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Review Article

Digitalization in maxillofacial prosthodontics- A review

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ABSTRACT

Maxillofacial deformities that result from trauma, developmental abnormalities, destructive cancer surgeries, surgically operated mucormycosis can be difficult for a person to deal with as it affects the esthetics and functions and further degrades their quality of life. Hence, maxillofacial prosthesis not only corrects the deformity but also boost the self-confidence so that the patient can live his/ her life to the fullest. The creation of prostheses is currently undergoing a revolution, crediting the new, cutting-edge technologies including 3D modelling, printing, and imaging. These innovative methods are replacing the manual, labour-intensive, and expensive traditional methods of producing prosthetics with faster, less expensive methods that enable the creation of patient-specific prostheses. Our research aim to provide an update on the digital workflow of fabricating a maxillofacial prosthesis, highlighting the data collecting techniques at hand for extraoral, intraoral, and complex maxillofacial abnormalities, as well as evaluating the software's used for data processing and designing. Also as the demand for a digital approach to craniofacial rehabilitation increases, it may be seen that the work of software designers will be at demand to help create accessible and user-friendly modules similar to those used in dental laboratories. As the demand for a digital approach to craniofacial rehabilitation is increasing, it has been noticed that assistance from the software designer will be required in future to produce user-friendly and accessible modules comparable to those used in dentistry laboratories

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1. Introduction

Maxillofacial prosthetics is a specialised profession intended to meet the needs of patients with various degrees of facial deformities caused by congenital malformations, disease, surgery or trauma.[1] The "auricular prostheses" for ear defects, "facial prostheses" for facial abnormalities, "orbital prostheses" for eye defects, and "obturator prosthesis" for palatal defects have been some of the most difficult prosthetic parts to manufacture for decades.[2] Maxillofacial prosthesis use artificial materials to recreate the aesthetic and functional aspects of missing tissue, addressing the patient's social and emotional issues and enhancing their quality of life.[3,4]

Conventional workflow for the fabrication of maxillofacial prosthesis involves impression making of defect site with impression materials, fabrication of cast, making of wax pattern, sculpturing and carving, several try-in procedures, mould fabrication followed by investing. This traditional method depends on the expertise of the maxillofacial team which includes the maxillofacial prosthodontics and technician and entails multiple intricate stages that are expensive, demanding excessive time and also causing extreme distress to the patient.[4,5] Therefore, shortening of the lengthy process and increasing its efficiency is challenging for a prosthodontics.

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Recently, it has become possible to minimize patient discomfort while creating an accurate facial prosthesis owing to the application of digital technology.[6–10] The traditional impression, modeling, and processing techniques can in all probability be replaced with the introduction of the digital workflow (Figure 1), which includes 3D scanners, 3D software, and rapid prototyping technology. Also shade matching and adding surface characteristics to the prosthesis becomes much more easier and predictable. The use of digital technology in maxillofacial prosthodontics has evolved and is still progressing with huge potentials for improving both the process and the outcome.[11]

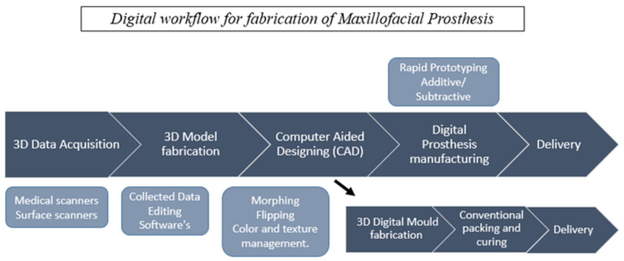

Fig. 1: Digital fabrication process of maxillofacial prostheses.

2. 3D- Data Acquisition

Medical and surface scans can be used to acquire defect data (Figure 2).[5]

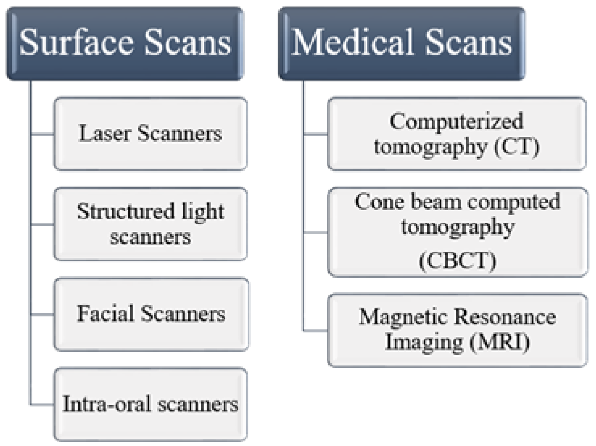

Fig. 2: Types of 3D scanners

Medical scanning includes computed tomography (CT) specific to the craniofacial region; cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI). CBCT scans can be used to image hard tissues, but they have limitations when imaging soft tissues due to their resolution limitations. The effective radiation dose increases as the resolution does as well. Soft tissues can be seen in great detail in MRI scans. As a result, auricular prostheses and orbital prostheses have been created using MRI scans. However, when multiple bony structures need to be imaged at once, MRI scans are not appropriate.[11]

In addition to medical scans, surface scanners, such as structured light scanners, laser scanners, facial scanners, and intraoral scanners, are a good choice for defect data acquisition.[5,12,13] A laser line that is moved in relation to the object being scanned makes up a laser scanner. A charged couple device (CCD) is used to record the resulting distortion of the light pattern on the subject when viewed from an off-centered angle. Triangulation is used to determine the surface's 3D coordinates.[11] Structured light scanners operate by projecting a predetermined light pattern onto the target object, and then photographing or filming the object while the pattern is projected. A physical cast made of plaster or alginate may also be scanned in place of the patient.[14] These scans may be obtained from a hand-held scanning tool or a stationary scanner.[15–17] Using specialized software, photogrammetry, which is the process of extracting 3D measurements from two-dimensional images of anatomical parts, is also used to create three-dimensional surface models of patients' faces.[18] Digital Imaging and Communication in Medicine (DICOM) files created from scans made with different scanners are used to create convertible 3D models of a patient's unique anatomy.

The most common tools used to collect defect data are surface scanners. However, unlike medical scanners, the laser scanners cannot penetrate and record deeper defects or detect concavities. As a result, both kinds of data acquisition methods are typically required.[5] Additionally, one is advised to perform a face scan using laser or structured light scanners prior to surgical removal of tumour when anatomical excision of a part is planned. Compared to laser and structured light scanners, CT and MRI expose the patient to higher radiation doses, compromising their safety. Spatial resolution is poor for CT, MRI and good for surface scanners. Data redundancy is high for CT and MRI and low for surface scanners. Medical imaging devices like CT and MRI scanners acquire internal slice images in addition to external slice images. However, external data are sufficient when making facial prostheses; data on internal tissues is not required. Contrarily, by scanning only the external data, light and laser scanners can reduce the image file size and processing time to convert scanned data into a 3D model. Accuracy for CT is about 1 mm, MRI less than 1 mm, laser scanner- 0.06-0.5 mm and structured light scanner -0.018mm. Hence comparatively, light and laser scanners are about two orders of magnitu Structure light and laser scanners are consequently roughly two orders of magnitude more accurate when compared. Medical imaging systems have a measurement error of nearly 1 mm. Speed is faster in laser scanners when compared to structured light scanners. It terms of expense/cost CT, MRI are more costlier than structured light scanners. Patient comfort is relatively good for surface scanners when compared to CT and MRI.[19]

3. Computer Aided Designing (CAD)

3D designing soft tissue reconstructions can be done using the following of approaches:

1. To acquire the most natural form of the anatomy to be rebuilt, it is recommended to scan the healthy facial surface preoperatively.[11]
2. If a preoperative scan is not available, a mirror image of the healthy side can be overlapped on the affected area. The healthy side can be scanned directly or by model obtained from conventional impression procedure. The 3-D image thus obtained is mirrored. The flipped image is superimposed on defective side with CAD software to determine the correct position. STL file is developed.[12]
3. Virtual "donor" can be used e.g. family or relatives. The anatomical part to be reconstructed is scanned from the"donor" and combined with the patient's anatomical surface.[11]
4. Using digital library.[20]In case of using digital library, a suitable size and shape can be selected by clinician as per the anatomy of patient and can be visualized by the patient and related team before the defect is rehabilitated.[21]

The various functionalities of the software used for creating models of prostheses or molds are as follows:

1) ability to convert the output of 3D scanners and MRI/CBCT, 2) the ability to create virtual new body parts (mirroring, donor or library, statistical or free-hand modeling), 3) the potential to add features to current anatomy and adapt new body parts to it (usually utilizing Boolean operation 4) functions to create a submittable model to the rapid prototyping machine. Currently, one software program is unable to perform all of these functions unassisted. To obtain a mould for the designed pattern, it is represented into negative volume and transformed into a new STL file and printed.[22]

The designing of external or internal maxillofacial prostheses is accomplished using various approaches.

The various existing open source (OS) or commercial (CA) CAD programs and software packages are as follows.[5]

1. Commercial software:Geomagic Studio (3D Systems, Rock Hill, SC, USA) Zbrush(Pixlogic Inc.), Rapidform (INUS Technology, Rhinoceros (Robert McNeel& Associates), Rock Hill, USA, 3D Systems, Rock Hill, USA, Free Form (SensAble Technologies, owned by 3D Systems),Magics (Materialize, Leuven, Belgium) , 3-Matic (Materialize, Leuven, Belgium, Solidworks (DassaultSystèmes), and Cinema 4D R18 (MAXON Computer, GmbH).
2. Open source software:Makerware (Makerbot Inc.), Meshmixer (AutoDesk Inc.) and C++ Visual Toolkit (VTK).

4. Rapid Prototyping

The facial prosthesis can be processed using the Rapid Prototyping (RP) technology once the CAD model has been successfully developed.[19] Rapid Prototyping (RP), also known as Solid Freeform Manufacturing is a relatively new technique used to create three-dimensional shapes from virtual designs. It can be divided into subtractive manufacturing and additive manufacturing. Subtractive manufacturing involves using a CNC (Computer Numerical Control) router to cut the prosthesis from a block of polymer material such as polyurethane.[23] Moreover, 3D printing, a kind of additive manufacturing, has lately superseded this procedure. It is a manufacturing process that builds 3D physical models layer by layer from CAD files.[24]

Figure 3 shows some common additive manufacturing approaches that can be used to create complex objects from a variety of materials such as acrylic rigid polymers, wax, molds, and even complete prosthesis.

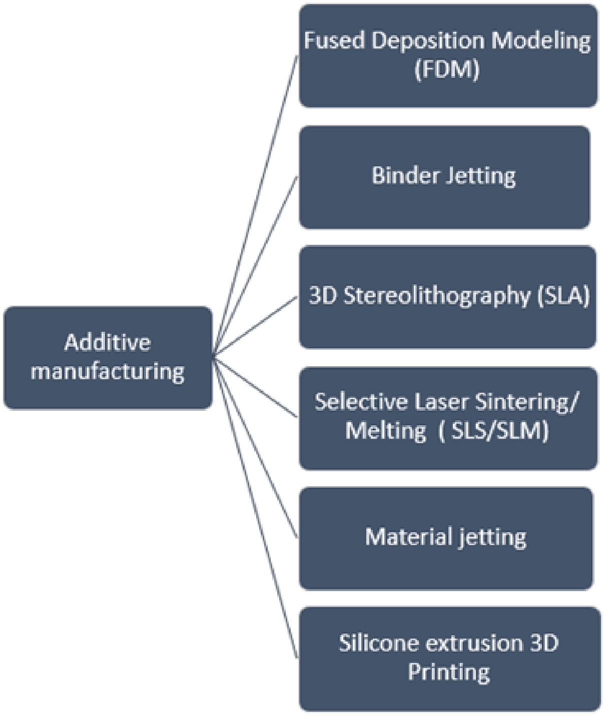

Fig. 3: Additive manufacturing techniques

5. Fused Deposition Modeling (FDM)

Fused Deposition Modeling (FDM) is a 3D printing process developed by Scott Crump in 1989.[25] In this procedure, a heated nozzle melts a thermoplastic polymer filament, which is then extruded onto a print bed to build a 3D item layer by layer. Acrylonitrile butadiene styrene (ABS) and polylactic acid are the most often used materials (PLA). FDM is a low-cost and well-liked 3D printing technique. However this extrusion method has a physical minimum thickness requirement for each layer, which is the limitation in this technique. This can be "jaggy" due to the layer-by-layer process used to create them.[26]

6. Powder Printing/ Binder Jetting

Powder printing, also known as binder jetting, uses injet technology in a 2D printer to combine layers of powdered material, such as gypsum or starch, with liquid resin.[26,27] With each layer of the printed material, the print bed is lowered and a fine layer of powder is spread across the print bed. With each layer of material to be printed, the print bed is lowered and a layer of fine powder is spread over the print bed. Repeating this process builds her 3D object layer by layer. The advantage of this approach is the ability to use multiple printheads, each emitting a different color, allowing for his 3D printed parts in full color.[27]

7. Stereolithography

In the 1980s, Charles Hull developed a process called Stereolithography (SLA) the first 3D printing process. SLA uses liquid photopolymer. It is a combination of container-contained monomeric and oligomeric components that are selectively cured layer-by-layer by UV crosslinking.[24,27] SLA has an advantage over other methods since the polymers are strongly cross-linked and have a robust polymer network. High printing resolution may be achieved by using a laser to manipulate the design. SLA can also create polymer materials with a variety of qualities, such as flexible and biocompatible polymers. The technique wastes extremely little material, and material prices are likewise rather modest. The biggest disadvantage of SLA is the potential for the polymer to distort and curl. Rapid polymerization and shrinkage during curing cause internal strains in the structure that are to blame for this deformation. But, by changing the curing speed, this curling and warping can be minimized.[27]

8. Selective Laser Sintering

Selective laser sintering (SLS) uses thermal energy to fuse layers of powder material. First a thin layer of powder material is applied using a roller and then lasers sinter the powder selectively into the desired pattern. The printed mattress is lowered with each layer created and a fine layer of powder is spread over the mattress. The powder coating is then selectively melted by a high-power infrared laser beam and sintered into the powder material.[28] SLA requires a lot of energy to power the laser beam, which acts as energy to fuse the particles of the material, rather than trigger for polymerization as in SLA. SLS can be used to create prosthetics from polystyrene resin, PBS (polybutylene succinate) prototypes, and wax prototypes.[26]

9. Material Jetting

Material jetting uses inkjet (piezoelectric) technology to selectively deposit liquid materials layer by layer. After deposition, the material is hardened by a UV lamp for photocurable polymers or by cooling for thermosetting materials (such as wax). The advantage of material jetting is that this process can be used to generate 3D objects from multiple materials with a high layer resolution of 0.1mm. Multi-head MJ printers can produce objects of complex nature from multiple materials and customise material properties on a microscopic scale. However, as with FDM, the overhang support structure need to be printed.[26]

10. Silicone 3D Printing

More recently, efforts have been made to directly print silicone prostheses. These printers are capable of revolutionizing the art of fabricating maxillofacial prosthesis by creating realistic, custom silicone prostheses directly from 3D models (RTV) from platinum-catalyzed silicone. These printers have the potential to revolutionize prosthesis manufacturing by enabling the production of realistic, customized silicone prostheses directly from 3D models (RTV) platinum-catalyzed silicone.[26] Fripp received a patent in 2016 for the Picsima, a brand-new 3D silicone printer technology. Their invention uses platinum-catalyzed silicone that is vulcanized at room temperature (RTV). By carefully introducing a catalyst into a vat of uncured silicone, 3D silicone objects can be made. The creation of an extrusion-based silicone 3D printer is a further attempt at direct silicone 3D printing as reported by Jindal et al.[29,30] This printer has two part RTV silicone. Two silicone components are loaded into a controlled syringe pump mounted above the vertical axis of the printer. The components are pushed together into the blender before being placed in the x-y table. RTV silicones used in printers typically cure in less than a minute, so a modifier was added into both parts in order to increase the working time upto 30 minutes.32 A thixotropic agent which is a time-dependent shear thinning agent is added to both to increase the viscosity of the printed silicone paper, which makes the printed pattern stronger and more stable.[30]

These advances in printable silicones could have a significant impact on prosthesis manufacturing and enable directly printed prostheses with customizable material properties.

11. Conclusion

Maxillofacial prostheses have an effect on the lives of innumerable people around the world and its role cannot be underestimated. They significantly improve function and esthetics. CAD/CAM has revolutionized this field of maxillofacial prosthetics. From highly skilled, time-consuming, labour-intensive, costly, and patient-disrupting traditional workflows to simplified, predictable, digitized protocols, is the need of the hour. However, the limitations are that the software's and interfaces required to process and design maxillofacial prostheses are expensive and not typically used for this purpose, making the process more complicated. It also requires a learning curve for its use. The future demand is for easier-to-use software; higher resolution 3D scanners and printers; and improved materials used in the manufacturing of digitally fabricated maxillofacial prosthesis.

12. Source of Funding

None.

13. Conflict of Interest

None.

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