

New Approach to 3D Printing of Facial Prostheses Using Combination of Open Source Software and Conventional Techniques: A Case Report

Nafij B Jamayet¹⁾, Yap J Abdullah²⁾, Zainul A Rajion³⁾, Adam Husein⁴⁾ and Mohammad K Alam⁵⁾

¹⁾ *Maxillofacial Prosthetic Service, School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, 16150, Kelantan, Malaysia*

²⁾ *Research and Innovation Unit, School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, 16150, Kelantan, Malaysia*

³⁾ *Craniofacial Medical Imaging, School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, 16150, Kelantan, Malaysia*

⁴⁾ *Prosthodontic Unit, School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, 16150, Kelantan, Malaysia*

⁵⁾ *Orthodontic Department, College of Dentistry, Al Jouf University, Sakaka, 2388, Kingdom of Saudi Arabia*

Received 20 January, 2016/Accepted for publication 1 August, 2016

Abstract

The wax sculpting of a maxillofacial prosthesis is challenging, time-consuming, and requires great skill. Rapid prototyping (RP) systems allow these hurdles to be overcome by enabling the creation of a customized 3D model of the desired prosthesis. Geomagic and Mimics are the most suitable software programs with which to design such prostheses. However, due to the high cost of these applications and the special training required to operate them, they are not widely used. Additionally, ill-fitting margins and other discrepancies in the final finished products of RP systems are also inevitable. Therefore, this process makes further treatment planning difficult for the maxillofacial prosthodontist. Here, we report the case of a 62-year-old woman who attended our clinic. Initially, she had presented with a right facial defect. This was later diagnosed as a squamous cell carcinoma and resected. The aim of this report is to describe a new technique for the 3D printing of facial prostheses which involves the combined use of open-source software, an RP system, and conventional methods of fabrication. The 3D design obtained was used to fabricate a maxillofacial prosthesis to restore the defect. The patient was happy with the esthetic outcome. This approach is relatively easy and cheap, does not require a high degree of non-medical training, and is beneficial in terms of clinical outcome.

Key words: 3D printing — Rapid prototyping (RP) system — Marginal discrepancy

Introduction

The surgical removal of oro-facial tumors may cause facial disfigurement, which can result in psychological disorders. The alteration of facial structures in the treatment of cancer often causes great difficulties in terms of social relationships and economic circumstances, which in turn can affect quality of life¹⁾. Small defects can now be restored using microvascular flaps. This may not be an option in some patients, however, due to the size of the defect, age-related considerations, complications arising from radiation therapy, or the patient's general medical condition. In such cases, a maxillofacial prosthesis could serve as a viable and definitive alternative⁷⁾.

A number of methods for constructing facial prostheses have been proposed, and all involve the contra-lateral matching of the anatomic morphologies of the face^{2,5,10,11)}. Computer-aided design (CAD), computer-aided manufacturing (CAM), and other rapid prototyping (RP) techniques have also recently been introduced as tools for use in this field^{3,4,18)}. Rapid prototyping techniques basically involve an additive procedure, in which the desired object is constructed layer-by-layer to specifications obtained by virtual slicing in a computerized 3D model^{15,16,19)}. The production of a variety of anatomical shapes and features is possible in a very short period of time using this method¹³⁾. However, with current CAD/CAM systems, it is still not possible to create the wax patterns required for a facial prosthesis as they do now allow for adaptable margins or no margin gaps^{8,17,18)}. To solve this issue, this clinical report describes a new technique for the construction of a 3D-printed facial prosthesis which uses a combination of conventional and RP methods and open source software.

Case Report

A 62-year-old woman presented at the Maxillofacial Prosthetic Service at the School of Dental Sciences of the Universiti Sains in



Fig. 1 Right-side facial defect

Malaysia with a right facial defect after resection of a tumor diagnosed as a squamous cell carcinoma (Fig. 1). Initially, the patient presented with a severely painful skin ulcer, which later penetrated the skin, invading the bone beneath. This lesion was subsequently diagnosed as a squamous cell carcinoma based on a biopsy. The whole lesion was excised, resulting in the concomitant loss of a portion of the malar bone and associated buccinator, masseter, and zygomaticus muscles.

1. Impression procedures

Three, single-piece partial facial impressions were planned (Fig. 2). Light-body polyvinyl siloxane (Multisil Epithetik; Dreve-Dentamid, Unna, Germany) was applied to the defect as the first layer, followed by regular-body polyvinyl siloxane impression material (Multisil Epithetik; Dreve-Dentamid). The impression material was then allowed to set. Pieces of tongue blade were incorporated to increase the stability of the material. The previously fabricated boxing wax rim was applied to the appropriate location on the face. Regular-set alginate (Dentsply Int., York, PA, USA) was mixed to a high flow consistency and

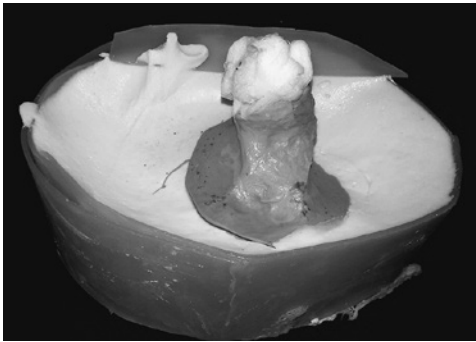


Fig. 2 Three, single-piece impression technique

poured onto the area. A layer of wet gauze was then immediately placed onto the alginate surface and allowed to set. Once it had set, a layer of plaster mixed with slurry water was applied to the surface of the gauze. The impression was cast with a type IV dental stone (Dental Vision, Bangkok, Thailand) according to the manufacturer's instructions and allowed to set.

2. 3D design of prosthesis

Computed tomography was conducted using the Siemens Somatom Definition AS + 128-slice (Siemens, Erlangen, Germany) at the Radiology Department of this institute. The obtained images, which had a slice thickness of 1 mm and matrix of 512×512 pixels, were transferred from the Picture Archiving and Communication System Server to a Dell Precision T7500 workstation in a Digital Imaging and Communications in Medicine format. The images were analyzed and processed using the open source MITK Workbench 2014.10.00¹⁴. The MITK Workbench is a versatile and user-friendly application for medical image analysis developed by the German Cancer Research Centre at Heidelberg in Germany. This application is designed to provide a clear distinction between different work areas (Fig. 3).

First, a 3D model of the patient's face was constructed to facilitate design of the maxillofacial prosthesis. A threshold of -200 HU was used to segment soft tissue using 3D tools;

the tissue was visualized in 3D using the "Create smoothed polygon model" function (Fig. 4).

Next, the images were cropped in 2D view using 2D tools to focus on the facial area with the defect. The cropped virtual 3D model was later saved in stereolithography (STL) format and then sent to a 3D printer (Objet30 Scholar, Stratasys, Eden Prairie, MN, USA) for printing of the physical 3D model (Fig. 5).

3. RP fabrication of maxillofacial prosthesis template

Traditionally, a template could be produced by initially taking an impression of the patient's face or of a physical 3D model. Alternatively, the template could be designed by CAD/CAM software. In the present study, the implant was produced by open-source MITK Workbench software, applying shape-based interpolation methods to segment the defects of the face. Here, the defects were manually filled by using the "Add" function in 2D tools. This was done in the coronal view every 5 slices until the defect was covered (Fig. 6).

The segmented coronal slices were interpolated with other slices using a shape-based interpolation method in MITK. The fully segmented template was then saved in STL format and sent to another 3D printer (Makerbot Replicator 2X, Makerbot, Brooklyn, NY, USA). After the 3D printing of the virtual model, the physical 3D template was obtained (Fig. 7).

4. Final prosthesis fabrication

The modified working cast obtained from the initial partial facial impression was used as a mold. Room temperature vulcanizing (RTV) Silicon A 2006 (Factor II, Lakeside, Az, USA) with intrinsic coloration was loaded into the mold to fabricate the final facial prosthesis (Fig. 8), which was attached using Daro adhesive extra strength (Factor II, USA). This water soluble adhesive has shown excellent results in water emulsion. It requires no solvents, and has shown extremely good patient acceptance over the last 20 years. This product is particularly suitable for heavier prosthe-

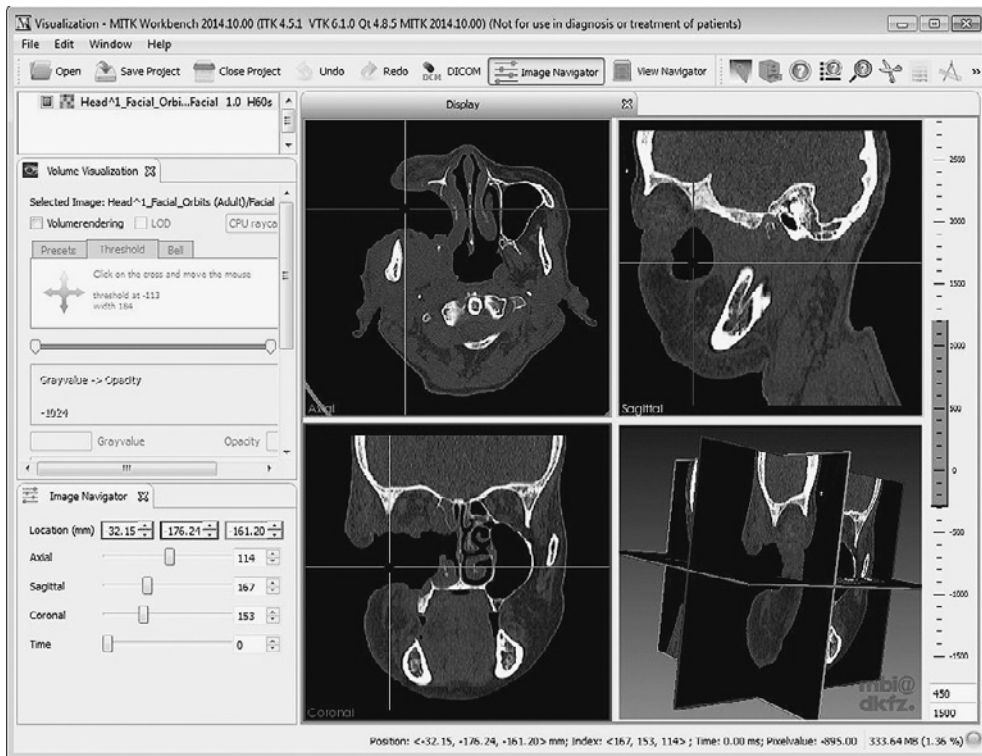


Fig. 3 MITK Workbench graphical user interface

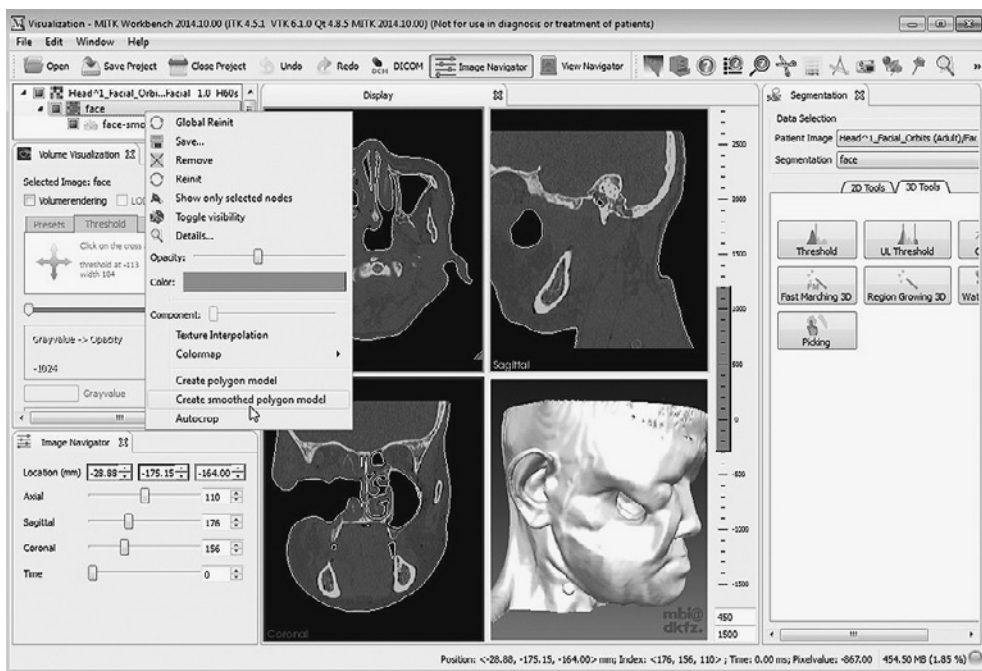


Fig. 4 Processing 2D computed tomography data into 3D using “Threshold” in 3D tools and “Create smoothed polygon model” in MITK Workbench

ses to be worn in climates that are cool and dry. Although initially white, it becomes trans-

parent when dry. Evaluations were performed at 1 week and at 3 months following implantation. No further complaints were voiced by the patient, who subsequently reported a significant improvement in their psychosocial condition and satisfaction with the esthetic outcome.

Discussion

A number of technical procedures have been proposed involving computer-assisted fabrication^{6,12,15)}. The present article describes a simple, inexpensive, and reproducible

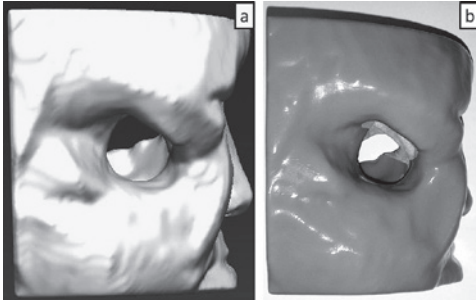


Fig. 5 Virtual (a) and physical 3D models (b)

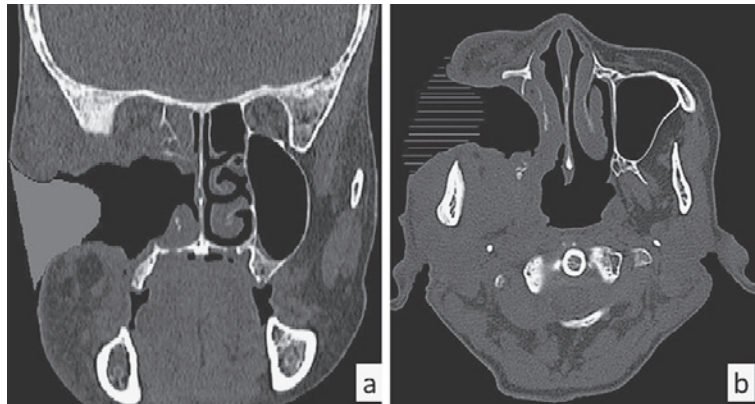


Fig. 6 Hole was manually filled to cover defect (a) every 5 slices; seen in axial view (b)

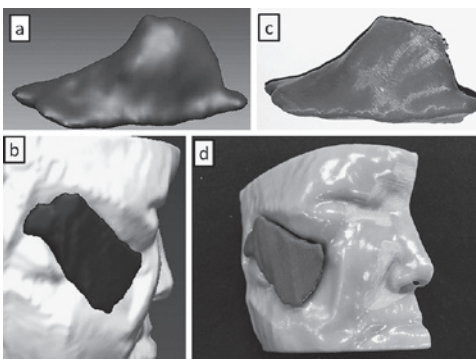


Fig. 7 Virtual model and 3D model inner surface (a) and outer surface (b); physical implant and 3D model inner surface (c) and outer surface (d)

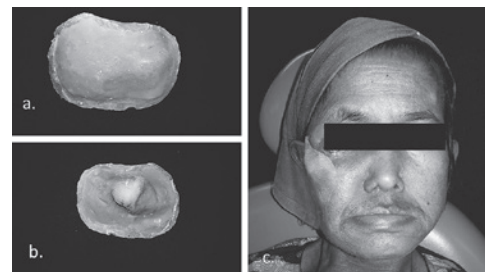


Fig. 8 Final prosthesis: outer surface (a), inner surface (b), and insertion (c)

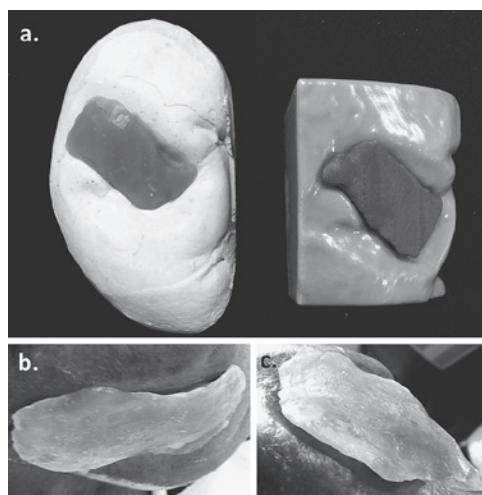


Fig. 9 Conversion of maxillofacial template into wax model (a) and wax try-in revealing marginal gaps (b and c)

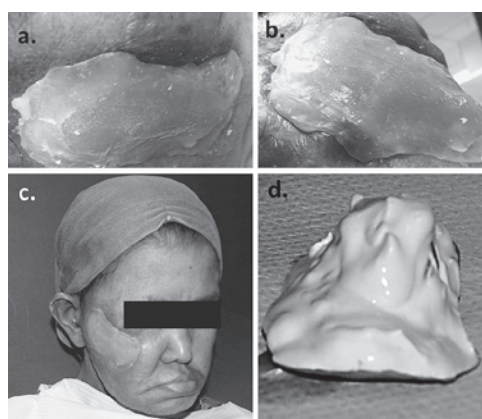


Fig. 10 Wax adaptation to improve marginal gap (a and b); final try in (c) and relining with plaster of Paris (d)

method of obtaining a wax sculpture of a specific maxillofacial prosthesis. Here, MITK software was used to design the prosthesis. The advantage of MITK is that it is open-source, whereas commercial software such as Mimics and Geomagic is very expensive. Moreover, MITK can provide an acceptable prosthesis design, which can later be printed using the economical Makerbot 3D printer. The use of open-source software to perform

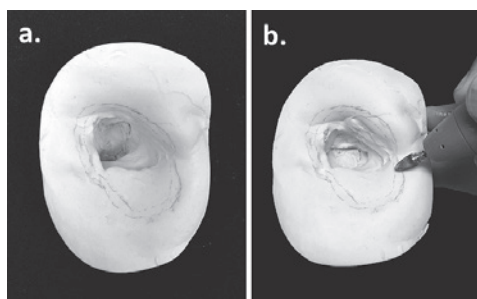


Fig. 11 Final working cast (a) and scraping of cast (b)

image segmentation and design maxillofacial prostheses provides an alternative platform for researchers or prosthodontists in developing research applications without costly software. Using MITK software, 3D models of the prosthesis were individually made based on the size and shape of the defect in the scanned model. Furthermore, one of the major challenges of the RP method is the direct production of wax sculptures with adaptable edge margins, together with the sculpture of other parts of the facial structure. Some evidence indicates that the material or powder used to fabricate the model is not strong or stable enough in thin sections. Moreover, as yet, RP technology does not allow adherence characteristics to be modeled with sufficient precision when dealing with the human face, resulting in materials presenting with open margins at the edges⁹⁾.

Therefore, if the virtual prosthesis to be implanted is directly designed and fabricated to correspond to the healthy side of the face, there is the danger that there will be multiple margin discrepancies at the edges.

To overcome this problem, a new technique was introduced in the current case, one which combines RP and conventional methods. A partial facial impression using light-body and regular polyvinyl siloxane impression materials was obtained and a working cast made by prior 3D design of the prosthesis. After obtaining the prosthesis template, it was converted into a wax model (Fig. 9a). A wax try-in was then performed with the patient, allowing any margin gaps to be identified

(Figs. 9b and 9c). To improve the surface adaptability and integrity of the facial prosthesis, a thin section of base-plate wax was adapted to these areas (Figs. 10a and 10b) and applied to the face of the patient at the final fitting (Fig. 10c). The fitting surface of the adapted wax template was then relined with plaster of Paris (Fig. 10d) and a new working cast fabricated (Fig. 11a). Following that, the new working cast was scraped to a depth of 0.5 mm at the edge of the prosthesis (Fig. 11b). The outer peripheral surface of the rapid-prototyped wax sculpture was then incorporated into the working cast. The final prosthesis was cured using the modified working cast, which over-compressed the prosthesis border edge. The chances of marginal discrepancies were thus reduced and maximum adaptability of the final prosthesis achieved.

However, the operating time and cost between the conventional and 3D model method vary. Software for 3D modeling and the materials required for printing are expensive; meanwhile, the conventional method is cost effective, but the facial prosthesis has to be adjusted for marginal adaptation, thus requiring extensive time and work.

Conclusion

The use of RP systems in the rehabilitation of facial defect cases marks a new era in maxillofacial prosthetics. The clinician must understand the principles and outcomes of digital methods so that potential errors can be minimized. Close collaboration between software experts and maxillofacial prosthodontists is needed to improve results.

Acknowledgements

USM research University team grant no: 1001/PPSG/852004 and USM short term grant no: 304/PPSG/61313144.

References

- 1) Beumer J, Curtis TA, Marunick MT (1996) Maxillofacial rehabilitation: prosthetic and surgical considerations, p.18, Ishiyaku Euro America, St Louis.
- 2) Choi JY, Choi JH, Kim NK, Kim Y, Lee JK, Kim MK, Lee JH, Kim MJ (2002) Analysis of errors in medical rapid prototyping models. *Int J Oral Maxillofac Surg* 31:23–32.
- 3) Ciocca L, Scotti R (2004) CAD-CAM generated ear cast by means of a laser scanner and rapid prototyping machine. *J Prosthet Dent* 92:591–595.
- 4) Coward TJ, Watson RM (1997) Use of laser scanning and CAD/CAM systems in the fabrication of auricular prostheses. *Quintessence Dent Technol* 20:47–54.
- 5) Coward TJ, Watson RM, Wilkinson IC (1999) Fabrication of a wax ear by rapid-process modeling using stereolithography. *Int J Prosthodont* 12:20–27.
- 6) Feng Z, Dong Y, Zhao Y, Bai S, Zhou B, Bi Y, Wu G (2010) Computer-assisted technique for the design and manufacture of realistic facial prostheses. *Br J Oral Maxillofac Surg* 48:105–109.
- 7) Hecker DM (2003) Maxillofacial rehabilitation of a large facial defect resulting from an arteriovenous malformation utilizing a two-piece prosthesis. *J Prosthet Dent* 89:109–113.
- 8) Jiao T, Zhang F, Huang X, Wang C (2004) Design and fabrication of auricular prostheses by CAD/CAM system. *Int J Prosthodont* 17: 460–463.
- 9) Kubon TM (2001) Creating an adaptable anterior margin for an implant retained auricular prosthesis. *J Prosthet Dent* 86:233–240.
- 10) Lemon JC, Chambers MS, Wesley PJ, Martin JW (1996) Technique for fabricating a mirror-image prosthetic ear. *J Prosthet Dent* 75: 292–293.
- 11) Mardini MA, Ercoli C, Graser GN (2015) A technique to produce a mirror-image wax pattern of an ear using rapid prototyping technology. *J Prosthet Dent* 94:195–198.
- 12) McGurk M, Amis AA, Potamianos P, Goodger NM (1997) Rapid prototyping techniques for anatomical modeling in medicine. *Am R Coll Surg Engl* 79:169–174.
- 13) Nolden M, Zelzer S, Seitel A, Wald D, Müller M, Franz AM, Maleike D, Fangerau M, Baumhauer M, Maier-Hein L, Maier-Hein KH, Meinzer HP, Wolf I (2013) The Medical Imaging Interaction Toolkit: challenges and advances: 10 years of open-source development. *Int J Comput Assist Radiol Surg* 8: 607–620.
- 14) Penkner K, Santler G, Mayer W, Pierer G,

- Lorenzoni M (1999) Fabricating auricular prostheses using three-dimensional soft tissue models. *J Prosthet Dent* 82:482–484.
- 15) Runte C, Dirksen D, Deleré H, Thomas C, Runte B, Meyer U, von Bally G, Bollmann F (2002) Optical data acquisition for computer-assisted design of facial prostheses. *Int J Prosthodont* 15:129–132.
- 16) Subburaj K, Nair C, Rajesh S, Meshram SM, Ravi B (2007) Rapid development of auricular prosthesis using CAD and rapid prototyping technologies. *Int J Oral Maxillofac Surg* 36: 938–943.
- 17) Sykes LM, Parrott AM, Owen CP, Snaddon DR (2004) Applications of rapid prototyping technology in maxillofacial prosthetics. *Int J Prosthodont* 17:454–459.
- 18) Tsuji M, Noguchi N, Ihara K, Yamashita Y, Shikimori M, Goto M (2004) Fabrication of a maxillofacial prosthesis using a computer-aided design and manufacturing system. *J Prosthodont* 13:179–183.
- 19) Verdonck HW, Poukens J, Overveld HV, Riediger D (2003) Computer-assisted maxillofacial prosthodontics: a new treatment protocol. *Int J Prosthodont* 16:326–328.

Correspondence:

Dr. Nafij Bin Jamayet
BDS, Grad.Dip.Clin.Sc, M.Sc.Dent
Senior Lecturer
School of Dental Sciences,
Health Campus Universiti Sains Malaysia,
Kubang Kerian, 16150, Kelantan,
Malaysia
E-mail: dr.nafijusm@gmail.com