Review Article

Recent advances in the modelling of extraoral defects

A. M. Bhat

Department of Prosthodontics, Meenakshi Ammal Dental College and Hospital, Maduravoyal, Chennai - 600 095, India

For correspondence

Aruna M. Bhat, Department of Prosthodontics, Meenakshi Ammal Dental College and Hospital, Alapakkam Main Road, Maduravoyal, Chennai - 600 095, India. E-mail: drarunabhat3@yahoo.co.in

Maxillofacial prostheses are usually fabricated on the basis of conventional impressions and techniques. The extent to which the prosthesis reproduces normal facial morphology depends on the clinical judgment and skill of the individual fabricating the prosthesis. Recently, as a result of advances in technology, various computer-aided design and manufacturing techniques have been successfully introduced for the automated fabrication of maxillofacial prostheses. These systems are able to provide more consistently accurate reproduction of facial morphology. This article reviews literature concerning such methods. Peer-reviewed literature published in the English language between 1988 and 2005 obtained using Medline and hand searches is reviewed and the various techniques involved in the automated fabrication of extraoral prostheses are described. The advantages as well as the limitations in the currently available techniques and the current body of knowledge are identified and directions for future research have been discussed.

Key words: Optical modeling, maxillofacial prosthesis, computer-aided design and manufacturing, rapid prototyping, stereolithography

INTRODUCTION

Until recent past, conventional impression materials such as irreversible hydrocolloid or silicones and techniques have been used to fabricate maxillofacial prosthesis and extraoral radiation devices. Potential problems associated with conventional impressions include patient discomfort and distortion of the facial soft tissues. Also, the conventional techniques available require the technician to spend time carving and adapting the prosthesis to a cast of the deficient side of the face. Hence, these techniques rely upon the skill and individual ability of the technician. Recently, as a result of advances in digitized imaging technology, it has become possible to obtain non-contact 3-dimensional facial measurements and 3-D anatomic models.

The purpose of this paper is to present a review of literature highlighting the various strategies or procedures involved in the automated modeling of extraoral defect.

Literature review

For convenience the basic steps involved in the automated fabrication of extraoral prosthesis will be discussed under the following headings:

1. Collection of 3-dimensional anatomic data (3-D facial measurements) using scanning techniques:
   - Computerized Tomography (CT) Scanning
   - Magnetic Resonance Imaging (MRI) Scanning
   - 3-D Optical Scanning
2. Generation of a 3-D Computer Model ("blueprint") of the extraoral defect
3. Manufacture of a physical prototype:
   - Computer Numerically Controlled (CNC) milling
   - Rapid Prototyping

Collection of 3-dimensional anatomic data using scanning techniques

Computerized Tomography (CT) scanning

Acquisition of three dimensional anatomic data became possible in the 1960's with the development of computer assisted tomography (CT scanning) and expression of that data as 3D surface images was pioneered by Gobor Herman.[1] Since the initial report of application of that technology for fabricating a prosthetic scalp, by Mankovich *et al*[2] in 1986, many basic and clinical investigations regarding computer assisted designing and manufacturing techniques have been reported in the field of maxillofacial prosthetics.

Advantages and Limitations[3]

Computed tomography scans are readily available. The use of CT scans allows parts of the body to be serially recorded slice by slice. The 3-dimensional computed data obtained can be used to construct an anatomic model or prosthesis of exactly the same dimensions and geometry of the deformed side of the face.

Watson *et al*[4] used CT data in planning and positioning implants to support an artificial prosthetic ear for patients with hemifacial microsomia. This technique required a large number of contiguous slices (30-40 slices 2 mm apart) for bone depth to be assessed with reasonable accuracy.

However, the use of CT scans to obtain 3-D anatomic data cannot be ethically justified because of the high dose of radiation administered.

Magnetic Resonance Imaging (MRI) scanning

Advantages and Limitations[3]

Magnetic resonance image scanning is a non-invasive (zero radiation) alternative that projects a 3-dimensional image of the soft tissues together with bone.

The possible disadvantages remain the length of time the patient is required to remain motionless during the entire length of scanning and the high cost entailed.

A further exclusion of this method would arise when many stainless steel wires have been previously used to secure jaw fragments in corrective surgery.

3-D Optical scanning

To avoid the disadvantages of CT scanning or MRI an optical modeling process for extaoral defects and body areas was developed. The development was based on experience in the collection of digitized data for tooth related model dependant representations.[5-7] The optical 3-dimensional scanning unit provides a point cloud or virtual model of the face.

The two main types of optical 3-D scanners are:

a. 3-D scanner based on self-calibrating fringe projection technology (“Kolibri-mobile”)
b. 3-D laser scanning system

3-D scanner based on self-calibrating fringe projection technology (“Kolibri-mobile”)[8]

It is a mobile, multiview 3-D measuring system developed by the Fraunhofer Institute for Applied Optics and Precision Engineering in Jena, Germany, that facilitates the fully automatic recording of the body part from various directions in one measuring process. The maximum field diameter of the system i.e. the area that can be recorded at one time is 650 mm. Therefore, the complete human face can be recorded in a single operation. The face is illuminated by two grating sequences rotated 90-degrees from different directions. The object is illuminated from different directions by means of a network of fixed mirrors (M_{21}, M_{22}, M_{23}, M_{24} and M_{25}) and simultaneously observed by cameras from different directions [Figure 1 and 2]. The switching of the projection direction is done by the rotating central mirror M_1.The observing cameras capture these fringe pictures simultaneously, resulting in at least 4 phase values for each pixel of the camera. Using these phase values, the 3-D coordinates are calculated.

The position and number of the mirrors and cameras can be selected, thereby adapting the system for the relevant body part. Optimum measurement of an extaoral defect involves 4 cameras and 5 projection directions where more measurements are made from below, 2 of the cameras as well as 3 of the projection directions are directed from below to measure the chin.

The duration time of recording up to the 3-D point cloud is approximately 20 seconds. The measuring accuracy is less than 100 µm. Thus, points with a distance of 100µm and greater can be recorded separately. The data obtained is adapted for further use by equalizing the point clouds to obtain a Computer Aided Design (CAD) model based on which a definitive prosthesis is produced.

Advantages

a. The system is mobile.
b. Simple to use.
c. Measurements are made within seconds (approximately 20 seconds)
d. The complete human face can be recorded in a single operation.
e. The procedure avoids the stress experienced by patients when conventional modeling methods are used.
f. Avoids exposure to radiation when using a CT or MRI.

3-D laser scanning system

A laser scan of the full face takes 30 seconds and is a non-invasive means of collecting digitized data. Coward and Watson[3] emphasized the use of a laser scanner and CAD/CAM systems in the fabrication of auricular prosthesis in the late 90's. Some of the constraints to the use of this technique remain loss of some information of the ear caused by light reflection from the hair and inaccessibility of the internal undercut surfaces of the ear by the vertically projected lines of the laser beam.

These problems were overcome by a 3-D laser scanning system[9] (Geodigm Corp, Chanhassen Minn) developed recently to produce a 3-D dental cast known as “emodel”. The scanner projects a laser stripe onto the surface of the cast and then processes the images of the laser stripe captured by two digital cameras. The cast is then translated and rotated under computer control to expose all surfaces of the cast to the cameras. This scanning process produces a cloud of over one million data points that describe the surface contours of the cast. These 3-D data points are loaded into the scanning systems proprietary emodel software (Geodigm Corp) and interconnected to form a triangular mesh (tessellate) which is then inverted to produce a 3-D mirror image of the scanned cast. The data obtained is used in conjunction with rapid prototyping machines to obtain the physical prototype that will be described later in this article.

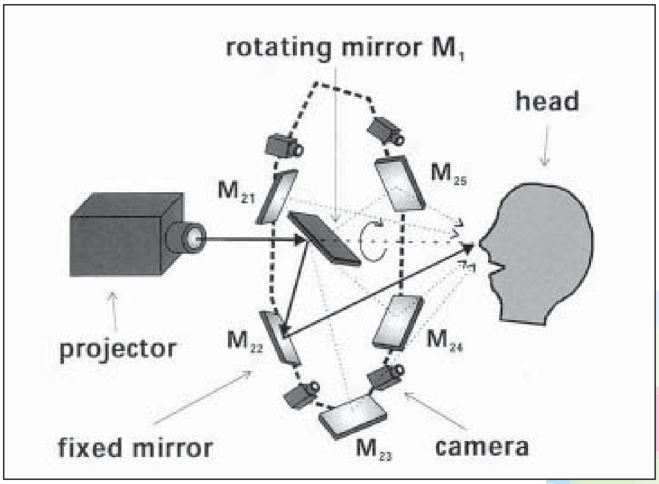

Figure 1: Schematic representation of 'Kolibri-mobile' (M_{21},M_{22},M_{23},M_{24}, and M_{25} represent fixed mirrors)

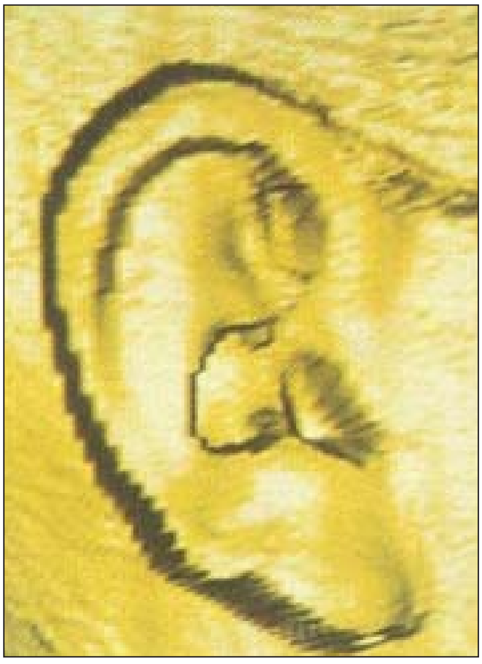

Figure 2: Model ear milled from a block of polyurethane using 3-axes milling machine

The method used also uses a more advanced scanner that requires only 1 scan, compared to a similar technique described recently by Ciocca *et al*[10] that required 8 random scans to record all the undercut areas.

Generation of a 3-D Computer Model ("blueprint") of the extraoral defect

Once accurate geometric information of the defect is collected using the scanning techniques, the information is imported into the scanning systems proprietary computer –aided design (CAD) software package for manipulation and the production of a "blueprint" (CAD model) from which the prototype is manufactured.

Manufacture of a physical prototype

Computer Numerically Controlled (CNC) milling

Data obtained by optical laser scanners have been

Figure 3: SLA (stereolithographic anatomic) models for mock surgery

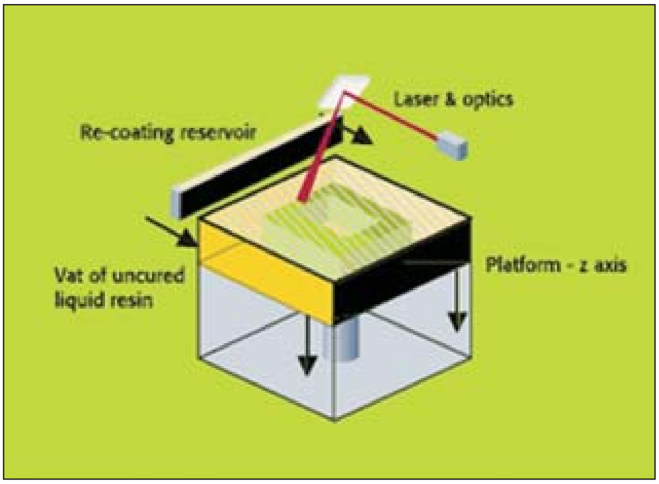

Figure 4: Schematic representation of Stereolithography i.e. recreation of the data in the resin slice by slice until the final layer has been completed and the platform elevated from the vat of liquid resin

used in conjunction with computer software which converts 3-D data sets into an instruction sequence for a CNC milling machine to prepare a reverse model of the normal ear.[3] The data set comprised a depth map of a given view of the scanned object, which was translated into physical movements of a cutter in 3 axes, enabling an ear pattern to be milled from a block of expanded polyurethane [Figure 2]. Plaster of Paris encompassed the polyurethane model to produce a negative mold, into which molten wax was then poured. The wax model ear was adjusted by the maxillofacial technician to create the undercut contours.

Limitations[3,11]

Milling machines reproduce only the outer surface contours. The details of the internal geometry (undercut contours) are created by freehand –carving (by the technician).

These limitations led to the development of rapid prototyping techniques.

Rapid Prototyping (RP)[12]

During the late 1980's the introduction of rapid prototyping technologies offered new possibilities for modeling extaoral defects. Developed primarily for the automotive and aerospace industries to shorten the time between design and construction of prototype parts, it operates on the principle of depositing material in layers or slices to build up a model rather than forming a model from a solid block thus offering a great advantage of creating all the internal geometry as well rather than just the outer surface contours as with a milling machine.

There are currently many variants that are marketed, but the 3 dominant technologies include:

a. Stereolithography: uses an ultraviolet laser to solidify a liquid plastic (resin) layer by layer
b. Laser sintering: uses a laser to selectively fuse a thin layer of powered plastic or metal to previously fused layers and;
c. Laminated object manufacturing: laminates thin sheets of material successively and cuts and destroys material with a laser, leaving behind a solid laminated part.

In each of these techniques, the layers added can be thinner than 0.5 mm with a vertical wall thickness of as low as 0.2 mm.

However, the STL (stereolithography) files have become the manufacturing industry's de facto standard for data transmission to RP technologies.

Stereolithography

Stereolithography was the first rapid prototyping technology to be developed, in the 1980s, and is the technique most commonly used to create stereolithographic anatomic (SLA) models for surgery [Figure 3] and transferring CAD models to RP technologies.[9] The CAD model of the part to be created is cut into a series of two-dimensional slices. This data is used to control a laser beam that draws each slice of the model in turn on the surface of a tank of resin. The photosensitive resin is instantaneously cured to a solid where the laser beam strikes [Figure 4].

At the start of the process a platform is positioned the thickness of one 0·25 mm 'slice' below the surface of the liquid resin. Once the first layer has been drawn, it descends to allow resin to cover the top of the model so that the next slice can be constructed at the top of the model. As the platform descends, the model is built from the base up.[3]

Advantages

The model is created directly from computer data. So there is no human error and no limit on the complexity of the geometry to be built.

DISCUSSION

Conventional impression materials have been used for decades in dentistry and maxillofacial prosthetics. However, the challenge for a field that still relies largely on the 16th century approach of creating prostheses by hand is the vital importance of getting exactly the right fit with existing tissue and bone. By happy coincidence, this is exactly the same thing that the field of technology has been focusing to address in recent years by coming up with different computer-aided techniques of producing high-quality prototypes for the fabrication of maxillofacial prosthesis. Several techniques have been reported to fabricate a mirror image wax cast for maxillofacial prostheses.[2,3,9,10] However, the usefulness of rapid prototyping has been proved beyond a shadow of a doubt. So recent studies have focused on computer-assisted rapid prototyping machines to sculpt facial prosthesis.[3,8,13-15]

Although computer-aided design and manufacture techniques have shown some promising applications in the fabrication of facial prosthesis it is limited to the production of an intermediate wax pattern from which the definitive prosthesis is subsequently obtained through conventional procedures. In addition problems relating to the color compatibility of the facial prosthesis with surrounding tissues remain to be overcome.

The development and evaluation of these advances continue. It can be anticipated that future developments may include direct fabrication of high precision computer designed definitive facial prosthesis without the need to produce an intermediate wax pattern and a color map of the definitive prosthesis by means of a spectrophotometer-assisted color calibration of the surface.

So in this scenario it would be apt to believe that the profession is destined to go through modernization in the years to come and computer-aided design and techniques may eventually become the next generation of methods of fabrication of extraoral prosthesis!

REFERENCES

1. Marsh JL, Vannier MW, Fujino T, Nishitani H, Lombrecht JT, Lemke HU. On foundation of computer–aided surgery. Comput Aid Surg 1994;1:1.
2. Mankovich NJ, Curtis DA, Kagawat, Beumer J 3rd. Comparison of computer based fabrication of alloplastic cranial implants with conventional techniques. J Prosthet Dent 1986;55:606–9.
3. Coward JJ, Watson RM, Wilkinson IC. Fabrication of a wax ear by rapid process modeling using stereolithography. Int J Prosthodont 1999;12:20–7.
4. Watson RM, Coward JJ, Forman GH, Moss JP. Considerations in treatment planning for implant-supported auricular prostheses. Int J Oral Maxillofac Implants 1993;8:688–94.
5. Persson M, Andersson M, Bergman B. The accuracy of a high precision digitizer for CAD/CAM of crowns. J Prosthet Dent 1995;74:223–9.
6. Willer J, Bossbach A, Weber HP. Computer–assisted milling of dental restorations using a new CAD/CAM data acquisition system. J Prosthet Dent 1995;74:223–9.
7. Luthardt RG, Sandkuhl O, Herold V, Walter MH. Accuracy of mechanical digitizing with CAD/CAM system for fixed restorations. Int J Prosthodont 2001;14:146–51.
8. Reitemeier B, Notni G, Heinze M, Schone C, Schmidt A, Fichtner D, *et al*. Optical modeling of extaoral defects. J Prosthet Dent 2004;91:80–4
9. Mardini MA, Ercoli C, Graser GN. A technique to produce a mirror–image wax pattern of an ear using rapid prototyping technology. J Prosthet Dent 2005;94:195–7.
10. Ciocca L, Scotti R. CAD/CAM generated ear cast by means of a laser scanner and rapid prototyping machine. J Prosthet Dent 2004;92:591–5.
11. Tsuji M, Noguchi N, Ihara K, Yamashita Y, Shikimori M, Goto M, *et al*. Fabrication of a maxillofacial prosthesis using a computer–aided design and manufacturing system. J Prosthodont 2004;13:179–83.
12. Beumer J, Curtis TA, Marunick MT. Maxillofacial rehabilitation, prosthodontic and surgical considerations. St. Louis: Ishiyaku Euro Am; 1996. p. 399–402.
13. Girod S, Keeve E, Girod B. Advances in interactive craniofacial surgery planning by 3D simulation and visualization. Int J Oral Maxillofac Surg 1995;24:120–5.
14. Penkener K, Santler G, Mayer W, Pierer G, Lorenzoni M. Fabricating auricular prostheses using three–dimensional soft tissue models. J Prosthet Dent 1999;82:482–4.
15. Runte C, Dirksen D, Delere H, Thomas C, Runte B, Meyer U, *et al*. Optical data acquisition for computer–assisted design of facial prosthesis. Int J Prosthodont 2002;15:129–32.