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Maxillofacial Prosthetics Evolution in Digital Age: A Review

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ABSTRACT

Maxillofacial prosthetics, a specialized field, addresses the aesthetic and functional needs of patients with facial deformities caused by congenital conditions, disease, trauma, or surgery. Traditional fabrication of prostheses like auricular, facial, orbital, and obturator has long been a complex, labor-intensive process dependent on the clinician's skill. However, digital technology, such as 3D scanning and rapid prototyping, has revolutionized the field, enhancing precision and reducing manual labor. The workflow typically involves data acquisition through medical imaging techniques like CT, CBCT, and MRI, alongside surface scanners like laser and structured light scanners. While medical imaging is ideal for internal structures, surface scanners provide more accurate and efficient data for external facial prostheses. Digital software plays a crucial role in designing these prostheses, utilizing virtual modeling techniques like mirroring, donor matching, or digital libraries.

Once designed, prostheses are created using various rapid prototyping methods, including fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), and material jetting. These additive manufacturing techniques allow for the production of precise, customized prostheses. Recent advancements have also enabled the direct 3D printing of silicone prostheses, further improving material properties and patient-specific customization. These developments in digital technology and 3D printing hold significant promise for the future of maxillofacial prosthetics, offering more efficient, accurate, and patient-centered outcomes.

KEYWORDS

Maxillofacial Prosthetics, 3D Printing, Digital Workflow, Rapid Prototyping

I. INTRODUCTION

Maxillofacial prosthetics is a specialized field dedicated to addressing the needs of patients with facial deformities resulting from congenital anomalies, disease, surgery, or trauma. Over the years, creating prostheses for ear defects (auricular prostheses), facial deformities, eye defects (orbital prostheses), and palatal defects (obturator prostheses) has posed significant challenges due to the complexity involved. These prostheses use artificial materials to replicate the lost tissue's aesthetic and functional qualities, thereby addressing not only the physical aspects but also the social and emotional well-being of patients, ultimately improving their quality of life.

Traditionally, the fabrication of maxillofacial prostheses involves multiple complex steps, requiring considerable manual labor and skill from the clinician. However, with the advent of digital technology, this field has witnessed a transformation. Digital workflows incorporating 3D scanners, CAD software, and rapid prototyping techniques have reduced manual labor while improving precision. These advancements also make shade matching and the addition of surface details more accurate and predictable. The continued evolution of digital technology, including 3D printing and various data acquisition methods, holds immense potential for enhancing both the fabrication process and the final outcome of maxillofacial prosthetics.

Designing and modelling depends on the type of data acquisition. This plays an important role in the digital workflow as there exists the ability of sculpting the anatomic details and deforming the virtual clay models into the required form.

The manufacturing technique is known as 3D printing or rapid prototyping. These include stereo lithography, LASER sintering, fused deposition modelling and inkjet based systems.

The key elements involved in the digital rehabilitation are:

1. Visualization
2. Design
3. Manufacture
4. Evaluation

3D-DATAACQUISITION

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.

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.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.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.These scans may be obtained from a hand-held scanning tool or a stationary scanner.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.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 typicallyrequired.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 magnitude 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.

RAPID PROTOTYPING

The facial prosthesis can be processed using the Rapid Prototyping (RP) technology once the CAD model has been successfully developed. 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.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.

FUSED DEPOSITION MODELING (FDM)

Fused Deposition Modeling (FDM) is a 3D printing process developed by Scott Crump in 1989.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.

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.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.

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.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.

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.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.

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.

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

II. 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.

3D printing, with advancements in materials like silicone, has opened new avenues for creating highly customized and realistic prostheses. Future prospects in maxillofacial prosthetics include further developments in 3D printing technologies, such as direct silicone printing, which promises to enhance the customization and quality of prostheses. As technology continues to evolve, the potential for combining AI, advanced imaging, and even biocompatible materials could lead to more patient-centered care, improving both the process and outcomes in facial prosthetic rehabilitation.

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