International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)
ISSN: 2456-236X
Vol. 10 Issue 01 | 2025

THE USE OF ADDITIVE MANUFACTURING TECHNOLOGIES IN REPARATIVE DENTISTRY

Mr. Nitesh Somnath Gurav [1], Prof. N. A. Kharche[2], Prof. P. V. Chopde[3], Prof. S. R. Shekokar[4]
[1]student, mechanical engineering, Padmashri Dr. V. B. Kolte college of engineering, Malkapur, Maharashtra, India
[2,3,4] Assistant Professor, Padmashri Dr. V. B. Kolte college of engineering, Malkapur, Maharashtra, India

DOI: 10.5281/zenodo.16413058

ABSTRACT

In the modern day, as in most other fields, there has been a swift shift towards digitalization within dentistry with the application of computer-aided design and computer-aided manufacturing (CAD/CAM) technology becoming more prevalent. Within dentistry, three separate concepts are utilized to create a tangible prototype: additive, subtractive and hybrid. Additive manufacturing processes, used based on CAD/CAM technology, have proved to be a substitute for subtractive processes with the advantages that they provide, and due to this, their application in dentistry has spread at a fast pace. Additive manufacturing techniques are projected to become the primary means of digital manufacturing in dentistry in the future since they have already been applied in numerous dental procedures. In this review, an attempt was made to review CAM methods used frequently in dentistry; to assess the pros and cons of these methods in a systematic manner; to analyze the working procedures of additive manufacturing technologies employed in dentistry; and to assess the applications and advancements of these additive manufacturing techniques in restorative dentistry. For this intention, a scan of literature was performed employing Mesh words corresponding to the topic ("manufacturing, fabrication techniques", "CAD/CAM, restorations", "digital dentistry", "additive, subtractive systems", "additive manufacturing in restorative dentistry") in medical databases (Medline-PubMed, Embase).

***Keyword:** 3D printing, additive manufacturing, CAD/CAM, digital dentistry, subtractive manufacturing.*

1. INTRODUCTION:

Computer-aided design and computer-aided manufacturing (CAD/CAM) software has spread extensively in dentistry due to growing technological developments in this area. These applications are favored due to advantages like facilitating the production and utilization of new materials, taking less workforce, being cost-efficient, and possessing control over quality. The idea of utilizing CAD/CAM approaches to finish indirect restorations fabricated from a material with better biological and mechanical characteristics in one sitting and providing them to the patient was the origin of indirect restoration applications.In CAD/CAM applications, three various manufacturing approaches exist: subtractive, additive, and hybrid.3-5 Because it can produce more intricate, advanced structures with less wasted material, additive manufacturing is now being used as an alternative to subtractive approaches in dentistry. The purpose of this article was to provide information regarding three-dimensional (3D) printing technologies applied in dentistry and to analyze the areas of application of these technologies in restorative dentistry.

Over the past decade, additive manufacturing (AM), popularly known as 3D printing, has transformed many industries, and dentistry is not an exception. Reparative dentistry, which deals with the restoration of the form and function of decayed or damaged teeth, has been immensely advanced by the use of this technology. Additive manufacturing allows for accurate, personalized, and cost-effective fabrication of dental restorations like crowns, bridges, dentures, and implants, enhancing clinical outcomes as well as patient satisfaction. By enabling digital design and on-demand manufacturing, AM technologies save time, material, and human labor in comparison to conventional approaches.

Additionally, they provide improved ability to create complex geometries and biocompatible materials custom-made for individual patients. Consequently, 3D printing not only improves the accuracy and functionality of dental restorations but also revolutionizes treatment workflows in dental clinics and dental labs. This article discusses the application of additive manufacturing in reparative dentistry, with current utilizations, technological innovation, material use, and clinical implementation difficulties being analyzed. The article also assesses the potential future of AM in transforming dental treatment via greater precision, customization, and cost savings.

2. CAD/CAM TECHNOLOGIES IN REPARATIVE DENTISTRY:

Reparative dentistry aims at repairing and conserving lost, decayed, or broken teeth to regain function, esthetics, and oral health. It encompasses fillings, crowns, bridges, veneers, inlays/inlays, and implants. Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technologies are now a norm in contemporary reparative dentistry, improving the precision, efficiency, and individualization of dental restorations.

All CAD/CAM systems, old and new, basically offer services based on three functional components.8 The first component scans the region which has been prepared by the dentist intraorally or extra orally and collects information regarding the involved area. The restoration may be planned and created in three dimensions on a computer due to the second component, CAD. The last component, CAM, allows the production of the restoration that has been virtually mounted.

CAD/CAM systems are divided into "Open" and "Closed" systems depending on how they can share digital data.10 All CAD/CAM activities, such as data acquisition, virtual design, and restoration manufacturing, are incorporated into closed systems; however, data exchange with these systems and other hardware and software is not allowed. Closed systems possess this limitation, but open systems allow the initial digital data created on a specific device to be read and processed by most CAD programs and CAM devices.

2.1. What is CAD/CAM in Dentistry?

CAD (Computer-Aided Design):

CAD in dentistry is utilized to create digital representations of dental restorations through 3D scans of the mouth. The designs can be engineered with high precision to replicate the tooth or jaw anatomy.

2.2CAM (Computer-Aided Manufacturing):

CAM employs the virtual design done in CAD to instruct machines (such as mills or 3D printers) to make the final restoration. This is possible chairside (in the dental clinic) or in a dental laboratory.

3.SUBTRACTIVE MANUFACTURING TECHNOLOGIES:

Subtractive manufacturing is a computer-based fabrication method which has transformed reparative dentistry through the ability to produce precise dental restorations. Subtractive manufacturing differs from the traditional methods based on manual impressions and laboratory production since it employs sophisticated CAD/CAM systems in creating restorations from blocks of material using a controlled mechanism of material reduction.

The workflow of subtractive manufacturing starts with the recording of digital impressions. Intraoral scanners take a 3D picture of the dentition of the patient without the use of traditional impression material. The digital model is processed by a CAD software, where the restoration is designed by the clinician or dental technician. Margin lines, occlusal anatomy, and proximal contacts are defined accurately in the digital world. Once the design is finished, the file is uploaded into CAM software, which produces tool paths for the milling machine. The milling machine is the hub of dentistry's subtractive manufacturing.

The machines employ rotating cutting instruments in the form of diamond or carbide burs to progressively reduce prefabricated zirconia, lithium disilicate (e.g., IPS e.max), composite resin, or polymethyl methacrylate (PMMA) blocks. Whether dry or wet, the process, depending on the material, can be done. The restorations that are produced are extremely accurate and usually have little need for adjustment prior to seating. Subtractive manufacturing is extensively employed in crown, bridge, veneer, inlay/onlay, and abutment implant fabrication and even full-arch prostheses. Among its most important advantages is the convenience and speed it provides. Chairside systems permit same-day restorations, minimizing patient visits and enhancing the efficiency of treatment. In laboratories, the technology enhances productivity and delivers repeatable and consistent results.

The benefits of subtractive manufacturing are high accuracy, good material properties, and greater patient comfort through digital impressions. The restoration produced is generally stronger and more durable than restorations produced using conventional techniques, particularly where materials such as zirconia or lithium disilicate are used. Digital storage of the patient's information also facilitates simple remakes and future access. Subtractive manufacturing does have some drawbacks, though. It can be wasteful, with much of the block being milled away and wasted. The process also has trouble creating very thin or intricate geometries, particularly in parts that are inaccessible to the milling tool. In addition, purchasing and owning CAD/CAM equipment can be expensive, and the tools employed in milling need to be replaced as they degrade over time.

In spite of these limitations, subtractive manufacturing continues to be a keystone of digital dentistry. Subtractive manufacturing has revolutionized the quality, speed, and predictability of dental restorations. More advanced hybrid systems that combine additive manufacturing (3D printing) are now being developed, which provide increased design freedom and minimize material waste. Additionally, the incorporation of artificial intelligence and machine learning into design software will continue to advance treatment outcomes. Overall, the technologies of subtractive manufacturing have revolutionized reparative dentistry. They provide accurate, long-lasting, and cosmetically acceptable restorations, and they improve both clinician workflow and patient experience. Future technological advancements will continue to add to its potential and popularity in the coming years.

FIG: SUBTRACTIVE MANUFACTURING TECHNOLOGIES

The basic idea behind subtractive manufacturing is that the end result is milled from pre-fabricated blocks or disks made of some materials. The process has some disadvantages despite the fact that it is able to complete the final restoration. 90% is utilized in the block and 10% is lost with no opportunity for recycling. Apart from that, the milling parts utilized in this system undergo severe abrasion, the production system is not adequate for producing complex shapes, and shrinkage and cracks can also be observed in the material. Based on the prevailing drawbacks of this process and the fast advances in additive manufacturing, application of additive manufacturing methods in dentistry has come to the forefront and research on this topic gained significance today.

4. ADDITIVE MANUFACTURING TECHNOLOGIES:

Those systems that allow the creation of a 3D-designed object by stacking layers over layers with the help of a computer are referred to as additive manufacturing systems. Moreover, additive manufacturing is defined by the American Society for Testing and Materials as "the process of building up materials by layering (adding layer on top of layer) to create objects from computer data of a 3D model, as opposed to subtractive manufacturing processes.Besides being referred to as 3D printing, additive fabrication, rapid prototyping, rapid manufacturing, freeform manufacturing, layered manufacturing, and solid freeform fabrication, additive manufacturing technology is now a standard procedure in dentistry today.

Compared to subtractive manufacturing, which forms solid materials through milling, additive manufacturing entails layering powder or liquid-based ingredients to form solid objects. Although other methods employ inkjet printing nozzles to spray the binder or solvent on the powdered ceramic or polymer, others employ thermal energy from optically guided laser or electron beams to melt or sinter metal or plastic powders onto one another.Two distinct forms of materials, build materials and support materials, are usually deposited in an additive manufacturing machine. Support material is not part of the final product, but it must be used to assist the build material put in voids and overhangs. Even with the multitude of disparate additive manufacturing processes that construct and assemble layers in many ways, each approach actually consists of three steps are:

1. Development of a 3D design within a computing environment and translating it into a conventional additive manufacturing programming language or prevailing additive manufacturing file format.
2. Downloading the produced design file to a machine incorporating additive manufacturing technology for making adjustments like positioning, adjustment and sizing of the object to be manufactured.
3. Layer-by-layer creation of the designed object.

4.1.VAT POLYMERIZATION TECHNIQUES:Vat photopolymerization is an additive manufacturing technique which employs light-induced polymerization to selectively polymerize a liquid photopolymer in a vat. Vat polymerization is a process that is applied in additive manufacturing technologies like stereolithography (SLA), digital light processing (DLP), continuous liquid interface production, and multiphoton polymerization (MPP).

4.2. STEREOLITHOGRAPHY: SLA is dependent upon the process of photopolymerization, wherein monomers create polymeric structures using photons provided by a ultraviolet (UV) light source. It involves the process of creating geometric cross-sections brought into software on a light-cured resin surface by a laser light source operating under mirrors.22

4.3.DIGITAL LIGHT PROCESSING: DLP relies on layer-by-layer manufacturing through the selective curing of a resin curable in light by a light source, as in the case of SLA. DLP is also referred to as dynamic mask photolithography because it heavily draws from SLA. Unlike SLA, the light source polymerizes the resin at the same time in every layer of the object being manufactured. Also, this technology employs a different direction of production compared to SLA.21

4.4.CONTINUOUS LIQUID INTERFACE PRODUCTION: The principle is almost identical to standard DLP. The only difference is the utilization of an oxygen-permeable film for surface inhibition of polymerization near the UV source and thus doing away with an intermediate coating process per layer.

4.5.MULTIPHOTON POLYMERIZATION: The term "multiphoton" acknowledges the fact that absorption of three or more photons at the same time is possible (even with extremely small probability) and photopolymerization will be realized. With the advent of high-power and high-technology lasers, this method has become possible. Yet, the time for production and the object size that can be produced remain short of expectations (production object size is only 30x30 μm). Unlike conventional SLA, MPP is the process of creating the whole desired object simultaneously by MPP without employing the layer-on-layer approach. Therefore, intricate structures that cannot be manufactured in SLA can be manufactured.

5.MATERIAL EXTRUSION METHODS IN REPARATIVE DENTISTRY:

Material extrusion is an additive manufacturing method (more popularly known as 3D printing) that is beginning to be important in reparative dentistry. In contrast to subtractive manufacturing, which carves away material from a solid block of material, material extrusion constructs dental parts layer by layer by extruding material out through a nozzle and depositing it based on digital design. The most prevalent technique in this category is Fused Deposition Modeling (FDM), though other methods such as Direct Ink Writing (DIW) and syringe extrusion find application in specific dental applications.

Material extrusion finds application in the fabrication of custom dental models, provisional restorations, surgical guides, trays, and splints in reparative dentistry. The procedure starts with a digital impression of the dentition of the patient, which is usually recorded through an intraoral scanner. The 3D data is subsequently utilized in CAD software to model the needed dental component. The model is sliced into layers, and the 3D printer traces along these layers, extruding material—most commonly a thermoplastic or resin composite to construct the object bottom-up. The most common materials printed with dental extrusion are polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyether ether ketone (PEEK), and dental-grade biopolymers. The materials are chosen based on their biocompatibility, durability, and compatibility. Some research and experimental environments are testing ceramic-loaded pastes and bio-inks for more sophisticated purposes, including tissue scaffolding or implantation-specific use. The main benefits of material extrusion in dentistry are cost savings, quick prototyping, and the capacity to generate complex shapes that are hard to machine with subtractive techniques. The technology is especially ideal for temporary or experimental restorations; wherein high strength is not the foremost concern. Dentists and laboratories can rapidly generate and evaluate a provisional restoration prior to investing in a permanent material, saving turnaround time and improving patient satisfaction.

Although increasingly relevant, material extrusion in the field of reparative dentistry also comes with limitations. The layer-by-layer building process can lead to a more textured surface finish, potentially needing post-processing like polishing or coating. The dimensional precision tends to be less than that attainable by subtractive manufacturing or other high-resolution 3D printing technologies like stereolithography (SLA) or digital light processing (DLP). Furthermore, the options for materials to be used in intraoral permanent restorations are also still sparse, though this is improving with investigation and regulatory permits. However, the incorporation of extrusion-based 3D printing into dental practice promotes a more adaptable, digital treatment planning and restorative methodology. With ongoing advancements in extrusion technology and printable biomaterials, there is immense potential for the technique to play an even greater role in tailor-made dental prosthetics, implants, and even regenerative therapies in the future.

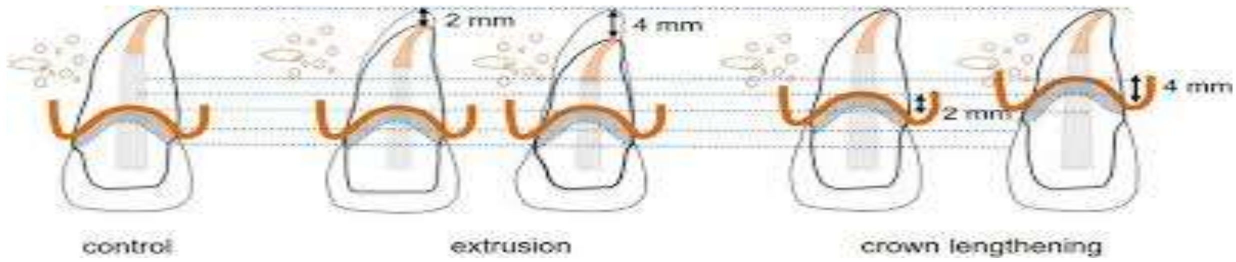

Fig.2: MATERIAL EXTRUSION METHODS IN REPARATIVE DENTISTRY

6.POWDER BED FUSION IN REPARATIVE DENTISTRY:

Powder Bed Fusion (PBF) is a sophisticated additive manufacturing (AM) process that has a revolutionary impact on reparative dentistry, especially for the fabrication of metal-based dental restorations. PBF produces intricate dental parts by melting or sintering thin layers of powdered material with a high-energy heat source like a laser or electron beam. The process works by layering and selectively melting or sintering powder based on a 3D computer-aided design (CAD) model.

Two of the most popular PBF technologies employed in dentistry are:

Selective Laser Melting (SLM) – fully melts the powder particles into a solid object.

Selective Laser Sintering (SLS) – fuses particles without melting them completely.

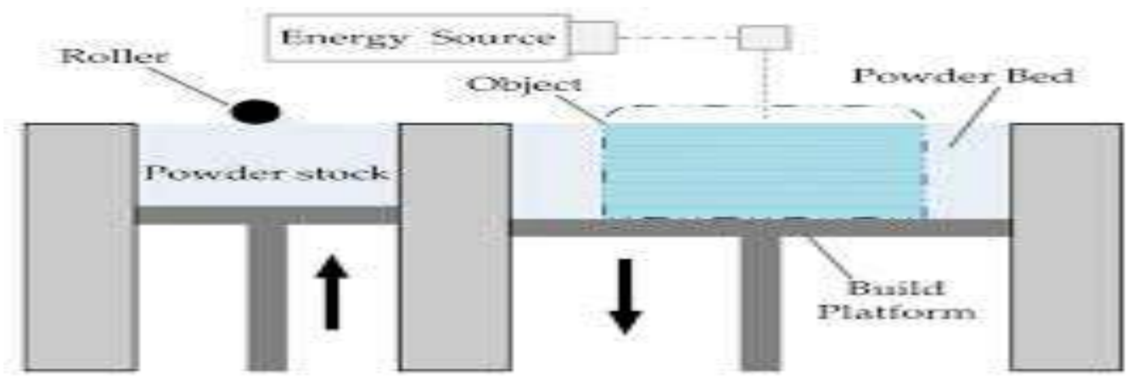

FIG3.POWDER BED FUSION IN REPARATIVE DENTISTRY

6.1.HOW THE PROCESS WORKS:

1. Digital Design: The procedure starts with a digital impression of the patient's mouth with intraoral scanners. This information is then used to produce a 3D CAD model of the necessary dental part, i.e., a crown or frame.
2. Slicing and Setup: The digital model is sliced into thin sections, and the sections are transferred into the control system of the PBF machine.
3. Powder Application: A thin metal powder (often cobalt-chromium, titanium, or stainless steel) is uniformly spread across the build platform.
4. Laser Sintering/Melting: A powerful laser selectively melts the powder according to the sliced design. The platform descends after processing each layer, and a fresh layer of powder is applied.
5. Post-Processing: After completion, the part is taken out of the powder bed, and any powder that has not fused is reused. The part can go through additional processes such as heat treatment, support removal, polishing, and veneering.

7.CUNCLUSION:

Additive manufacturing (AM), also referred to as 3D printing, is a revolutionary technology in reparative dentistry, as it facilitates the creation of highly individualized, precise, and effective dental restorations. In contrast to conventional techniques that depend on subtractive or manual methods, AM constructs dental parts layer by layer from computer-aided designs, promoting unparalleled individualization and connectivity within digital workflows. The most prevalent AM processes in dentistry are Material Extrusion (e.g., FDM), Vat Photopolymerization (e.g., SLA, DLP), and Powder Bed Fusion (e.g., SLM, SLS) Each has its own applications ranging from the production of temporary crowns and surgical guides to the creation of hard metal frameworks and implant parts. They contribute to better treatment planning, lower production times, and better clinical outcomes through the provision of high-precision, patient-specific restorations.

One of the most significant benefits of additive manufacturing is its capacity to generate complex shapes and reduce material waste, with ease of incorporation into CAD/CAM systems and digital impressions. This facilitates quicker turnaround times, fewer patient visits, and more reproducible results. Furthermore, the opportunity to utilize biocompatible and next-generation materials is growing, widening its scope to include permanent restorations and even tissue engineering. Nonetheless, constraints like high initial expenses, material limitations, surface finish quality, and post-processing needs remain an issue. Yet, ongoing development in printer technology, material science, and artificial intelligence is quickly resolving these issues. In summary, additive manufacturing technologies are revolutionizing the field of reparative dentistry. They present drastic advancements in accuracy, productivity, and individualization, resulting in improved patient care. As the technology advances and gains popularity, it is poised to become a core element of contemporary dental practice and innovation.

8.REFERENCE:

1.Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent Mater J. 2009; 28(1): 44-56.

2.Şahin E, Aktaş GÜ, Özcan N, Hasanoğlu Aydın D, Akça KI. Restoratif diş hekimliğinde CAD/CAM klinik uygulamalar: Sirona CEREC sistemi. Clinical Dentistry and Research. 2009; 33(4): 34-40.

3.Şeker E, Ersoy AE. Restoratif CAD/CAM distemper diş hekimliğinde. ADO Klinik Bilimler Dergisi. 2010; 4(1): 493-504.

4.Koch GK, Gallucci GO, Lee SJ. Accuracy in the digital workflow: from data acquisition to the digitally milled cast. J Prosthet Dent. 2016; 115(6): 749-54.

5.Liu Y, Di P, Zhao Y, Hao Q, Tian J, Cui H. Accuracy of multi-implant impressions with 3D-printing custom trays and splinting compared to conventional methods for complete arches. Int J Oral Maxillofac Implants. 2019; 34(4): 1007-14.

6.Merklein M, Junker D, Schaub A, Neubauer F. Hybrid additive manufacturing technologies—an analysis regarding potentials and applications. Phys Procedia. 2016; 83: 549-59.

7.Rekow ED. Digital dentistry: The new state of the art - Is it disruptive or destructive? Dent Mater. 2020; 36(1).

8.Lebon N, Tapie L, Duret F, Attal JP. Understanding dental CAD/CAM for restorations - dental milling machines from a mechanical engineering viewpoint. Part A: chairside milling machines. Int J Comput Dent. 2016; 19(1): 45-62.

9.Ting-Shu S, Jian S. Intraoral digital ımpression technique: a review. J Prosthodont. 2015; 24(4): 313-21.

10.Correia AR, Sampaio Fernandes JC, Cardoso JA, Leal-Da-Silva C. CAD-CAM: informatics applied to fixed prosthodontics. Rev Odontol UNESP. 2006; 35(2): 183-9.

11.Liu Q, Leu MC, Schmitt SM. Rapid prototyping in dentistry: technology and application. Int J Adv Manuf Technol. 2006; 29: 317-35.

12.van Noort R. The future of dental devices is digital. Dent Mater. 2012; 28(1): 3-12.

13.Alghazzawi TF. Advances in CAD/CAM technology: possibilities for clinical application. J Prosthodont Res. 2016; 60(2):

72-84.

14.Braian M, Jönsson D, Kevci M, Wennerberg A. Geometrical accuracy of metallic objects manufactured using additive or subtractive manufacturing: A comparative in vitro study. Dent Mater. 2018; 34(7): 978-93.

15.Kim HR, Jang SH, Kim YK, Son JS, Min BK, Kim KH, et al. Microstructures and mechanical properties of Co-Cr dental alloys fabricated by three CAD/CAM-based processing techniques. Materials (Basel). 2016; 9(7): 596.

16.Kocaağaoğlu H, Kılınç Hİ, Albayrak H, Kara M. In vitro evaluation of marginal, axial, and occlusal discrepancies in metal ceramic restorations produced with new technologies. J Prosthet Dent. 2016; 116(3): 368-74.

17.González-Henríquez CM, Sarabia-Vallejos MA, Rodriguez-Hernandez J. Polymers for additive manufacturing and 4D-printing: Materials, methodologies, and biomedical applications. Progress in Polymer Science. 2019; 94: 57-116.

18.Mani M, Lyons KW, Gupta SK. Sustainability characterization for additive manufacturing. J Res Natl Inst Stand Technol. 2014; 119: 419-28.

19.Revilla-León M, Özcan M. Additive manufacturing technologies used for 3D metal printing in dentistry. Current Oral Health Reports. 2017; 4(3): 1-8.

20.Anadioti E, Kane B, Soulas E. Current and emerging applications of 3D printing in restorative dentistry. Current Oral Health Reports. 2018; 5(10): 133-9.