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Rapid prototyping and stereolithography in dentistry: Radiographic role

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Abstract
Emergence of advanced digital technology has opened up new perspectives for design and production in the field of dentistry. Rapid prototyping (RP) is a technique to quickly and automatically construct a three-dimensional (3D) model of a part or product using 3D printers or stereolithography machine. The first method for rapid prototyping was introduced in the 1980s in the field of engineering for the fabrication of a solid model based on a computed file. The innovation of digital technology have revolutionized dentistry, and this digitized medical treatment. Rapid prototyping is a type of computer aided manufacturing that make physical objects from computer data. It is a technology that is capable of making physical objects directly from 3D computer data by adding a layer upon layer and 3D physical structures are known as rapid prototypes. These includes steriolithography, selective laser sintering, 3D Printers and fused deposition modeling. Rapid prototyping presents fascinating opportunities, but the process is difficult as it demands a high level of artistic skill, which means that the dental technicians should be able to work with the models obtained after impression to form a mirror image and achieve good esthetics. This review aims to focus on various RP methods and its application in dentistry.

Keywords: 3D Printers, computed file, rapid prototyping

Introduction

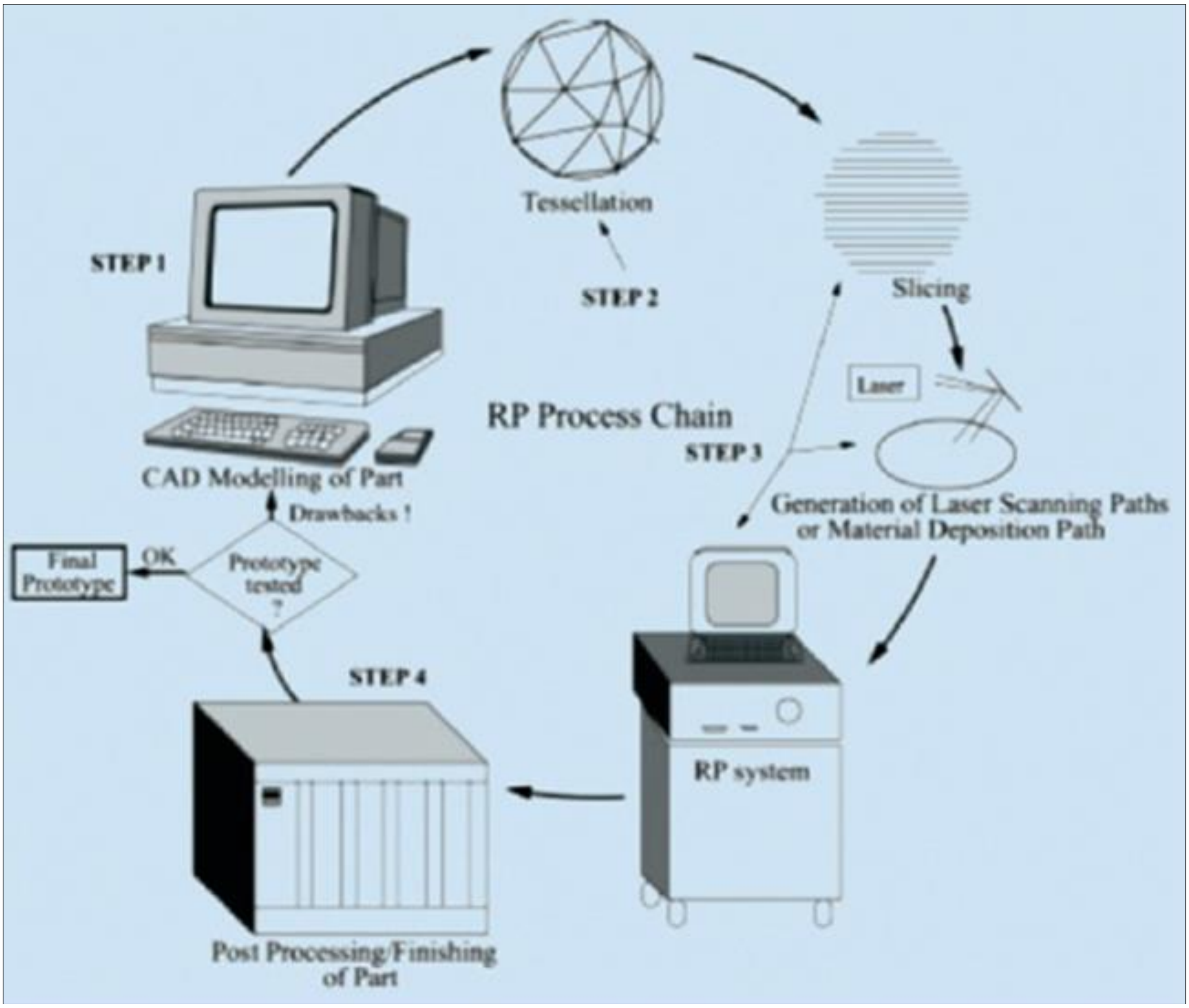
In 1987, Brix and Lambrecht used, for the first time, a prototype in health care. It was a three-dimensional model manufactured using a computer numerical control device, a type of machine that was the predecessor of RP. In 1991, human anatomy models produced with a technology called stereolithography were first used in a maxillofacial surgery clinic in Viena [1]. RP has proposed various applications in dental fields, such as fabrication of implant surgical guides, zirconia prosthesis and molds for metal castings, maxillofacial prosthesis and frameworks for fixed and removable partial dentures, and wax patterns for the dental prosthesis and complete denture. Prosthesis should be customized precisely when attempting to restore a face with prosthesis; the prosthesis should restore the anatomy as closely as possible [2]. Fabrication of prosthesis by these technologies has reduced reliance on human variables and thus has overcome the limitations of conventional method which requires considerable human intervention and manipulation of materials that may exhibit inherent processing shrinkage/expansion [3].

What Is Rapid Prototyping?

RP is a type of computer-aided manufacturing (CAM) and is one of the components of rapid manufacturing. It is a technology that is capable of making physical objects directly from three-dimensional (3D) computer data by adding a layer upon layer. First, slicing of the digital model is done, and then through an automated process of layer-by-layer construction, transverse sections are physically produced. These 3D physical structures are known as rapid prototypes. Rapid prototypes contain mobile parts with complex geometry that is impossible to be made by other construction techniques. In addition, before definitive fabrication of prosthesis, this technique allows visualization and testing of objects, which reduces costs [4, 5, 6].

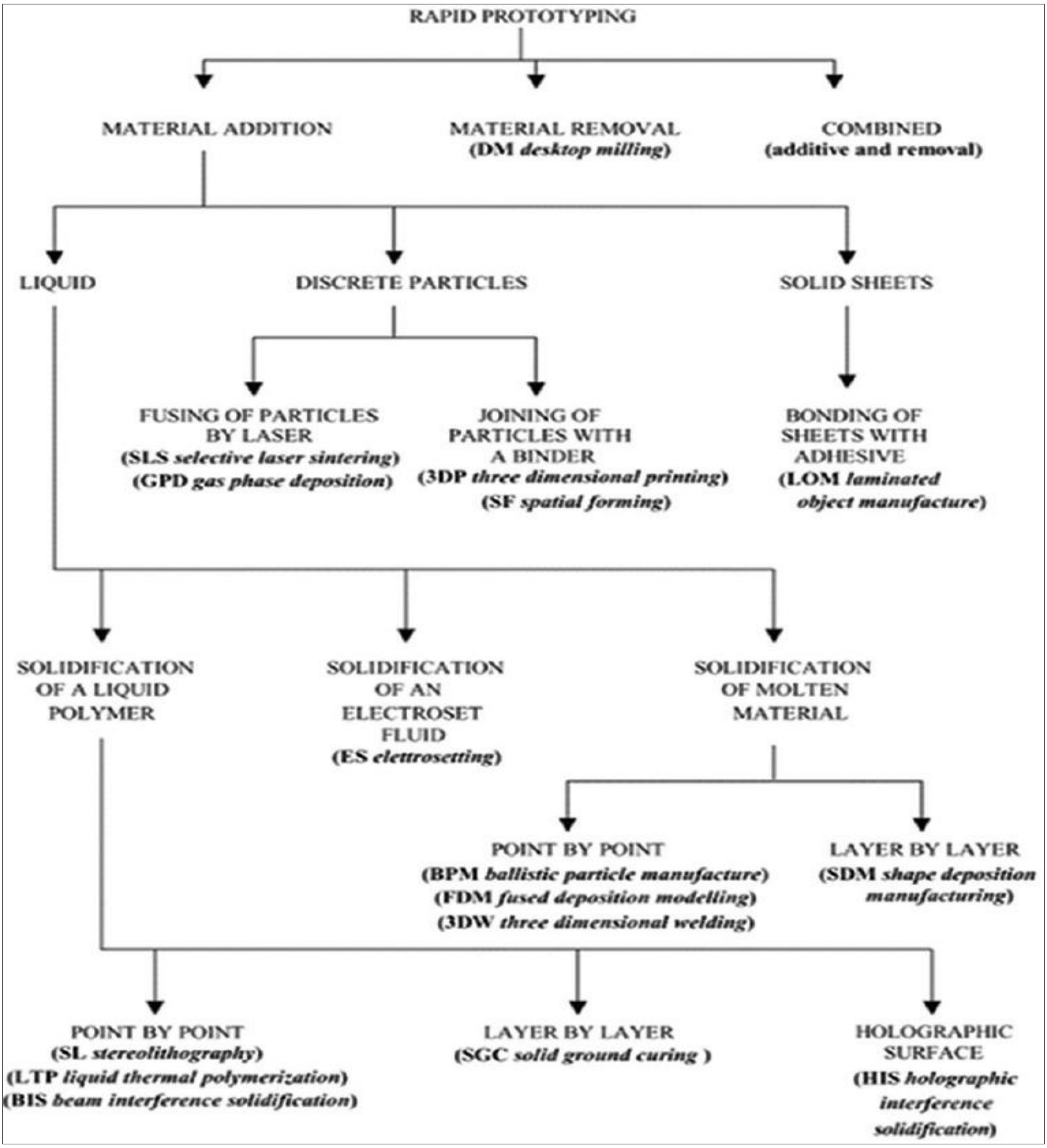
Basic Principle

The key idea of this new RP technology is based on the decomposition of three-dimensional computer models in the layers section transverse thin, followed physically forming layers and piling layer by layer. The generation of three-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 [7].



Classification of Rapid Prototyping Method

The most popular among currently available RP technologies is perhaps stereolithography and is the first commercially available rapid prototype. Stereolithography apparatus was invented by Charle Hull of 3D Systems Inc. This relies on a photosensitive monomer resin which from a polymer and solidifies when exposed to ultraviolet (UV) light. Due to the absorption and scattering of the beam this reaction only takes place near the surface. This produces parabolically cylindrical voxels which are characterized by horizontal line width and vertical cure depth. An stereolithography machine consists of a build platform (substrate) which is mounted in a vat of resin and a UV helium-cadmium or argon ion laser [8]. The first layer of the part is imaged on the resin surface by the using information obtained from the three-dimensional solid CAD model. Once the contour of the layer has been scanned, and the interior either hatched or solidly filled, the platform is next lowered to the base of the vat in order to coat the part thoroughly. It is then raised such that the top of the solidified part is level with the surface and a blade wipes the resin leaving exactly one layer of resin above the part. The part is then lowered to one layer below the surface and left until the liquid has settled. This is done to ensure a flat, even surface and to inhibit bubbles formation. The next layer may then be scanned [9].



Bio-printing and Its Difference from 3D Printing

Bio-printing is one of the techniques used for the printing of tissues and organs. It uses bio ink to print living cells instead of metal or plastic using layer by layer technique. Patients' specific organs are easily printed, which helps perform complicated cases. Bioink is an essential component of bio-printing made up of living cell structure used to print specific live tissues layer by layer. The fundamental difference between bio-printing and 3D printing is that bio-printing is used to print several tissue types, while 3D printing is applicable for producing or printing medical tools and devices [10, 11].

Need for 3D Printing in Radiology

A patient-specific implant requires a 3D physical model for better understanding and treatment, which is not possible by just capturing images by different medical imaging technologies. 3D printing technology has conceded with the best-suited technologies to perform the appropriate medical treatment process in radiology. It involves customized manufacturing of parts in lesser time and cost as compared with traditional manufacturing methods. Due to its time-saving benefits, pharmaceutical companies take economic advantages to complete personalized treatment. 3D printing technology provides great research and development opportunities in radiology because of its high resolution and possibility to print multi material during the same printing operation. Based on its biocompatibility and conductivity, researchers propose this manufacturing system for personalized treatments [12, 13].

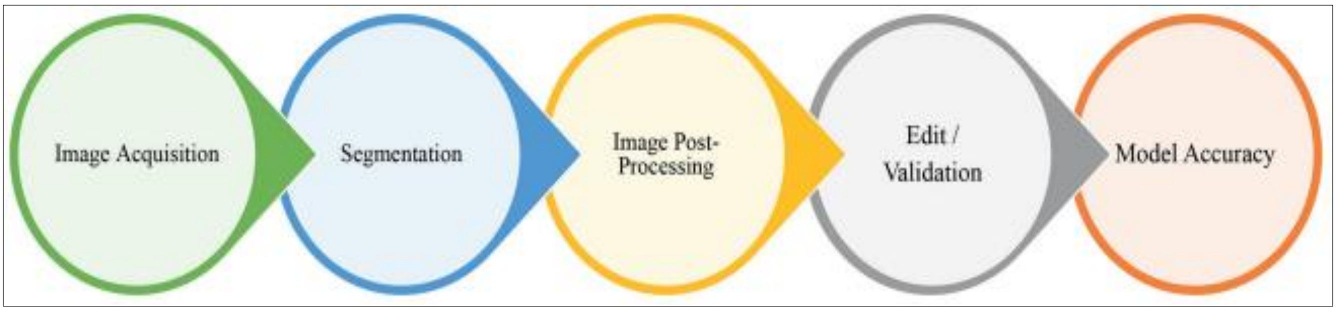


Fig 1: specific features of three-dimensional (3d) printing for radiology.

Features of 3D Printing Important for Radiology

The major features of 3D printing, which have made radiologists capabilities more impactful and impressive, are exemplified. The accuracy and precision in the design and development are always sought as the crucial elements and base for improving the product quality. The features like image acquisition, segmentation, image pre- and post-processing, editing in the segmentation details as per the need and its further validation, accuracy of the model are the more commonly known and highlighted ones when we move toward the applications of 3D product/part development in radiology [14-16].

The 3D digital model to be printed can also be scaled as per the necessity, and the complexity can be minimized by using the fundamentals of rapid prototyping technique. The segmentation process is being developed in a manual and automated manner. When it comes to visualizing any data in the plane, 3D printing enables us with specific imaging pre- and post-processing features. Furthermore, the traits like validation and accuracy of the developed model provide significant depths through the applications of 3D printing in radiology [17, 18].

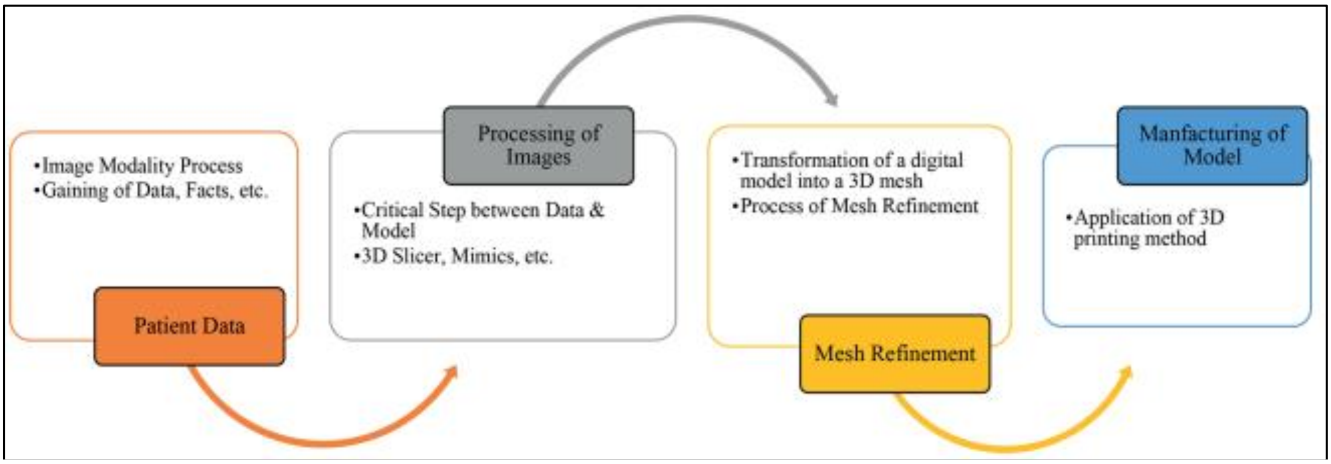


Fig 2: Process steps of three-dimensional (3D) printing for radiology.

3. Classification for medical Applications of rapid prototyping

During the last years even more medical applications of RP have been developed and reported. This area of RP is highly challenging because the application development is always multidisciplinary and includes in minimum tasks related to medical imaging and 3D modeling, medical treatment and actual RP technology. The optimization of treatment processes requires team work across these disciplines. There are several requirements related to RP technology when applying these in medical and health care areas. Thus, we propose application solution oriented classification system for medical applications of RP.

For each group common requirements for RP technologies can be identified. Basically, from the health care process point of view, in each class the RP technologies have a similar role.

3.1 Models for preoperative planning, education and training

Using initial data from medical images it is possible to rapid manufacture preoperative models. These models can be used for planning or simulating the surgery preoperatively. (McDonald, J. A. *et al*. 2001) [19] Models can be also used for educating students as well as patients and families and for surgical training purposes, such as temporal bone dissection (Mäkitie A. *et al*. 2008) [20]. Depending on the application different qualities of the models such as anatomical accuracy, material characteristics or haptic response of the model become important. Real haptic response of bone is highly desirable especially in surgical training models (Mäkitie A. *et al*. 2008; Kanerva J. 2008) [20].

3.2 Inert implants

In this class are rapid manufactured implants used in medical operations. The implants are created based on medical imaging and 3D modeling. Inert implants can be rapid manufactured directly or indirectly. Janssens & Poukens (2007) have presented a digitally designed and rapid manufactured cranial plate implant as an example of directly rapid manufactured implant. (Janssens M. & Poukens J. 2007) [21]. Indirect rapid manufacturing means that rapid manufactured models are used to create the implant through e.g. casting and replication techniques. Eppley (2002) reports on a case where seven patients with large bony lesions of the anterior cranial vault and orbit underwent simultaneous bony excision and reconstruction with preoperatively fabricated custom implants. The predicted amount of bone excision was first performed on the patient's anatomical model rapid manufactured on the basis of medical modeling. The resulting defect in the model was thenused to create an alloplastic implant for surgical reconstruction (Eppley B. L. 2002). RM technologies potentially offer more anatomical accuracy and better implant fit than traditional manufacturing methods (Janssens M. & Poukens J. 2007) [21].

3.3 Tools, instruments and parts for medical devices

In this class are applications in which RP is used to create tools and hardware for medical applications.

An example is treatment of dental malocclusion by rapid manufacturing a mold for a series of clear and removable appliances. (Miller J. R. *et al*. 2002) Also manufacturing of e.g. operation specific instruments or preforms belong to this class [22].

3.4 Medical aids, supportive guides, splints and prostheses

In this class RM technologies are utilized to possible anatomic personalization of a device or corresponding element. Prosthetic sockets can be manufactured using rapid prototyping technology. Creating the socket has traditionally been labor intensive and it usually takes two to three days to make one socket. Using CAM systems and rapid manufacturing technologies the time is reduced to less than 4 hours. (Ng P. *et al*. 2002). In cochlear implant surgery rapid manufactured drill guides have been used and these reduced operative time and overall costs. (Labadie R. F. *et al*. 2008) [23]

3.5 Bio-manufacturing

Freeform culture media can be manufactured with RP technologies. These applications include bio-logcally compatible parts and parts to be used when manufacturing these components. Such scaffolds can be used as a skeleton for cells. The scaffold acts as support, protects the cells from external physical forces and provides an optimal medium for 3D culture of cells. (Yan, Y. *et al*. 2003) [11]. Next step is direct rapid manufacturing of tissues and research in this area is rapidly increasing (Hutmacher, D. W. *et al*. 2004; Wang X. *et al*. 2006; Xu W. *et al*. 2007) [23, 24].

Dental Applications of Rapid Prototyping

Implantology

The use of dental implants has evolved rapidly over the past decade since the advent of the concept of osseointegration.

Development in the field of oral implantology has led to the development of successful and predictable restorative options for partially as well as completely edentulous patients. Correct placement of the implant is an important phase. Improper implant placement can have a detrimental effect on the long-term predictability and success of the implant-supported prosthesis [25].

The use of computer-aided design (CAD)/CAM technology has gained popularity in implant dentistry. Application of RP in implantology pertains to 3D imaging and using 3D software for treatment planning. Surgical guides are fabricated using additive RP, while fabrication of all-ceramic restorations is done using subtractive RP.RP technology allows for industrial fabrication of customized 3D objects from CAD data [26].

Automatic wax-up construction is possible with the introduction of RP technology. After fabrication of the wax pattern by RP, the traditional lost-wax process is still needed. In comparison to the laser melting or sintering direct manufacturing processes, which is financially unattainable for most dental laboratories, this process is more affordable.

Direct dental metal prosthesis fabrication For the quick fabrication of high-precision metal parts, RP technologies including selective laser melting (SLM) and SLS technology are used. Dental prostheses processed by employing SLS/SLM technique are very appropriate regarding their complex geometry and their capability to be customized without the extensive manual pre- or post-processing steps.

All-ceramic restoration fabrication

For the fabrication of green zirconia, all-ceramic dental restoration direct inkjet fabrication process has been anticipated using a slurry micro extrusion process. This innovative method is a favorable CAD/RP system with great ability to produce all-ceramic dental restorations with high precision, cost competence, and minimum material intake. This method is still in the experimental phase [26].

Mold for complete dentures

In the field of complete denture, there is limited literature available which reveals that advanced manufacturing technologies have not been successfully implemented yet. For parameterization positioning of artificial teeth, a 3D record is taken, which yields 3D data of edentulous models and rims in centric relation. Using 3DP, physical flasks (molds) are fabricated, but finishing the complete denture is done using a traditional laboratory procedure.

Maxillofacial prosthodontics

Patients suffering from facial deformity due to congenital defect or defect due to trauma or ablative surgery are treated by maxillofacial units using a variety of surgical and prosthetic techniques so that the defect can be restored to normal function and appearance.

In maxillofacial prosthetics, RP is being used for: (i) fabrication of obturators, (ii) production of auricular and nasal prosthesis, (iii) manufacturing of surgical stents for patients with large tumors scheduled for excision manufacturing of lead shields to protect healthy tissue during radiotherapy treatment, and (iv) fabrications of burn stents, where burned area can be scanned rather than subjecting delicate, sensitive burn tissue to impression-taking procedures. Duplication of existing maxillary/mandibular prosthesis is especially crucial when an accurate fit to natural teeth or an osseointegrated implant is needed [27, 28].

Limitations and Future Scope

There is a requirement for appropriate patient data captured by CT, MRI, or other medical imaging technologies. Accurate segmentation of the patient image is required for 3D printing technology. Specialized software is required for this purpose; additional cost is acquired. Thus, to convert the imaging data, there is a requirement for a skilled workforce to create CAD digital model precisely. 3D printing technology acquires extra cost during the multi material printing process.

In the future, the shortage of tissue and organ can be dealt with quickly by using bioprinting with the input of biomaterial and living cells. Researchers are continuously working on 3D printing technology, and in the future, this technology will come into the picture for more innovative medical application.

Conclusion

With advancements in various RP system, this technology is becoming portable and more pervasive. The availability of this technology is growing as well. Nowadays, CAD and RP technology are being used in various fields of medical and dentistry, have had a considerable impact especially on the rehabilitation of patients with head and neck defects. With newer innovations currently, these systems are also being used for presurgical planning in dentistry.

treatment planning and placement of implants, fabrication of facial prosthesis, fabrication of cranioplasty prosthesis, contouring of reconstruction plates before mandibular resection and reconstruction, sophisticated reconstruction of maxilla and a variety of other purpose.

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