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Hamit Serdar Çötert
D.D.S., Ph.D., Professor,
Department of Prosthodontics,
İzmir, Turkey, Ege University,
Faculty of Dentistry,
Prosthodontics, 35100,
Bornova, Izmir; Turkey.

Correspondence
Hamit Serdar Çötert
D.D.S., Ph.D., Professor,
Department of Prosthodontics,
İzmir, Turkey, Ege University,
Faculty of Dentistry,
Prosthodontics, 35100,
Bornova, Izmir; Turkey.

Stereolithographic rapid prototyping of ear prostheses

Hamit Serdar Çötert

Abstract
This paper aims to describe the stereolithographic rapid prototyping of the ear prosthesis in an anotia case and to evaluate the advantages and disadvantages. Virtual model of the patient's head was produced from the computerized tomography scan of the patient. Three-dimensional image of the healthy contralateral ear was extracted, inverted and re-located on the virtual model. Data was transferred to the stereolithography unit and the thermoplastic prototype of the prosthesis was made. Prototype was duplicated with set-up wax. Wax prototype was processed with polydimethyl siloxane elastomeric material by using pack and press technique. The system used was easy, time consuming and successful. Nevertheless, high cost and the irradiation during the computerized tomography imaging should be considered.

Keywords: Facial Prosthesis, Ear Prosthesis, Rapid Prototyping, Stereolithography.

1. Introduction
Etiology of the defects of the maxillo-facial region varies from a trauma such as a traffic accident, a gunshot wound or burn injuries, to the removal of a neoplasm. Congenital defects such as micro and/or anotia should also be mentioned. Either plastic surgical reconstruction, or prosthetic rehabilitation may be used for the treatment. Surgical reconstruction is preferable but prosthetic approach may be necessary in some circumstances such as the presence of complex or large defects, requirement of the recurrence control, local or general contraindications of surgery, damaged neighboring tissues due to the radiotherapy, general poor health, failed reconstructive attempts previously made, refusal of the surgery by the patient, high esthetic demands, the desire for a quick recovery and palliatively operated patients [1, 2, 3].
For the facial prostheses, surgical retention provided by skin-penetrating osseointegrated implants, are the most preferred retention sources [1, 2].
Whether it is implant supported or not, designing a prototype is essential prior to the making of the definitive facial prosthesis. Prototyping may be done by either real or virtual techniques [1].
To fabricate a real prototype, it is necessary to make a facial moulage with an impression material and then to pour it into a dental stone. Afterwards, a wax prototype is sculpted on the stone cast by using the free-hand technique [1, 4]. With this method, the success of the wax prototype depends on the artistic skills of the technician. It is important to note that the impression materials may depress the thin and unsupported regions of the face and the stone cast may not be an identical copy of the patient's face [4, 5].
Virtual designing of the facial prostheses requires various 3D (three dimensional) imaging systems such as digital photogrammetric images, laser images, magnetic resonance (MR) images and computerized tomographic (CT) images [4-10]. Various types of softwares process images and the obtained data may be used for different purposes such as the description of the implant locations, the production of the surgical guides and the prototyping of the prostheses [1, 6]. Stereolithographic (STL) methods employing computer-aided-designing and manufacturing (CAD-CAM) techniques are used for prototyping [7, 11-15].
The aim of this report is to describe the stereolithographic rapid prototyping work flow in the manufacture of an ear prosthesis.

2. Case Report

A 17-year-old female who had lost her left ear two years ago due to a traffic accident, was referred to the department of prosthodontics. Consequent surgical interventions haven't been able to establish appropriate esthetics. A CT scan of the head was obtained initially. Surgical insertion of the implants (EO Implant, Institut Straumann AG, Waldenburg, Switzerland) was performed under the guidance of the STL surgical guide. For this purpose, a 3D virtual model was created by software (ProPlan CMF, Materialise NV, Leuven, Belgium) from the 2D stacked uncompressed CT images. The surgical guide was designed on this model. The data was transferred to the rapid prototyping system (ProJet 3D Systems, Rock Hill, SC, USA) by using the STL module (ProPlan STL^+ Module, Materialise NV, Leuven, Belgium) and the surgical guide was designed and manufactured by using this system.

Six weeks after the first intervention, abutments (Cone Abutment, Institut Straumann AG, Waldenburg, Switzerland) were screwed onto the implants.

After the completion of the soft tissue healing and the establishment of the final tissue contours, a bar-retained ear prosthesis from the polydimethyl siloxane material was made. 3D virtual model previously used for the designing of the surgical guide, was used again for the virtual designing of the ear prosthesis. An image of the healthy right ear was extracted from the virtual model, inverted and its mirror image was produced (Fig 1). The data was processed (ProPlan CMF, Materialise NV, Leuven, Belgium), and then this data was saved as a Standard Triangle Language file (STL) by using the STL module (ProPlan STL^+ Module, Materialise NV, Leuven, Belgium). To process the ear prosthesis a rapid prototyping system (ProJet 3D Systems, Rock Hill, SC, USA) was used and a thermoplastic prototype of the ear prosthesis was obtained (Fig 2).

The thermoplastic prototype was duplicated with pink modeling wax by using an irreversible hydrocolloid impression material and archived for the patient's further prosthetic requirements. Wax prototype was mounted on the magnetic abutments on the stone cast obtained from the facial moulage (Fig 3), flasked and the bar-clip retained ear prosthesis was processed by using high temperature vulcanizing (HTV), polydimethyl siloxane (PDMS) elastomeric material (Figs 4, 5). The borders of the prosthesis were kept wider than required and the final external coloring was not finished due to the continuing dermatological laser treatment of the burn scars.

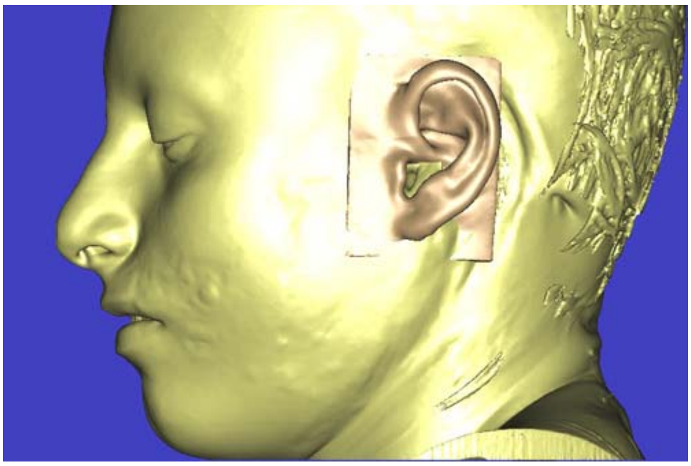

Fig 1: Extraction, inversion and relocation of the healthy right ear image on the virtual model.

Fig 2: Thermoplastic prototype of the ear prosthesis made stereolithographically.

Fig 3: Wax prototype used for processing of the PDMS prosthesis.

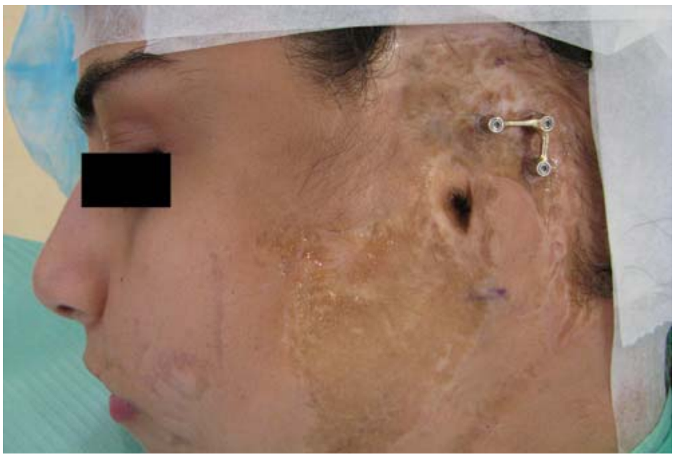

Fig 4: Implant- supported retentive bar infrastructure.

Fig 5: Implant- supported bar-clip retaining ear prosthesis from PDMS elastomer. Note the effects of the dermatological laser treatment on the burn scars. Final contouring and external coloring of the prosthesis were delayed until the completion of the dermatological treatment.

3. Discussion

Free hand sculptured wax prototype depends on the accuracy of the stone cast and the artistic skills of the technician. However Sykes *et al*. [13] reported that the free-hand-carved ear prosthesis was found to be of poorer quality with regard to shape and esthetic appeal. On the other hand, the fabrication of a virtual prototype requires the 3D images of the patient. Various 3D imaging systems such as digital photogrammetric images [4, 5, 9, 10], laser scanner images [4, 8], magnetic resonance (MR) images [7], and CT images [6] have been used for this purpose. Among the various imaging systems, CT is the most preferred instrument in the production of implant supported facial prostheses because it is not only useful for diagnostic purposes, but also for surgical and prosthetic planning [6, 11]. CT was also used in present study in order to implant planning, surgical guide designing and rapid prototyping. For these purposes CT was found helpful in this study. However the exposure to radiation during CT imaging should be taken into account.

Rapid prototyping of the ear prosthesis by creating the mirror image of the contralateral ear was described by Coward *et al*. [7] Authors extracted the image of the healthy contralateral ear from the digitized and reformatted 3D MR image; mirrored and positioned onto the image of the deformed side. The digitized data was used in the production of the prototype of the ear prosthesis from light polymerized resin, in conjunction with stereolithography. The wax prototype was obtained by pouring molten wax into the silicone mold of the light polymerized resin ear prototype [7]. Al Mardini *et al*. [12] described a different approach to the rapid prototyping. They obtained a 3D virtual model of the conventional cast of the patient by using an optical surface capture device (scanner), inverted the virtual model and prototyped the ear prosthesis from the physical thermoplastic material (wax) by using a rapid prototyping machine.

Feng *et al*. [15] described a technique for the design and fabrication of a realistic facial prostheses using 3D optical imaging. 3D data acquisition using a scanner and computer-assisted design and manufacture of the prosthesis enables to see the whole face without damaging the soft tissues or causing discomfort to the patient or exposure to radiation.

Feng *et al*. [14] described an approach to designing facial prostheses using the transplantation concept and computer-assisted technology for extensive, large, maxillofacial defects that cross the facial midline. For this purpose, three-dimensional (3D) facial surface images of a patient and his relative were reconstructed using data obtained through optical scanning. Based on these images, the corresponding portion of the relative's face was transplanted to the patient's face where the defect was located. The wax prototype was manufactured through rapid prototyping and the definitive silicone prosthesis was completed. Authors outlined that the optical 3D imaging and CAD-CAM system used in this study could design and fabricate facial prostheses more precisely than conventional manual sculpting techniques. The discomfort generally associated with such conventional methods was decreased greatly. The virtual transplantation was used to design the facial prosthesis for the maxillofacial defect, which crossed the facial midline.

Cheah *et al*. [8] presented an article that integrates laser surface digitizing/scanning and computer-aided design and manufacturing (CAD/CAM) to achieve automated fabrication of spatially and anatomically accurate extraoral facial prostheses. For this purpose, fabricating the positive replicas of prostheses, the approaches presented here are focused on designing and producing negative molds of the final prostheses using CAD, rapid prototyping, and rapid tooling techniques. The molds were applied directly to cast the final prostheses, thereby eliminating conventional flasking and investing procedures.

The software and the rapid prototyping equipment used in this study were found useful. Extraction and the inversion of the healthy ear image were easily performed, Standard Triangle Language (STL) file was also easily transferred and the thermoplastic ear was easily prototyped. A wax duplicate of the prototype was used for the flasking procedures of the prosthesis. The original prototype was archived for further use. The prosthesis was manufactured with PDMS material by using conventional pack and press technique.

4. Conclusion

The use of stereolithography from a CT scan is a suitable technique for rapidly prototyping the ear prosthesis. Major advantages of the application were observed as the ability to produce virtual models using digital methods, to produce more natural-looking prototypes compared with free-hand sculptured ones, to archive the prototype for the further use and to perform both of the implant planning and the rapid prototyping procedures on the same image of the patient.

On the other hand, higher expenses required for the virtual modeling and rapid prototyping applications and the irradiation occurred during the CT scanning, were noticed as the disadvantages.

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