ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at:www.ijdsir.com

Volume – 9, Issue – 3, May – 2026, Page No. : 09 – 17

Precision in Practice: CAD/CAM and 3D Printing in the New Era of Dentistry- A Literature Review

[1]Dr Sheetal Shivaji Patil, BDS, Goregaon Dental Centre, India

[2]Dr Anoli Agrawal, MDS, Public Health Dentistry, ACPM Dental College, Dhule and Goregaon Dental Centre, India

[3]Dr Asma Shaik, BDS, RDA(USA)

Corresponding Author: Dr Sheetal Shivaji Patil, BDS, Goregaon Dental Centre, India

Citation of this Article: Dr Sheetal Shivaji Patil, Dr Anoli Agrawal, Dr Asma Shaik, "Precision in Practice: CAD/CAM and 3D Printing in the New Era of Dentistry- A Literature Review", IJDSIR- May – 2026, Volume – 9, Issue – 3, P. No. 09 – 17.

Type of Publication: Review Article

Conflicts of Interest: Nil

Abstract

Purpose: This literature review explores the impact of CAD/CAM and 3D printing technologies on modern dentistry. It highlights how these digital tools are reshaping treatment planning, improving clinical outcomes, and enhancing patient comfort across various specialties.

Methodology: A systematic search was conducted using PubMed, Scopus, and Google Scholar. Studies published in the last 10 years were reviewed, including clinical trials, case reports, in vitro studies, and systematic reviews. Keywords used included "3D printing" and "CAD/CAM technology in dentistry.

Conclusion: The integration of CAD/CAM and 3D printing in dentistry represents a transformative shift in clinical practice. While current evidence supports their benefits, further research and training are essential for broader implementation. This review provides valuable insights to support evidence-based decision-making in digital dental workflows.

Keywords: CAD/CAM, 3D printing, digital dentistry, prosthodontics, pediatric dentistry, implantology, endodontics, orthognathic surgery

Introduction

In the last few years, 3D technology and CAD/CAM systems have changed the way dentistry is practiced. What used to rely heavily on manual skills has now shifted toward digital tools that allow for greater precision and efficiency. This change didn't happen overnight—it grew out of the need for faster results, better accuracy, and improved patient care.[1]

The use of 3D technology in dentistry actually began earlier than many people realize. While these systems were first developed for use in industries like manufacturing and engineering, a few forward-thinking dentists helped bring them into clinical practice.[1,2] One of the earliest pioneers was Dr. François Duret. Back in

1971, he started working on a method that used optical impressions to scan teeth, design crowns that fit functional jaw movements, and then create them using a milling machine.

Then came Dr. Werner Mörmann, who created the CEREC system. He was one of the first to bring this technology directly into the dental clinic. His idea was simple but revolutionary: scan the tooth with a small camera, design the restoration on a screen, and then carve it from a ceramic block all while the patient was still in the chair.[2] Another key figure was Dr. Matts Andersson, the developer of the Procera system. In the early 1980s, dentists were switching to nickel-chromium alloys because gold had become too expensive. But these materials caused allergic reactions in some patients, especially in Northern Europe. To solve this, Dr. Andersson began working with titanium, which is biocompatible but hard to cast using traditional methods. He found a way to machine titanium precisely using spark erosion and added CAD/CAM into the process to make reliable frameworks for ceramic restorations. These early innovations laid the foundation for the digital tools we use today. What started as industrial equipment has now become an essential part of dentistry, improving everything from accuracy and workflow to patient comfort and clinical outcomes.[2]

So, 3D Technology is an additive manufacturing method that constructs objects by depositing material layer-by-layer. However this is just a robotic device to fabricate objects, which needs a software that designs the intended object and that is CAD/CAM.CAD stands for Computer-Aided Design, which is the process of creating detailed drawings or models on a computer. CAM means Computer-Aided Manufacturing, which uses computer software to control machines during the manufacturing process. In dentistry, this involves designing the shape of a restoration, selecting the right tools, and guiding the milling machine to produce the final piece with precision.[3]

Today CAD/CAM in dentistry are majorly used for digitally designing and manufacturing dental restorations such as crowns, bridges, veneers, inlays, dentures, and implant-supported prostheses that is typically done using two types of software:

1. exocad: An open-system CAD software that has a user-friendly interface with a relatively short learning curve, favored by small labs, freelancers, and outsourcing services for fast design and STL file editing. It offers modules for implant, dentures, provisional restorations, and smile design, among others.[4]
2. 3Shape: A comprehensive CAD/CAM dental platform with advanced AI-powered design automation and seamless integration with digital workflows. It is well-suited for larger dental clinics and labs with complex workflows, providing excellent tools for implant design, digital smile design, and orthodontic applications. It has a more detailed interface, generally requiring more training. It integrates best with its own scanners (e.g., Trios) and high-end lab machines.[4]

While software like Exocad and 3Shape forms the backbone of digital design, translating these virtual models into physical restorations depends on the manufacturing hardware. This next stage involves either milling machines or 3D printers, each offering distinct advantages depending on the clinical need and material choice. So transitioning to hardware, dental restorations are fabricated using either subtractive or additive manufacturing devices. Milling machines, operating by carving restorations from solid blocks of materials like ceramics or zirconia with diamond rotary tools, represent the traditional subtractive approach. In contrast, 3D printers build dental parts layer-by-layer from printable materials such as resins, making use of several advanced additive technologies. Among these, SLA (Stereolithography) employs a laser to cure liquid resin with exceptional accuracy, DLP (Digital Light Processing) cures full layers rapidly using a digital projector, and SLS (Selective Laser Sintering) sinters powdered materials such as nylon or metals, albeit less commonly in general dental restorations and more for frameworks or metal components.[3][4]As these designs are turned into real dental restorations using milling or 3D printing, it's clear that dentistry is moving quickly from manual techniques to digital processes. With so many changes happening, it's important to step back and understand how this technology is actually being used.

This article is to highlight the growing adaptation of digital technology that has redefined the traditional methods of treatment planning in various dental fields that has turned around time. The article aims to evaluate the current applications, benefits, challenges and future trends using systemic evaluation of current evidence. This review is necessary to bridge the existing knowledge gap and provide clarity to guide clinical decision making and future research.

Methodology: To conduct the literature, Studies were selected from PubMed, Scopus and Google Scholar database. The search was restricted to publication from the past 10 years, to provide a comprehensive overview of current knowledge on 3D printing and CAD/CAM technology. The review focused on evaluating the benefits of this technology and its limitations. The search terms included: “3D printing”, “CAD/CAM Technology in dentistry”. The research encompasses Case report, Clinical studies, Laboratory studies and systemic studies.

Discussion

Pediatric dentistry: A distinct dental branch that encompasses various subfields- Preventive, Endodontics, Prosthodontics, Orthodontics while simultaneously addressing needs of particular age groups, and those who need special care. Owing to these Pediatric dentists face multifaceted challenges like uncooperative patients, delivering lengthy procedures, multiple dental visits, and strong gag reflex.[5] Application of 3D technology and CAD/CAM provides significant solutions in

Digital impressions, Intraoral scanning replaces traditionally used impression trays, significantly enhancing the comfort with those with gag reflexes. Further it eliminates the physical storage need of impressions.[3,5] A recent clinical report by Trivedi et al. (2024) assessed the clinical utility and fabrication accuracy of a 3D-printed lingual arch space maintainer in pediatric dentistry. The authors reported a precise fit of the 3D-printed appliance, attributed to digital intraoral scans and computer-guided customization, which eliminated the need for traditional alginate impressions and laboratory fabrication. The fabrication process was faster and required fewer appointments, significantly reducing chairside time and improving overall patient compliance. Clinical placement was well-tolerated, and follow-up observations indicated minimal adjustment needs, high patient comfort, and no breakage or detachment over the evaluation period. Although the report does not provide exact numeric data such as p-values or deviation in mm, it emphasizes the qualitative benefits of 3D printing in pediatric appliance fabrication: time efficiency, comfort, structural precision, and biocompatibility.[6] Also traditionally manufactured space Maintainers were prone to failure majorly due to solder breakage and patient compliance, 3D printed space maintainers offer better adaptability, a precise fit and minimal risk of breakage due to their solder-free design.3D printing in pediatric dentistry has proven to be a "direct flight" — cutting down on time, complications, and discomfort.[5,6,7]

Prosthodontics: 3D technology and CAD/CAM has notably shown advantages in complete denture, partial dentures and crown fabrication. The conventional denture Base material contains residual monomer (polymethylmethacrylate) which migrate from the denture material into surrounding soft tissues or saliva can result in various adverse effects, including allergic responses, stomatitis, oral ulcerations, and sensations of burning discomfort.[8]

A study by Srinivasan et al. (2022) evaluated the concentration of residual methylmethacrylate (MMC) monomer in complete dentures fabricated by CAD/CAM techniques—comparing milled and 3D-printed groups using High-Performance Liquid Chromatography (HPLC). A total of 32 specimens were divided into four groups (n = 8 per group), with the 3D-printed group further subdivided based on different rinsing cycles: EWC (Ethanol Wash Cycle), SWC (Single Wash Cycle), and SWC2 (Double Wash Cycle).

The milled denture group exhibited the highest residual MMC concentration at 24 hours, while the 3D-printed subgroups showed significantly lower levels:

EWC: 1.38 ± 0.65 mg

SWC: 0.154 ± 0.07 mg

SWC2: 0.662 ± 0.23 mg

SWC2 (extended rinse): 0.100 ± 0.023 mg

These results indicate that 3D-printed dentures, particularly with extended rinsing protocols, release significantly less residual monomer than milled dentures, suggesting improved biocompatibility and reduced potential for adverse tissue reactions ($p < 0.05$).Residual MMCs are known to exert cytotoxic effects on oral mucosa, potentially leading to tissue irritation, allergic reactions, and sensitivity. Therefore, the markedly lower levels of residual monomer observed in the 3D-printed and thoroughly rinsed dentures underscore their clinical relevance in enhancing biocompatibility and reducing mucosal complications.[6]

While 3D-printed dentures offer clinical utility, challenges remain, particularly regarding the bond strength between the printed denture base and the artificial teeth. This bond requires further validation in terms of mechanical integrity and resistance to deformation. Similarly, although custom trays produced via 3D printing offer practical advantages, they still demand significant time and effort during the design phase. A study by Vladimir Prpic, DMD, et al. (2020) demonstrated that the mechanical properties of denture bases fabricated using CAD/CAM technology exhibited superior flexural strength and surface hardness, highlighting their potential to enhance appliance precision and improve patient comfort.[9,10]

Unlike milling systems, which are constrained by design complexity, 3D printers can create intricate geometries such as hollow structures that were once impossible to achieve. This advancement not only allows for the production of lighter prostheses but also significantly enhances design flexibility. Additionally, 3D printing is more material-efficient, as it constructs structures layer by layer, minimizing waste compared to subtractive milling processes, which carve shapes from solid blocks.[11]

Implants: The design and fabrication of implant surgical guides including support types, fixation screws and sleeves, significantly improved surgical accuracy. A recent systematic review by Shi et al. (2023) assessed the accuracy of digital surgical guides for dental implantation, analyzing 41 studies (in vivo and in vitro) published between 2018 and 2022. The review evaluated the impact of support type, manufacturing method, and guide design (including fixation screws and sleeves) on surgical precision.[9]

The table below illustrates the summary of accuracy outcomes for digital surgical guides in implantology.

Table 1: Summary of Accuracy Outcomes for Digital Surgical Guides in Implantology (Shi et al., 2023)

Support Type	Manufacturing Method	Mean linear Deviation	Mean Angular Deviation	Key findings
Bilateral tooth-supported	Milled	<1mm	<5º	Highest in vitro accuracy; reliable in vivo accuracy as well
Unilateral tooth-supported	Milled and 3D-printed	~1mm	~5º	Slightly less accurate than bilateral, but still clinically acceptable
Mucosa supported	3D printed	>1.5mm	>6º	Lowest in vivo accuracy due to soft tissue instability
Tooth-supported (General)	Milled	<1mm	<5º	Milling offered slightly better accuracy than 3D printing in in vivo settings
Tooth-supported (General)	3D-printed	~1.2mm	~6º	Acceptable accuracy; more variability than milled guides
Various types	mixed	<2mm	<8º	Overall, digital guides are highly accurate across multiple

Among various designs, bilaterally tooth-supported and milled guides demonstrate the highest precision. In contrast, mucosa-supported and 3D-printed guides tend to show reduced accuracy. Despite some variability among operators, most digitally guided implant surgeries consistently achieve positional deviations of less than 2 mm and angular deviations below 8°, highlighting the overall reliability of these techniques[12] Implant-supported crowns crafted from 3D-printed definitive resin exhibit superior marginal adaptation and comparable fracture resistance when compared to those fabricated using millable materials.[13]

Endodontics: The rising prevalence of tooth obliteration can be attributed to several factors, including an aging population, the expanded use of regenerative endodontic procedures, frequent placement and removal of fiber posts, and the management of teeth with complex or atypical morphological variations. In endodontics, guided systems are increasingly utilized to navigate root canals in challenging cases. These systems aim to reduce treatment time, minimize procedural risks, and limit unnecessary removal of healthy tooth structure—key elements that contribute to the long-term success of the treatment.[14]A study by Zehnder et al. (2016) investigated the accuracy of 3D-printed guided endodontic templates in accessing root canals in vitro on single-rooted human teeth. The experiment used 60 teeth mounted on six maxillary jaw models (10 teeth per model), and templates were designed using coDiagnostiX™ implant planning software and fabricated with a 3D printer.

After access cavity preparation using the template, post-operative CBCT scans were analyzed to measure deviations between planned and achieved access paths. The results showed high precision, with mean linear deviations at the base of the bur ranging from 0.16 to 0.21 mm, and at the tip of the bur from 0.17 to 0.47 mm. The mean angular deviation was 1.81°, indicating excellent control over the bur trajectory. Notably, there was no significant difference in accuracy between operators, as shown by overlapping 95% confidence intervals.

These findings confirm that 3D-guided access templates can significantly enhance the precision of access cavity preparation, especially in challenging or obliterated canals, minimizing unnecessary removal of dentin and improving treatment outcomes.[15]

Orthognathic Surgery: Orthognathic surgery planning with digital 3D models involves handling large sets of imaging data, which need to be shared among clinicians and supporting team members. To ensure smooth collaboration during the planning and simulation stages, it's important that all parties have easy and consistent access to the same data.[16] Using cloud-based platforms, surgeons and technicians can share massive imaging data and collaborate in real-time to optimize surgical splints and guides before 3D printing them for use intraoperatively.[17] The additive technologies (SLA, DLP) and milling machines produce highly customized, patient-specific cutting guides, occlusal splints, and fixation plates, aiding precise bone repositioning and reducing intraoperative guesswork. This approach leads to high surgical accuracy, demonstrated by low discrepancies between planned and postoperative outcomes in bone and dental landmarks.[18]

A literature review by Lin et al. explored the clinical applications of 3D printing in orthognathic surgery (OGS), with a focus on its impact on surgical accuracy, planning efficiency, and outcome predictability. The review covered multiple clinical studies evaluating the precision of CAD/CAM-generated occlusal splints, osteotomy guides, and repositioning templates. Several studies cited in the review reported positional deviations of less than 1 mm between the virtual surgical plan and the postoperative result, particularly when 3D-printed splints and cutting guides were used.[19] Angular deviations were also minimal, typically below 2°, indicating excellent alignment with preoperative plans. One clinical study reported an average maxillary repositioning error of 0.8 mm, which was significantly lower than that observed in conventional, manually fabricated splints ($p < 0.05$).

The use of CAD/CAM-fabricated occlusal splints not only improved precision but also addressed key limitations of traditional methods such as inter-laboratory variability, manual fabrication errors, and prolonged turnaround time. Moreover, custom-designed guides with integrated markers enhanced intraoperative navigation and reduced surgical time.[19]

The integration of 3D technology and CAD/CAM systems has revolutionized dental treatment planning and outcomes. The incorporation of these digital tools into daily clinical practice significantly enhances both the efficiency and accuracy of various procedures. The convergence of intraoral scanning, CAD/CAM, and 3D printing marks a paradigm shift in patient care enabling faster, more precise, and more comfortable treatments.

Beyond clinical advantages, these technologies notably improve the overall patient experience, particularly for uncooperative or anxious individuals. However, despite their promising benefits, the adoption of these technologies comes with certain challenges and limitations. High initial costs of equipment and materials, the necessity for specialized training, and the complexities associated with digital design and workflow integration present considerable barriers. For instance, in prosthodontics, issues such as the bond strength of 3D-printed materials and the time-intensive nature of designing custom trays still require optimization. Compared to traditional approaches, digital dentistry helps minimize human error while providing enhanced patient comfort and satisfaction.

Future research—especially in the form of well-designed quantitative studies—is essential to further validate these benefits and address current limitations. Additionally, continued innovation, particularly the integration of artificial intelligence (AI) with 3D technology, holds great potential to elevate dental care to an even higher standard

Conclusion

The future of dentistry is undeniably digital. As innovation accelerates, there is a moral and professional responsibility to evolve alongside it. Digitizing dentistry should not be seen as limited to CAD/CAM and 3D printing alone. Ongoing innovation, coupled with continued research, is necessary to evaluate the long-term clinical outcomes, cost-effectiveness, and to bridge the existing knowledge and implementation gap. By fostering a digital mindset and evidence-based integration of these tools, the dental community can provide more precise, efficient, and patient-centered care. While CAD/CAM and 3D printing have already contributed to improving treatment outcomes, raising awareness and fostering digital literacy among dental professionals is crucial to fully harness these advancements. Their widespread adoption remains uneven. This review provides important information to help in the decision making process for the clinician in selecting the right manufacturing process for fabricating prosthesis and also treatment planning.

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