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Nasal Prosthesis Fabrication using Rapid Prototyping and 3D Printing (A Case Study)

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ABSTRACT: Facial defects resulting from neoplasms, congenital, acquired malformations or trauma can be restored with facial prosthesis using different materials and retention methods to achieve life-like look and function. A nasal prosthesis can re-establish aesthetic form and anatomic contours for mid-facial defects, often more effectively than by surgical reconstruction as the nose is relatively immobile structure. For successful results, lot of factors such as harmony, texture, color matching and blending of tissue interface with the prosthesis are important.The aim of this study is to describe the non-surgical rehabilitation with nasal prosthesis for an Iraqi patient who received rhinectomy as a result of squamous cell carcinoma of the nose. The prosthesis was made to restore the aesthetic appearance of the patient with a mechanical retained design using rapid prototyping technology.Rapid prototyping using 3D printing technology of maxillofacial prosthesis is useful technique in reducing time and increasing the quality of the final product while, conventional procedures have to depend on the patient's siblings or close relatives or prefabricated casts along with photographs which may not be available at all times. Computer-Aided Design offers limitless shapes and sizes of digitized nose that can be checked virtually on the patient's digitized face. Although it may seem to be costly in terms of money, it does reduce patient's number of visits and chairside time.

KEYWORDS: Rapid prototyping, 3D printing, Nasal prosthesis, Computer-Aided Design.

I. INTRODUCTION

Maxillofacial defects can be the result of a congenital anomaly, trauma, pathology or tumor surgery. These defects have very large impact on appearance, function and render an individual incapable of leading a relatively normal life. Surgical reconstruction may not be possible owing to size or location of the defect. The patient's medical condition or personal desires may also preclude reconstructive surgery. In such cases, prosthetic rehabilitation is indicated [1].The history of masking maxillofacial defects started centuries ago when Egyptians and Chinese used wax and resins to reconstruct defective portion of head and neck region [2].

Reconstruction of nasal defects has a long history dating back almost 2,000 years to the days of Sushruta, the famous Indian surgeon [3].

Partial nasal defects can be managed very well by surgery. However, for full nasal defects, the final aesthetic outcome still leaves much to be desired, even with the use of free tissue transfer by surgery. In addition, the risk of recurrence often adds further challenges to the reconstruction [4].

These pressures have led researchers to explore whether the cost and time savings associated with advanced design and product development technologies can be realized in maxillofacial prosthetics. Technologies such as 3D surface capture (3D scanning), three-dimensional computer-aided design (3D CAD) and layer additive manufacturing processes (or rapid prototyping and manufacturing (RP&M)) have been investigated in maxillofacial prosthetic applications [5].

Rapid prototyping (RP) refers to the rapid manufacture of complex 3D models or physical parts (prototypes) using 3D computer-aided design (CAD) data. It is widely used in product design in some industries and has found a use in the medical and dental fields over the past 30 years. In dentistry it is used specifically for improved and cost-effective diagnosis, treatment planning, and manufacture of certain types of prostheses [4].

The key idea of this new RP technology is based on the decomposition of three-dimensional computer models in the layers section transverse then followed physically forming layers and piling layer by layer. The generation of three-

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dimensional objects in this manner is an idea almost as old as human civilization. The developments since the Egyptian pyramids were probably block developed layer by layer [6].
The purpose of this study is to illustrate the steps of computer-aided design and rapid prototyping in fabrication of a nasal prosthesis.

II. RELATED WORK

RP has been applied to a range of medical specialties, including oral and maxillofacial surgery, dental implantology, neurosurgery, and orthopedics [7]. Applications of RP in maxillofacial prosthetics include:

- Production of auricular and nasal prosthesis.
- Obturators.
- Duplication of existing maxillary/mandibular prosthesis especially crucial when an accurate fit to natural teeth or an osseointegrated implant is needed.
- Manufacturing of surgical stents for patients with large tumors scheduled for excision.
- Manufacturing of lead shields to protect healthy tissue during radiotherapy treatment.
- Fabrications of burn stents, where burned area can be scanned rather than subjecting delicate, sensitive burn tissue to impression-taking procedures [8].

Ciocca and Scotti in 2004 fabricated an ear prosthesis using laser scanning of the face and rapid prototyping of the prosthesis. They developed a method to eliminate the use of conventional impressions and the necessity to depend on the artistic skills of an anaplastologist [9]. In another study, a nasal prosthesis was fabricated using RP technology for a 37-year old female patient with a nasal defect. A computerized tomographic (CT) scan of the defect area was made and converted into 3- dimensional (3D) digital data using dedicated medical imaging software. From the 3D image, a 3D nose model was designed and printed [10]. In 2013, a study discussed the fabrication of a template-based framework for nasal prosthesis using a 3D areal scanner and a CT scanner. The nasal prosthesis fabricated on the framework showed good fitness [4].

III. CASE STUDY

A 22-year old, female patient referred to Department of Prosthodontics, College of Dentistry, University of Baghdad with a nasal defect. The nasal defect was a postsurgical one following total rhinectomy for squamous cell carcinoma.
The defect extended superiorly to the root and inferiorly to the base of the nose and laterally short of the nasolabial fold (Fig.1). She had previously been restored with nasal plastic surgery but poor cosmetic looks was the main reason for her to seeka prosthesis.
The patient had no presurgical photograph that would have helped in sculpting a model of the prosthesis. Therefore, it was decided to use CAD-RP technology to design the nasal prosthesis.
Computed Tomography (CT) scans were made for the patient head using a CT scan device (Siemens AG Medical Solutions, Germany)
A contiguous spiral computerized tomography (CT) scan of the patient face was made at intervals of 0.6 mm thickness. The patient head was stabilized and a scan from supraorbital ridge to the junction of upper and lower lip was made. The data acquired was converted to Digital Imaging and Communication in Medicine (DICOM) images and downloaded.The acquired CT data sets were then subsequently converted into Stereolithography Interface Format (STL) files using Mimics Software (Materialise, Leuven, Belgium).

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Figure 1: Photograph of the patient showing the nasal defect.

The images were smoothed slightly before the actual segmentation (decimation factor 0.50, smoothing iterations 20). No post-segmentation smoothing or filtration was applied to the models.Midline of the face was used as axis of symmetry. The defect was measured in height and width.

Parametric model development

The human nose consists of a number of anatomical features that are similar for all individuals. However, differences in factors such as angle, thickness, and protrusion make each nose unique. Based on these standard features, a nose parametric model was developed with fully adjustable anatomical structures.

Zbrush sculpting software (PixologicInc, USA)was primarily used to create a basic nose prosthetic model.This basic nose model was superimposed on an STL file converted from patients head soft tissue CT scan to create a matching prosthesis (Fig.2).

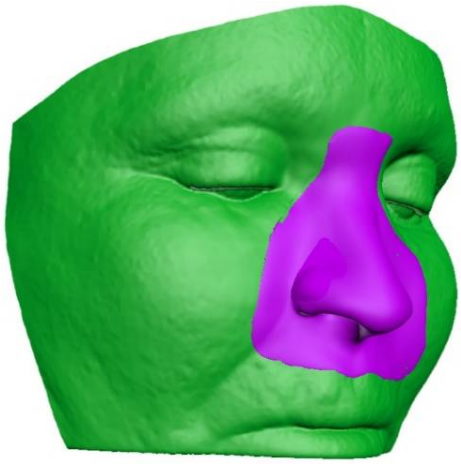

Figure 2: Final model of the nose is fitted onto the STL file of the patient face.

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The final model then converted into 3-matic Medical 11.0 (Materialise, Leuven, Belgium) for analysis and making the model air tight. Then the model sends to AutoMaker software for slicing and G-Code production in order to make RP. The final model of the nose is printed by using the 3D printer (RBX01CEL Robox 3D Printer, UK)in ABS filament, then finished by sand paper (Fig.3). Try in procedure is performed, and any pressure area was relieved (Fig. 4)

Figure 3:3D printed prototype.

Figure 4: Try-in of the 3D printing prototype.

The 3D printed model was invested into a mold using investment material and the ABS material was burned out in the oven. Maxillofacial silicone elastomer (Factor II, Inc., USA) was chosen to reproduce the qualities of skin. Mixing was according to manufacturer instructions and intrinsic pigments (Factor II, Inc., USA) was added to the siliconeto match the color of the patient's skin. Silicone was then poured into the mold.

After 24 hours the silicone prosthesis is removed from the mold, then polishing and finishing is done to have smooth surface prosthesis.Extrinsic pigments (Factor II, Inc., USA)are painted on the silicone prosthesis to resemble thetexture of patient's skin.

The nasal prosthesis was then inserted into the defect and retained by medical adhesive (Fig.5)

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Figure 5: Insertion of final prosthesis

IV. DISCUSSION

Loss of any part of the human body especially one from the face can be a very traumatic experience. Nose among them requires special mention as it is located in the prominent central part of the face. Moreover, it is one such structure that cannot be hid casually like (using tinted glasses) and ears (behind the hair).Therefore, a prosthesis that exactly replaces that of the patient's normal nose is very crucial to the success of rehabilitation[11].

Although it can be stated that unlike the eyes and ears, nose does not have any counterpart and therefore easy to reconstruct as there is no possibility of comparing it with the normal part. It is very important to consider the fact that unless a previous photograph or a cast of the normal structure is present, this is very difficult [12].

The standard procedure, Donor technique, involves taking an impression of the nose of a person who matches the patient's morphological feature (e.g. sibling, relative) and duplicating it in wax and this would be custom modified and processed [11].

Alternatively, nose pattern can be directly sculpted on the cast of the patient and tried. This involves usage of anatomic contours as reference augmented by preoperative photograph supplied by the patient [13,14].

Very rarely, a defect free presurgical cast of the patient along with a photograph, if available can serve as an excellent model for duplicating the nose of the patient [13]. However, this procedure did not allow the choice of using various types of nasal structures. This is because it is very time consuming to compare infinite wax models of the nasal structure. Moreover, such library of wax models of noses is not readily available.

The introduction of CT and MRI with 3D representation of human anatomy has opened up a new door for alternative methods of designing an anatomical structure. CAD allows precise designing of the form in term of both contour and texture and CAM allows precise reproduction of the designed model. So this recent technology was adopted for the fabrication of the nasal prosthesis [15].

Advantages of CAD-RP:

1. With a proper digital library, various shapes of the nasal structure could be superimposed on the digital model and the required one opted in a matter of a few hours [16,17].
2. For paired structure (e.g. eyes, ears), duplicating to the exact dimension and mirroring can be done [18,19]
3. Using RP, complex internal forms as the present in the external ear can be reproduced with the precision [9].

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4. Eliminates the need for an impression procedure [9].
5. Eliminates the dependency on close relatives for the nasal impression [9].
6. The digital model and the plastic prototype can be preserved. This is important as replacement of the prosthesis is required once in few years following discoloration, change in fit, tearing, aging and general wear. The plastic prototype also allows multiple pouring for shade matching purposes [9].
7. They don't require a skilled anaplastologist for sculpting the clay model of the defect area (especially the ears) [9].
8. The possibility of 3D visualization and easy virtual changes (type of nose, dimensions, position on face) ensure optimization of the whole process prior the manufacturing. In addition, it allows the feedback of the patient to be incorporated [17,20]

Disadvantages of CAD-RP

1. Cost factor [19].
2. Radiation dose: Several articles have reported various techniques to reduce the radiation dose [9,12,16,18].
3. Requires equipment and computational skills of the CAD-CAM methods [20].

The methods most commonly used for retaining nasal prosthesis include involving anatomical undercuts if available, medical adhesive, mechanical support (e.g. eyeglasses) [21], prosthetic connections to endosseous implant [22] and attachment to maxillary obturator [23].

The medical adhesive used to retain prosthesis may irritate soft tissues that contact the prosthesis when it is removed for maintenance and cleaning and eyeglasses-supported nasal prosthesis system may result in displacement, with and opening at the margins of the prosthesis. For definitive rehabilitation, osseointergarted craniofacial implant (two positioned in the premaxilla in the nasal floor and one in the glabella, if necessary) and a metal support bar to stabilize the prosthesis are the best for anchoring a nasal prosthesis to the skull [15].

V. CONCLUSION

Although it may seem to be costly in terms of money, RP does reduce patient's number of visits and chairside time. Recent article has shown how CAD prosthesis can be more economical on finance and time than a manually built prosthesis. It also, offers limitless shapes and sizes of digitized nose that can be checked virtually on the patient's digitized face.

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