Current Principles Of Advanced Digital Technologies In The Fabrication Of Maxillofacial Prosthesis

[1] Wg Cdr Naveen K S [2]Lt Col Poonam Prakash, [3]Brig S K Bhandari, [4] Lt Col Vijaya Kumar R

[1]MDS (Prosthodontics), [2]Reader & Instructor, AFMC Pune, [3]HOD, Department of Dental Surgery & Oral Health Sciences, AFMC, Pune,[4] Reader & Instructor, AFMC Pune

[1]Airforce Institute of Dental Sciences, Old Airport Road, Agram (Post), Bengaluru-560007, India.

Abstract : Maxillofacial prosthetics is a specialised profession that seeks to meet the needs of patients with various degrees of facial deformity by restoring aesthetic and functional aspect of missing tissue using artificial materials. The traditional workflow from making an impression of the maxillofacial defect until finalisation of the maxillofacial prosthesis is, technique sensitive involving multiple laboratory steps and is time consuming. Advanced digital technology has shown its potential in replacing certain steps in this traditional workflow of designing and fabricating facial prostheses. With the advent of three dimensional (3D) scanners, 3D software and rapid prototyping technology, the traditional impression, modelling and production techniques can probably be replaced by. This digital technology can be used for obtaining better results in shade matching or adding surface characters & details. The digital technology in maxillofacial prosthodontics is evolving and has tremendous potential in simplifying the workflow and its final outcome. This paper discuses the current status and principle of digital technology used in prosthetic rehabilitation of maxillofacial defects.

IndexTerms **- Maxillofacial Prosthetics, Digital Technologies.**

I.INTRODUCTION

Trauma, treatment of cancer and congenital diseases can result in maxillofacial defects. Rehabilitation of these defects is challenging as it involves restoration of both esthetic and functional needs.[1, 2].These maxillofacial defects can be restored by either surgical reconstruction or with silicone facial prostheses. Surgical reconstruction of maxillofacial defects is difficult to perform and the results are often unsatisfactory.[3, 4] Maxillofacial defects are usually reconstructed prosthetically which has a higher patient satisfaction as compared with surgical reconstruction

Manufacturing of a silicone maxillofacial prostheses is traditionally a labor-intensive work
Involving three phases:

1. Preparation phase : planning of the prosthetic rehabilitation and collecting data by taking impressions and making photographs of the affected and healthy contra lateral region.

2. Production phase: creating a try-on model, often made out of wax, by using plaster models of the defect to be reconstructed. The try-on model is fitted on the patient and adjusted to the patient's needs and wishes. The final try-on model is converted into a silicone prosthesis, usually by using plaster molds and individual coloured silicone materials.

3. Placement phase : the silicon prosthesis is placed on the patient and finalised chair-side by making colour adjustments and adding lifelike details, like eyelashes.

It has been shown that the aforementioned traditional workflow is reliable with a usually very satisfactory final outcome for both the prosthodontist and patient.[5]. A major disadvantage of the traditional workflow is the large number of laborious steps which are uncomfortable for the patients. It would be a great achievement when the workflow would become less laborious and less demanding for the patient. The traditional workflow from taking an impression of the maxillofacial defect until finalisation of the maxillofacial prosthesis is time-consuming, even though digital technology can be used for obtaining better results [6,7] For long, there was no alternative to this approach, but since the advent of three dimensional (3D) scanners, 3D software and rapid prototyping technology, the traditional impression, modelling and production techniques can probably be replaced by digital equivalents. The digital technology might particularly be an aid in the first two phases of fabrication of the maxillofacial prosthesis ,viz. with regard to collection of the data , designing the prosthesis and rapid prototyping the prosthesis or a mold for the prosthesis.

1. Digital data collection

The first step in the digital workflow is to replace the traditional impression by a detailed 3Dscan. For acquisition of maxillofacial defects, a variety of 3D scanning technologies are available. Amongst these technologies, transmissive scanning technologies, like cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) have been used with success to replace a traditional impression for a facial prosthesis.[8]. CBCT scans can be used for imaging of hard tissues and with limitations for soft tissues as CBCT scans have a restriction in resolution. An increase in resolution coincides with an increase in effective radiation dose. Furthermore, CBCT images suffer from scatter when metal parts, like filling materials, crowns or bridges or implants, are present. However 3D-CBCT scans can be very helpful in the workflow for facial prostheses as data sets of healthy contralateral sides have been successfully used to reconstruct auricular, orbital defects. CBCT scans have also been used as a basis for constructing nasal prostheses. Next to CBCT scans, MRI scans can be made. MRI scans are able to depict soft tissues in great detail. Therefore, MRI scans have been used for fabricating auricular prostheses and orbital prostheses. MRI scans however are not suitable when bony structures have to be imaged simultaneously.MRI is not applicable in claustrophobic patients, obese patients, and patients with ferromagnetic metals in their body. Even though transmissive technologies (CBCT, MRI) are of added value in the data collection the most commonly used scanning technologies are optical scanners, as these are safe (no radiation), relatively cheap and can obtain a higher resolution than in-vivo transmissive scanners (CT or MRI scanners).The optical 3D scanners mostly used for facial scanning are the laser scanner, the stereophotoscanner and the structured light scanner[9, 10].

Laser scanner

The laser scanner consists of a laser line that is moved relative to the object being scanned. The resultant distortion of the light pattern on the subject is viewed from an offset angle and captured on a charged couple device (CCD) device. The 3D co-ordinates of the object'ssurface are calculated by triangulation. Laser scanners have proven to be accurate and have been used successfully in digital acquisition for the production of auricular, nasal and orbital prostheses.

Stereo-photo scanner

Stereophotogrammetry uses multiple images of the same object taken from different viewpoints to reconstruct a 3D model. Common points are distinguished on each image and a virtual ray is constructed from each camera location to these points on the object. Because the distance between the cameras and the angle of the cameras are known, the distance to the specific points can be calculated via the principle of triangulation. A fundamental limitation of stereophotogrammetry is that obtaining correspondence between points on consecutive images is extremely difficult, commonly mentioned as the "correspondenceproblem". Photogrammetry scanners have been proven to be accurate when used for measurements of distances between anatomical landmarks on the face of a subject but the resolution of the 3D model produced by most photogrammetry scanners is too low to reproduce fine skin details. [11] 3D models produced from a photogrammetry scan were shown to be less accurate than 3D models produced with CBCT. Photogrammetry scanning has been used for nasal and orbital prostheses.

Structured light scanners

Structured light scanners work by projecting a known light pattern onto the object to be scanned. Photo- or video cameras capture the image of the object with the projected pattern. Structured light scanners can employ several algorithms for the range measurement of the 3D scanning process. Mostly the technology behind the scanner will employ triangulation to calculate the distance of projected light point or line(s) on the object to the sensor. Structured light scanners have also been proven to be accurate for measuring facial landmarks, ie distances and angles on the face of a subject. Structured light scanners have been used for auricularnasaland orbital prostheses.

2. Computer aided design

For 3D designing soft tissue reconstructions a variety of approaches is used:

a) When possible, it is preferable to capture the healthy facial surface preoperatively to get the most natural shape of the anatomy to be reconstructed

b) Mirroring of the healthy side to the affected site can be performed when a healthy side is present and when the facial defect does not cross the midline.

c) Using a virtual "donor", e.g., a family member. The anatomical part that needs to be reconstructed is scanned on the "donor" and combined with the anatomical surface of the patient.

The functionality of the software used for producing a model of the prosthesis or a mold can be divided into a number of categories:

1) functions to convert the output of the 3D scanneror MRI/CBCT scanner to a 3D model,

2) functions to produce a new body part (mirroring,library/donor, statistical model, freehand modelling).

3) functions to conform the new bodypart to the existing anatomy (most often using Boolean operations) and adding details and

4) functions to produce a model that can be sent to a rapid prototyping machine.

Currently, these functions are not combined in one software program. [12]

3. Rapid prototyping

In the traditional workflow, the production of facial prostheses is a time-consuming process that requires numerous steps with wax and plaster models that all are prone to technical errors. In a digital workflow the production phase of the prosthesis can be performed by rapid prototyping. Rapid prototyping is the way of producing the digitally designed model. There are two ways for rapid prototyping, viz., subtractive or by additivemanufacturing.

In subtractive manufacturing, computer controlled mechanical tools are used to cut away (milling) material to achieve a desired model. This technology is also known as "computer numerically controlled (CNC) machining". However, not all desired materials can be easily and precisely milled,e.g., plaster materials. Furthermore, subtractive manufacturing produces a lot of, often quite expensive, waste material. The use of additive manufacturing (building a model dotfor dot or layer for layer) is therefore more widespread and has largely replaced the use ofsubtractive manufacturing. [13]

The American Society for Testing and Materials (ASTM) has defined additive manufacturing as the process of joining materials to make objects from 3D model data, usually layer upon layer. There are many different additive manufacturing technologies available that can be used in the digital workflow for fabricating facial prostheses. A variety of materials is used for this purpose such as acrylics and wax.

With one of the aforementioned technologies a model or mold can be produced:

- Model of the facial defect: a model of the defect is occasionally used in the production phase, and is used in the traditional workflow.

- Direct try-on model of the facial prosthesis: a try-on model for a direct fit can be made with subtractive or additive techniques. Subtractive techniques were employed by milling a standard block of wax or polyurethane in the desired shape to form the computer aided designed facial prosthesis and directly fitting and adjusting the part on the patient. Such a try-on model can also be produced by a variety of additive manufacturing technologies, viz. selective laser sintering (SLS) , thermopolymer printing and stereolithography (SLA).

- Indirect try-on model of the facial prosthesis: another option is to produce a model of the prosthetic part by a rapid prototyping technique and converting this part to a try-on model through traditional techniques. This is sometimes done e.g. because of the somewhat brittle nature of the thin edges of the prototyped prosthesis.

- Mold for producing the facial prosthesis: fused deposition modelling, 3D printing , laminated object manufacturing and SLA have been used to directly produce a mold for a facial prosthesis.

- Direct production of the final facial prosthesis: direct printing of the final facial prosthesis has been accomplished, but the end-result lacked the necessary aesthetic and mechanicalproperties.

The most advocated production technology in digital workflows for facial prostheses are powdered 3D printers. These printers lay down a layer of powder on which on specific points a binder is applied to set the powder. A new layer of powder is then laid down and the process is repeated until the 3D model is completed. These printers were claimed to be accurate enough for facial prostheses. However, the minimum feature size a powdered 3D printer can produce is 100 μm, which is actually not sufficient for a facial prosthesis. [14]The reason that, notwithstanding the limitation in feature size, powdered 3D printers were extensively used in the workflow of facial prostheses is probably that the technology these printers use was much more affordable than rather expensive technologies like SLA in the early days of rapid prototyping. Currently, the highest resolution of 3D printers using PolyJet technology is about 16 μm which suffices. However, no biocompatible materials with the proper mechanical and aesthetic properties are yet available for those printers.

Discussion

Although there are several ways to obtain digital data, design prostheses and print 3D try on models/molds, this has not led to a full 3D workflow for fabricating all facial prostheses. Apart from their limitation in resolution, these scanners unfortunately also have other disadvantages to consider. Some 3D scanners, like intra-oral scanners, have a higher resolution and would be able to depict important skin details. Unfortunately, these scanners have a limited field-of-view which means that many scans have to be taken and combined to scan a larger surface which increases the likelihood of movement artifacts. However, technology is developing quickly and modern high resolution 3D scanners can already obtain an accuracy of 25 μm which is close to the ANSI/ADA standards for traditional impression materials. The application of improved scanning techniques and printers will also result in more detailed 3D models of surface structures. The future 3D scanners should also have a large field of view and a short acquisition time, so they are able to capture all detail of the target area within one second to avoid movement artifacts.

Designing facial prostheses with computer software:

For the computer aided design phase, comprehensive software is needed to design a final model of the facial prosthesis that can be rapid prototyped. 3D planning and design of facial prostheses, particularly with regard to the soft tissues, is yet still largely limited due to the lack of user-friendly software. As the market is small and therefore not commercially attractive for software companies, development of optimal software will probably progress slowly. As long as such software is not available, a combination of commercially and free available software can be used for the necessary conversions and adding the necessary detail to the 3D model, like is done in the process for designing cranial implants ,surgical guides or applying texture relief. [15,16]

Production of facial prostheses:

For the production phase, the use of printable silicon materials with the proper mechanical properties would be the first choice as these materials are the most widely applied materials for facial prostheses. Silicones can be matched with skin colors by adding pigments, have an excellent detail reproduction capacity and can reproduce details up to 20 μm.However, very few printers are yet available that can directly print silicone. However, a major disadvantage of this approach is the restricted resolution of the printers due to the particle size of the printing powder as well as that the color of the silicon material is hard to match the skin color of the patient.

Conclusion

The current limitations in 3D technology (software and hardware) to allow for a full digital workflow to design and make a facial prosthesis are likely to be solved. The resolution of 3D scanners and printers will continue to increase and appropriate materials will become available for direct 3D printing of facial prostheses. Moreover, dedicated software will become available with time for the intuitive production of facial prostheses, to modify the design and to introduce characteristic details that are representative for the face of the patient. Such a workflow has the potential to make the (re)production of facial prostheses easier, cheaper and faster than the traditionally workflow. In addition, this workflow is presumed to be more convenient to the patient and to result in an improved aesthetic end product.

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