ISSN: 2582-9904

LITERATURE REVIEW

The Advent of Rapid Prototyping in Maxillofacial Prosthodontics – Exploring Into The Third Dimension

Rangarajan S[a], Abraham HM[b], Venkatakrishnan CJ[c], Philip JM[d]

ABSTRACT
Rapid prototyping technology has opened new design and production possibilities in the realm of maxillofacial prosthodontics. Rapid prototyping is a technology that allows us to create physical objects from 3D computer data by sequential layering. Rapid prototyping has transformed dentistry with faster processing and increased precision of various prosthetic devices. This article attempts to enhance knowledge on history, materials used for rapid prototyping and an insight on applications of rapid prototyping in maxillofacial prosthodontics.

Keywords: COVID 19, Infection control, Sterilization, and disinfection.

How to cite this article: *Rangarajan S, Abraham HM, Venkatakrishnan CJ, Philip JM. The advent of rapid prototyping in maxillofacial prosthodontics – exploring into the third dimension. J Clin Prosth Impl 2022;4(1):6-10.* ***https://doi.org/10.55995/j-cpi.2022002***

INTRODUCTION
A combination of surgical and prosthetic procedures are required to treat patients with maxillo- facial deformities that are either congenital, traumatic, or the product of an ablative surgery.[1] When restoring maxillofacial defects, the prosthesis should ideally be customized to the person's needs, and similar to the human anatomy. When the defect is unilateral, more realistic results can be achieved by comparing and repeating proportions from the non-defect side of the same individual because individual proportion indices differ from the average. To shape a mirror image and achieve a good esthetic match, traditional method of prosthesis fabrication can be challenging, time-consuming and also requires a high degree of artistic ability. The implementation of three-dimensional representations of human anatomy in computerized tomography (CT) and magnetic resonance imaging (MRI) has opened new possibilities to reproduce more complex and intricate details required to restore challenging maxillofacial defects.[2] Rapid prototyping (RP) systems have enabled the development of customized 3-D anatomic models with a degree of complexity previously unattainable by traditional methods. RP methodologies use an additive process of constructing an object in layers specified by a computer model that has been virtually sliced, which necessitates the use of Computer numerical control (CNC) based equipment.[3,4] This enables the development of intricate shapes with internal details.[5]

HISTORY OF MAXILLOFACIAL PROSTHETIC MATERIALS:
During the 16th century, Ambroise Paré was the first person to employ maxillofacial prosthetics. Paré's idealized prostheses were created from a variety of materials, including leather, ivory, gold, and silver. In 1560's Tycho Brache replaced his own nose with a metal nose. Pierre Fauchard in 1678 made significant contributions to the field of facial prosthetics. In 1905, Ottofy, Baird and Baker et al reported using black vulcanized rubber. Acrylic resin was first used in dentistry between 1940 and 1960. The development of several types of elastomers between 1960 and 1970 resulted in significant changes. Gonzalez described the use of polyurethane elastomer between 1970 and 1990.The introduction of 3D printed silicone prosthesis has made a drastic change in the field of maxillofacial prosthodontics.[6]

HISTORY OF RAPID PROTOTYPING:
Herbert Voelcker in 1960, suggested an idea with computer-controlled and automated machine tools,[7] and in the 1970s, he created the first mathematical theory and algorithms for solid modelling of three-dimensional structures, that were later used to build almost all mechanical objects, from toy cars to skyscrapers.[8]

[a] PG student, Department of Prosthodontics, Tagore Dental College
[b] Senior lecturer, Department of Prosthodontics, Tagore Dental College
[c] Principal and Head, Department of Prosthodontics, Tagore Dental College
[d] Reader, Department of Prosthodontics, Tagore Dental College.

Stereolithography (SLA) was the first RP technology invented by Charles Hull in 1984 for fabricating solid items by 'printing' small layers of ultraviolet curable material one on top of the other. Carl Deckard in 1987 introduced layering by CAD or a 3D digital model, which evolved into the second RP technology known as Selective Laser Sintering (SLS).10 Brix and Lambrecht used a 3D model in health care for the first time in the same year, using an RP predecessor called a computer numerical control (CNC) unit. Scott Crump developed the third RP technique, fused deposition modeling (FDM), in an open space in 1988. Helisys released and commercialized the first system of laminated object manufacturing (LOM) which became the fourth RP technology.[10]

CLASSIFICATION OF RAPID PROTOTYPING TECHNOLOGIES:

RP technologies used in medicine can be classified based on the initial state of the substance and the forming methods used. (*Fig 1*) However, only few of these methods are employed for prosthesis fabrication, of which the most common are stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling (FDM), laminated object modeling (LOM), and 3D printing(3DP).[9]

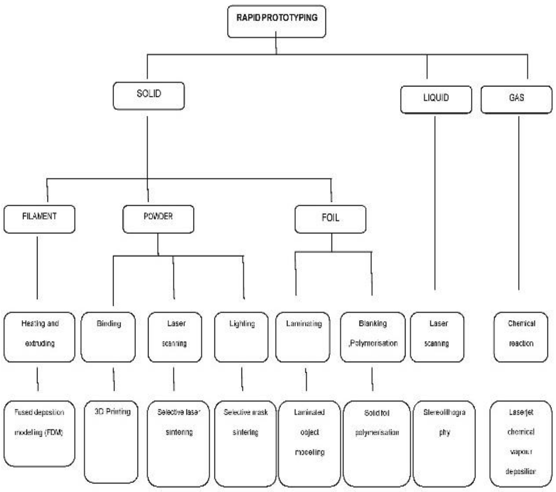

Fig 1: Various Rapid Prototyping technologies

MATERIALS FOR RP ASSISTED MAXILLOFACIAL REHABILITATION:

Materials for manufacturing custom implants and prostheses dictates the success of RP technologies in maxillofacial prosthodontics. Casting wax, thermoplastic materials, ceramics(Hydroxyapatite), metals(Titanium) and polymers (PMMA) and PEEK have been used to fabricate 3D printed maxillofacial prosthesis.[10] (*Table 1*)

	SLA	SLS	FDM	LOM	3D P
Materials	Photopolymers (acrylic and epoxy resins)	Metals, sand, thermoplastic (PA12, PC, PS)	Thermoplastics (ABS, PC, ABS-PC-blend, PPSU)	Foils (paper, polymers, metals, ceramics)	Thermoplastics, cement, cast sand
System type	Liquid-based	Powder-based	Solid-based	Solid-based	Powder-based
Forming technique	Laser/light-based	Laser/heat based	Heat and extrusion/ nozzle-based	Lamination	Adhesives/molding
Accuracy	<0.05 mm	0.05–0.1 mm	0.1 mm	0.15mm	0.1/600T540 dpi
Cost	Very High	Costlier than FDM.Very high cost for metals	Low	Low	High
Application	Surgical guides and templates for designing soft tissue incisions, surgical resection margins, Implant surgeries. Models for assessment of bony defects for grafting, Fabrication of custom MFP prostheses	Surgical osteotomy guides, Custom- made titanium orbital floors, Custom made orbital grids, Sub-periosteal dental implants, Custom-made cranial plates	Manufacturing surgical guides for preoperative planning of complex surgical treatments.	Surgical template fabrication	Contour models, Surgical guides,Splints,3D printed Implants,Fabrication of custom ocular,auricular,nasal and combination prostheses.

Table 1: Comparison between Rapid prototyping technologies

METHODS OF 3D PRINTING:

The method used for 3D printing is dictated by the material and type of prosthesis being fabricated. Models and surgical guides can be printed using SLA and FDM. Patient specific implants are usually printed using SLS, SLM, or EBM. Unlike SLA and FDM, SLS does not require support structures during 3D printing to print overhangs. This is because the surrounding powder supports the unconnected portions being printed. This allows for printing of previously inconceivable geometries.[11]

PROCEDURE WORKFLOW:

The procedure is based on three main steps: Data capture, Computer aided design–computer aided manufacturing (CAD–CAM) processing, and manufacturing phase. (*Fig 2*)

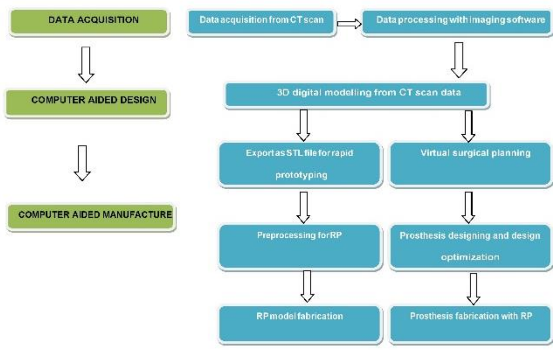

Fig 2: Procedural workflow

ADVANTAGES OF RAPID PROTOTYPING:[12]

•High-precision manufacturing

•Short manufacturing cycle, simple production process, and low production cost

•Personalized manufacturing

•Diversity of manufacturing materials

•Complex manufacturing

•Early visualization of product design

APPLICATIONS OF RAPID PROTOTYPING IN MAXILLOFACIAL PROSTHODONTICS:

Rapid prototyping is being widely used in the field of maxillofacial prosthodontics, to rehabilitate extraoral and intraoral facial defects. Orbital, Ocular, Nasal, Auricular, Cranial, Maxillary and Mandibular defects have been successfully rehabilitated using 3D printed maxillofacial prosthesis.

CRANIAL PROSTHESIS:

Trauma and neurosurgical treatments such as decompressive craniotomy, tumor resections, infection, and congenital anomalies are all common causes of cranial defects. Cranioplasty is a neurosurgical procedure which is done to rehabilitate the cranial defects. Alloplastic cranioplasty technique using PMMA is the most common method of restoring lost cranial bone which has several complications such as infection, fragmentation, bone resorption. Also this technique requires modelling of the plastic during its polymerization which can be difficult with respect to modeling the shape of the skull and thus the aesthetic outcome. Another major problem is that, under surgical conditions, free modeling of a large PMMA plastic is difficult. Jesús A. Morales et al demonstrated a cranioplasty with customized, 3D printed prefabricated implant which helped to overcome the complications of alloplastic cranioplasty and improved cosmetic outcome and reduced treatment time.[13]

OCULAR PROSTHESIS:

In most cases, proper digital fabrication of an ocular prosthesis remains a challenge. The eye is located inside a socket surrounded by hard and soft tissue, unlike auricular or nasal defects, which are projections on the face. Anophthalmus of the socket, makes ocular impression procedure challenging. Ruiters Sébastien et al reported fabrication of a 3D printed ocular prosthesis for an anophthalmic socket with less soft tissue distortion, easier and precise reproduction of defect margins and better fit due to customizability. The time required for casting, duplication of impression, were omitted, lessening the overall treatment time.[14]

MANDIBULAR PROSTHESIS:

Although rehabilitation of hemimandibulectomy defects were successfully done,[15] the world's first complete mandible was fabricated using additive technology and placed into a patient by Dr. Jules Poukens and team in Belgium in 2012.[16]

TMJ PROSTHESIS:

Stock TMJ prosthesis lacks in obtaining satisfying and effective results due to biometric and anthropometric dissimilarities in humans. Custom made prosthetic TMJ is the sustainable and vital key for patient suffering from end stage, complex bone and joint disorders. Mehak Sharma[17] has created a unique and customized TMJ prosthesis for the first time in India using 3D CAD modelling for design and DMLS technique for fabrication which was economical.

OBTURATOR PROSTHESIS:

A major issue with conventional obturator prosthesis is its weight. PEEK has been considered as a promising material for restoring maxillofacial defects and was used by Theodoros et al has for 3D printing maxillary obturator prosthesis of significantly lighter weight.[18]

PATIENT SPECIFIC IMPLANT:

The most recent advancement in the use of 3D printing is Patient specific implant (PSI). Patient-specific implants are designed using 3D imaging, resulting in precisely fitting implants that are used to restore proper anatomy, relation and function.[19] Patient specific implant can be utilized in cases with bone defects where grafts cannot be placed increasing the possibility of rehabilitation with implants.

HAND PROSTHESIS:

The function of an ideal prosthetic limb is to effectively replace both appearance and functionality. While cosmetic limbs are purely nonfunctional and are used only for the appearance "the world's first clinically approved 3D printed bionic arm, the Hero Arm, with multi-grip functionality and empowering aesthetics was designed to meet the disadvantages such as limited aesthetics, rigid 3D printed prosthetics.[20]

IMPLANT SURGICAL GUIDE:

3D printed surgical guides facilitate the orientation and execution of ostetotomy drillings, permit a correct dental implant placement and angulation, as predicted in preoperative planning. Yasmin Ghantous performed a prosthetically driven preoperative planning and fabricated a 3D metal drill guide which was used to allow full control of the accurate location and angulation of the zygomatic implant insertion.[21]

APPLICATION IN FORENSIC SCIENCE:

In forensic science, creating 3D reproductions might be advantageous Unknown human remains can be identified via forensic facial reconstruction, also known as facial approximation. Quick, fast, and cost-effective computerized 3D forensics are now possible because of advances in 3D technology. The facial reconstruction process makes it easier for family members to recognize the victim visually.[22] Chase RJ et al [23] in their review reported the value of forensic imaging and 3D printing as demonstrative aid in court, while simultaneously emphasizing the importance of evidence-based data to back up such claims.

Rapid prototyping has also been extensively used in the fabrication of custom nasal,[18] auricular [22] and combination prostheses [1] from 2000s till 2021. RP technology used to restore extraoral maxillofacial defects are time saving, comfortable for the patient, do not cause distortion of the site, avoids deformation of the soft tissue from pressure of the impression material, avoids changes in tissue location with variation of the patient's position.[24]

CONCLUSION

The restoration of craniofacial abnormalities using prosthetics is an ancient skill whose success has always been hampered by the lack of appropriate materials. Technology advancements have a significant impact on the restoration of form and function in the craniofacial region. RPM is one of the most advanced and resilient fabrication technique. The clinical use of medical RPM has improved the quality of the treatment such as preoperative planning and simulation process.[5] Conventional dentistry will be replaced soon by prototyping in the near future and will make it more effective, reliable, and predictable. Complicated machinery and reliance on experience to operate the machinery during development are two of the RP technology's disadvantages, as is the high cost of the machines. More advanced RPM implementations will become accessible over time, which will yield high satisfaction in patients.[25]

CONFLICT OF INTEREST

There is no conflict of interest

REFERENCES

1. Richard Bibb, Dominic Eggbeer, Peter Evans. Rapid prototyping technologies in soft tissue facial prosthetics: current state of the art. Rapid Prototyping Journal.2010;16 (2):130-137.
2. Petzold R, Zeilhofer HF, Kalender WA. Rapid prototyping technology in medicine—Basics and applications. Comput Med Imaging Graph 1999;23:277–284.
3. Webb PA. A review of rapid prototyping (RP) techniques in the medical and biomedical sector. J Med Eng Technol 2000;24:149–153.
4. Löppönen H, Holma T, Sorri M, et al. Computed tomography data based rapid prototyping model of the temporal bone before cochlear implant surgery. Acta Otolaryngol Suppl 1997;529:47–49.
5. Rimell JT, Marquis PM. Selective laser sintering of ultrahigh molecular weight polyethylene for clinical applications. J Biomed Mater Res 2000;53:414–420.
6. Ahmed Yaseen Alqutaibi. Materials of facial prosthesis: History and advance. International Journal of Contemporary Dental and Medical Reviews.2015;1-4.
7. Boehm T, Carnasciali MI, Douglas ME, Fern á ndez MG, Williams C. Rapid prototyping industry analysis . Atlanta, Georgia: Georgia Institute of Technology; 2004.
8. Torres K, Staśkiewicz G, Śnieżyński M, Drop A, Maciejewski R. Application of rapid prototyping techniques for modelling of anatomical structures in medical training and education . Folia Morphol.2011; 70 : 1 – 4 .
9. Wendel B, Rietzel D, Kühnlein F, Feulner R, Hülder G, Schmachtenberg E . Additive processing of polymers . Macromol Mater Eng. 2008 ; 293 : 799 – 809 .
10. Madhav VN V, Daule R.Rapid Prototyping and its Application in Dentistry. Journal of Dental and Allied Sciences. 2013;2(2):57–61.
11. Yan X, Gu P. A review of rapid prototyping technologies and systems. Computer-Aided Design. 1996;28:307–18.
12. Wu P. 3D printing technology and its future development. Printing Quality Standardization. 2014 ; 1 : 8 – 10 .
13. Jesús A. Morales-Gómez et al. Cranioplasty with a low-cost customized polymethylmethacrylate implant using a desktop 3D printer. Journal of Neurosurgery. 2019;130(5):1-10.
14. Ruiters Sébastien, Sun Yi2, De Jong Stéphan, Politis Constantinus, Mombaerts Ilse. Computer- aided Design and 3-dimensional Printing in the Manufacturing of an Ocular Prosthesis. Acta Ophthalmologica.2016; 94(256).
15. Shailendra Kumar Sahu, B.K. Motwani,Anurag Dani. Prosthetic rehabilitation of edentulous hemimandibulectomy patient: a clinical report. Clinical Case Reports.2017;5(11): 1739-1742.
16. Mehreen Bhat,V Vidyashree Nandini,V. The Realm of Patient Specific Implants (PSI) In Maxillofacial Prosthodontics: A Review. IOSR-JDMS.2020;19(11): 13-19.
17. Mehak Sharma , Manoj Soni. Direct metal laser sintering of TI6Al4V alloy for patient-specific

temporo mandibular joint prosthesis and implant. Materials Today: Proceedings.2020

18. Theodoros Tasopoulos et al. PEEK Maxillary Obturator Prosthesis Fabrication Using Intraoral Scanning, 3D Printing, and CAD/CAM. The International Journal of Prosthodontics.2020;30(3):333-339
19. Dr. Mehreen Bhat , Dr. V VidyashreeNandini. The Realm of Patient Specific Implants (PSI) In Maxillofacial Prosthodontics: A Review. IOSR.2020;19:13-19.
20. Open bionics. NHS launches world's first trial of 3D printed bionic hands for children [Internet]. NHS England, the Bristol Centre for Enablement, Bath University.UK. Katie Forster.2017 12:44.
21. Yasmin Ghantous. Three-Dimensional Technology Applications in Maxillofacial Reconstructive Surgery: Current Surgical Implications. Nanomaterials.2020;10: 2523
22. Lee WJ, Wilkinson CM, Hwang HS. An accuracy assessment of forensic computerized facial reconstruction employing cone-beam computed tomography from live subjects. J Forensic Sci 2012;57:318-27.
23. Chase RJ, La Porte G:. The next generation of crime tools and challenges: 3D printing. c201.
24. Qian Peng, Zhangui Tang, Ousheng Liu & Zhiwei Peng. Rapid prototyping-assisted maxillofacial reconstruction, Annals of Medicine. 2015; 47(3): 186-208
25. Pooja Negi, Astha Jaikaria, Suhani Kukreja. Rapid Prototyping in Dentistry. International Journal of Science and Healthcare Research. 2019;4(4):113-116.

Corresponding Author: Dr. Sahana Rangarajan, Postgraduate, Tagore dental college and hospital, Chennai Tamilnadu
E-mail: saisahana29@gmail.com , Ph.No.: +919500905677