyping (RP) technologies (Manners, C. R., 1993, “STL File Format” obtained on request from 3D Systems Inc., Valencia, California). The quality of such a file is a function of how closely the triangular facets approximate the original surface. A large number of small facets will provide a higher quality of surface model but at the expense of increased file size. It is common to adjust the compromise between quality and file size to suit the given application. The triangle size for the present study was comparatively large to minimize file size thus enabling easy and rapid data manipulation during the research. Greater accuracy may be achieved with smaller triangles for methodology that may be eventually used for patients.

It was necessary to develop an electronic method of surveying for this process. Electronic surveying of a scanned cast enables a pattern for a metal framework to be fabricated on the computer screen (Surface Studio; Alias-Wavefront, Toronto, Ontario, Canada) according to the principles of removable partial denture design.^{13,14} Programs were written for this study using mathematical software (MatLab; The MathWorks Inc., Natick, Mass) that reads in triangular faceted surface models (using the STL file format). Identification of a survey line was achieved electronically by writing a mathematical program that identified all downward facing surface triangles on the computer scan described above. In the interest of reducing memory requirements and therefore increasing processing speed when creating programs, the software was developed using a simple cylinder shape. As work progressed, a ‘barrel’ shape (Fig. 1) was used for development. The program defined the surface area of teeth apical to the survey line by identifying the downward facing triangles. The upper boundary of this area defined the survey

line. As in physical dental cast surveying, the electronic survey line is affected by the inclination of the cast. A series of rotational transformations allowed survey lines at various tilts of the cast to be identified. Figure 2 shows the barrel with a tilt of 20 degrees. The effects when these programs are transferred to larger files of surface models of a scanned tooth and a cast are shown in Figures 3 and 4.

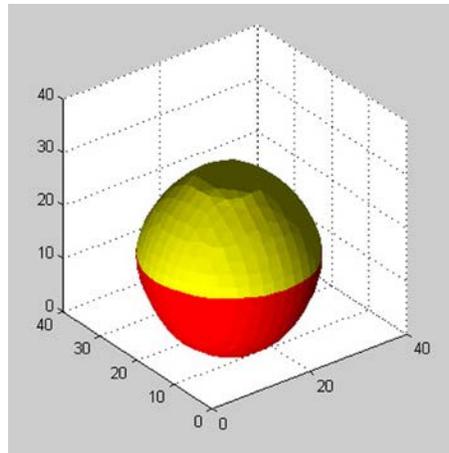


Fig. 1. Illustration of program identifying undercut and non-undercut areas electronically.

File size: 56 KB.

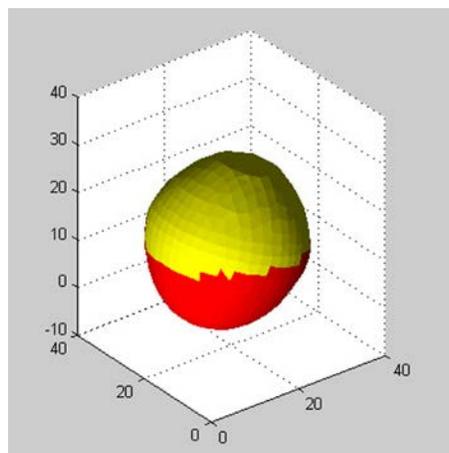


Fig. 2. Same shape tilted and new survey line electronically identified by program.

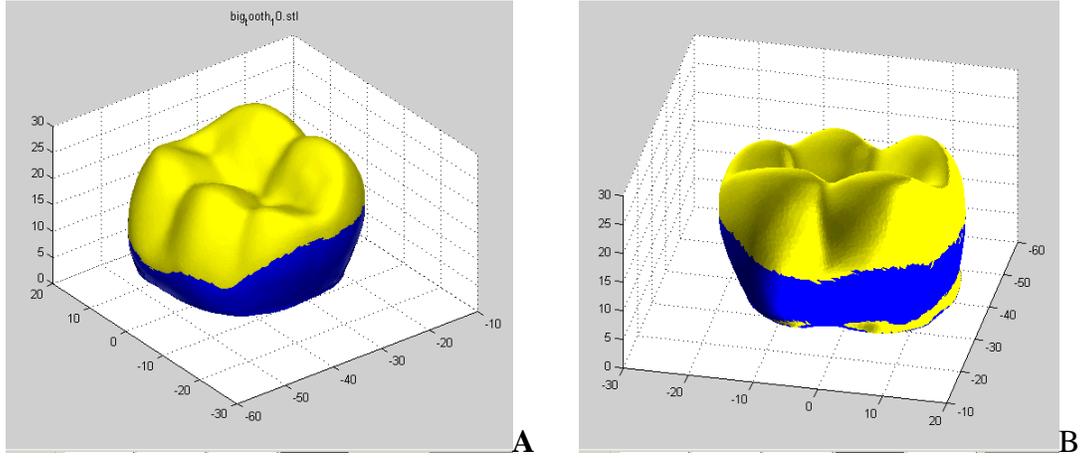


Fig. 3. A, Program used to identify survey line on 3-D scan of model of large tooth – distobuccal view. File size: 517 KB. B, Lingual view of the electronically surveyed tooth shown in A.

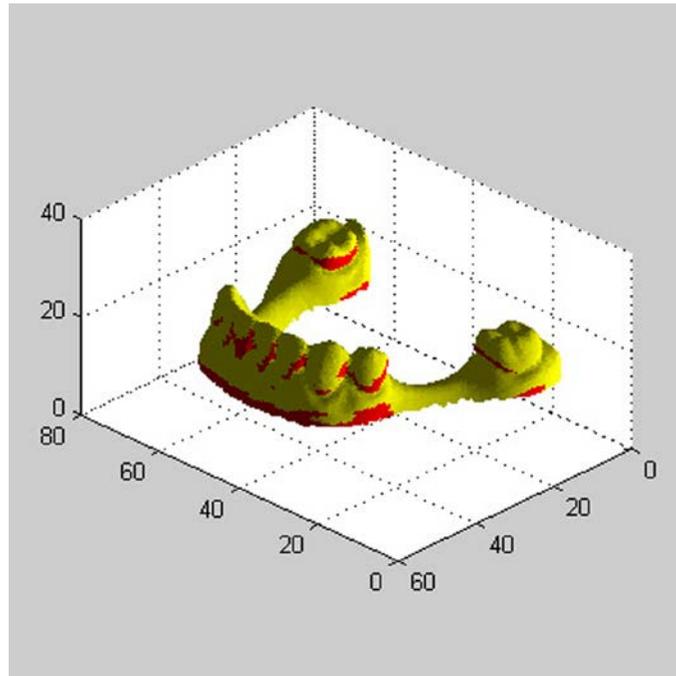


Fig. 4. Undercuts electronically identified on surveyed cast. File size 2764 KB.

Most of the current methods utilizing CAD/CAM fabrication techniques in dentistry have concentrated on milling from a solid block of material. However, machining complex shaped, thin-walled metal plates, bars or clasps required for a removable partial denture is difficult to achieve. The problems of securing the work piece to the bed of the milling machine and deflection of the thin walled work piece under machining load are well documented in the machining industry.¹⁵

This study developed and investigated digital techniques that may eventually enable removable prosthodontic procedures such as surveying and the production of sacrificial patterns to be performed digitally using CAD/CAM and RP techniques.

In this article 2 simple clasps, guide planes and a connector were designed (Fig. 5, A) using CAD based on a scan of a cast of the posterior section of a patient's mandibular left arch with the first premolar and second molar present and the second premolar and first molar absent. Due to the experimental nature of the study, occlusal rests were not added to simplify the casting.

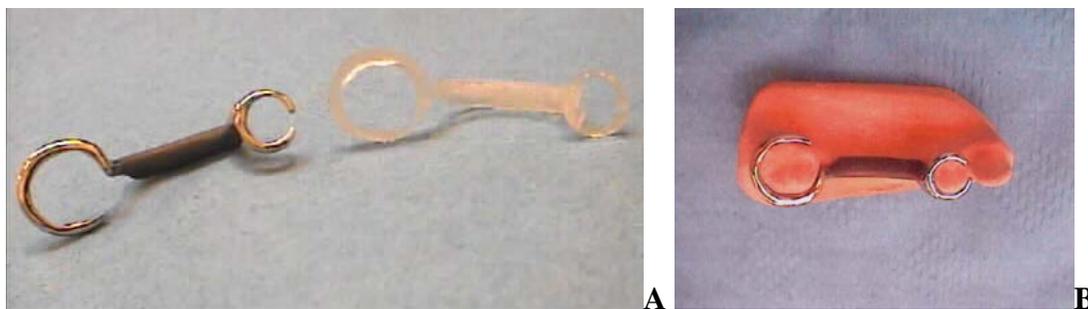


Fig. 5. A, Plastic pattern is shown on the right and casting produced similar pattern on left.

B, Casting finished and fitted to cast used for article

TECHNIQUE

3D Surface Capture

1. Obtain a 3-dimensional computer model of a cast of a patient using an optical surface capture device (Comet 250 scanner; Steinbichler Optotechnik GmbH, Neubeuern, Germany).
2. Align and combine the data points from each of these scans using CAD software, (Polyworks; InnovMetric Software Inc, Sainte-Foy, Quebec, Canada) to provide a single coherent data set of the entire object. Use the resultant data points (termed a 'point cloud') to create a 3-dimensional surface model.
3. Produce a solid 3-dimensional computer model on screen using a triangular faceted polygon mesh (EvalViewer; Alias-Wavefront Inc).

3D Computer Aided Design

4. Electronically survey the scan using the MatLab software package described above. The depth of undercut can be copied from the definitive cast to determine clasp termination.
5. Model the shape of the components of a removable partial denture framework on the scanned surface model using 3-dimensional CAD software (Surface Studio; Alias-Wavefront)
6. Use a RP (stereolithography) machine (SLA 250/40; 3D Systems Inc, Valencia, Calif) to produce a plastic (WaterClear 10110 Epoxy Resin for Stereolithography; DSM Somos, New Castle, Delaware, USA) physical model of the components described above. Use RP processes to create a sacrificial pattern of a removable partial denture framework, to be incorporated directly into existing casting procedures found in the typical dental laboratory.¹⁴

Fabrication

7. Use the sacrificial pattern to invest, cast, and finish¹⁴ (Fig. 5).

DISCUSSION

This method of production was established as sound by visual inspection, as is the case with most removable partial denture frameworks used for patients. Much work must be achieved before the above methods can be fully applied to the fabrication of metal removable partial denture frameworks. The disadvantages of the methods at this time include the cost of the scanning equipment, CAD software and RP techniques. Furthermore, a degree of time and experience is needed to create a valid surface from scanned 'point cloud' data. However, as familiarity with this technology increases and more sophisticated software becomes available, these issues may be addressed so that the anticipated time to create a solid computer model from the scanned data may take a matter of minutes. The time required for the computer to calculate the survey line may similarly be achieved in a matter of minutes when software is developed using a more sophisticated programming environment. This may then compare favorably with the considerable amount of time required to manually survey a cast.

Another possible difficulty arising during this project was that some mold cracking appeared to develop at the investing stage resulting in small fins appearing on the divested casting. This may be due to expansion of the plastic pattern resulting from exothermic heat of the investment material during setting. However, utilizing other RP technologies to allow a plastic pattern to be replaced by a wax pattern may overcome this problem. The authors are investigating these matters.

The adoption of CAD/CAM techniques may be highly advantageous in the field of removable partial dentures. The electronic surveying technique described above allows the almost instant identification of survey lines but is only the first step in the development of dedicated dental design software. Future developments may enable the computer to automatically determine a suggested path of insertion and, with further research, unwanted undercuts could be eliminated and useful undercuts identified. At another stage, components of a removable partial denture could be stored in a library and 'dragged and dropped' in place on a scanned and surveyed cast from icons appearing on screen. This would allow virtual patterning to be carried out in a much faster time than is achieved by current techniques. In addition, as RP machines build the object directly, scaling factors may be precisely imposed that may compensate for shrinkage in casting. In addition to the potential time savings, the CAD/CAM process also delivers inherent repeatability, which may help to eliminate operator variation and improve quality control in the dental laboratory.

SUMMARY

This article has shown that rapid prototyping (RP) processes may be a more appropriate CAD/CAM fabrication method for the thin-walled, complex shapes, typical of removable partial denture frameworks than milling. This study demonstrated that automation of the surveying process is possible.

The authors thank Mr Mohammad Ibn Mgren for his help in developing a routine central to this article.

REFERENCES

1. Rekow D, Computer-aided design and manufacturing in dentistry. *J Prosthet Dent* 1987; 58: 512-516
2. Duret F, Preston J, Duret B. Performance of CAD/CAM crown restorations. *J Calif Dent Assoc* 1996; 9: 64-71
3. Bibb R, Freeman P, Brown R, Sugar A, Evans P, Bocca A. An Investigation of three-dimensional scanning of human body parts and its use in the design and manufacture of prostheses. *Proc Inst Mech Eng [H]* 2000; 214: 589-594
4. Hughes CW, Page K, Bibb R, Taylor J, Revington P. The custom-made titanium orbital floor prosthesis in reconstruction for orbital floor fractures. *Br J Oral Maxillofac Surg* 2003; 41: 50-53
5. van der Zel J, Vlaar S, de Ruiter W, Davidson C. The CICERO system for CAD/CAM fabrication of full ceramic crowns. *J Prosthet Dent* 2001; 85: 261-7
6. Mormann WH, Bindl A. The Cerec 3--a quantum leap for computer-aided restorations: initial clinical results. *Quintessence Int* 2000; 31: 699-712
7. Addi S, Hedayati-Khams A, Poya A, Sjogren G Interface gap size of manually and CAD/CAM-manufactured ceramic inlays/onlays in vitro. *J Dent* 2002; 30: 53-8
8. Chen Hong Yong, Hickel Reinhard, et al. Effects of surface finish and fatigue testing on the fracture strength of CAD-CAM and pressed ceramic crowns. *J Prosthet Dent* 1999; 82: 468-475.
9. Martin N, Jedynakiewicz NM Interface dimensions of CEREC-2 MOD inlays. *Dent Mater* 2000; 16: 68-74
10. Otto T, De Nisco S. Computer-aided direct ceramic restorations: a 10-year prospective clinical study of Cerec CAD/CAM inlays and onlays. *Int J Prosthodont* 2002; 15: 122-8

11. Brosky ME, Pesun IJ, Lowder PD, DeLong R, Hodges JS. Laser digitisation of casts to determine the effect of tray selection and cast formation technique on accuracy. *J Prosthet Dent* 2002; 87: 204-9
12. Sohmura T, Kojima T, Wakabayashi K, Takahashi J. Use of an ultrahigh-speed laser scanner for constructing three-dimensional shapes of dentition and occlusion. *J Prosthet Dent* 2000; 84: 345-52
13. Budtz-Jorgensen E, Bochet G. Alternate framework designs for removable partial dentures. *J Prosthet Dent* 1998; 80: 58-66
14. MacGivney GP, Carr AB. McCracken's removable partial prosthodontics. 10th ed. St Louis: Mosby; 2000. p. 173-196
15. Smith S, Dvorak D. Tool path strategies for high speed milling aluminium work pieces with thin webs. *Mechatronics* 1998; 8: 291-300

LEGENDS

Fig. 1. Illustration of program identifying undercut and non-undercut areas electronically. File size: 56 KB

Fig. 2. Same shape tilted and new survey line electronically identified by program.

Fig. 3A. Program used to identify survey line on 3D scan of model of large tooth – distobuccal view. File size: 517 KB Figure 3, B Lingual view of electronically surveyed tooth shown in Figure 3, A

Fig. 4. Undercuts electronically identified on surveyed cast. File size: 2764 KB

Fig. 5A. Plastic pattern shown on right and casting produced from similar pattern shown on left.

Fig. 5B. Casting finished and fitted to cast used for pilot study.