Application of CAD CAM in dentistry

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KEYWORDS

CAD/CAM in dentistry, digital dentistry, restorative dentistry, 3D printing, digital workflow.

ABSTRACT

CAD/CAM (Computer-Aided Design and Computer-Aided Manufacturing) has transformed modern dentistry by enhancing accuracy, efficiency, and patient outcomes. This paper explores the principles, components, and workflow of CAD/CAM, from digital impressions to the final restoration fabrication. Available in both chairside and lab-integrated setups, CAD/CAM has advanced significantly over the last 20 years due to improvements in computer technology and dental materials. CAD enables precise design, while CAM turns these virtual objects into real restorations. The use of 3D technology allows for better treatment planning and improved outcomes, especially in restorative dentistry, prosthodontics, implantology, and orthodontics. Future advancements in AI, 3D bioprinting, and nanomaterials will further enhance CAD/CAM applications, offering more tailored, durable solutions. However, challenges such as high costs, technical limitations, and the need for specialized training remain. This paper provides an overview of CAD/CAM in dentistry, highlighting current trends and future directions.

INTRODUCTION

The introduction of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) in dentistry marked a significant breakthrough, transforming the way dental professionals create restorations and prosthetics. The early development of CAD/CAM technology in dentistry can be traced back to the 1980s, when Dr. Werner Mörmann, a Swiss dentist, and his collaborator, Dr. Marco Donath, began pioneering its use for dental applications, most notably in the production of 1 ceramic crowns .Initially, these systems allowed for the design and manufacture of precise dental restorations, such as crowns, bridges, and inlays, which were traditionally produced manually by dental technicians [2]In the early years, the main application of CAD/CAM was in the production of high-quality ceramic dental restorations, which enabled a more efficient workflow by 3 eliminating the need for traditional impression materials and lengthy manual laborAs technology improved, the range of CAD/CAM applications expanded, with the introduction of digital impressions and computer-guided milling machines, which drastically reduced both chair time and the risk of human error .[4]Over time, CAD/CAM technology spread into various areas of dentistry, such as implantology, orthodontics, and prosthodontics. In implantology, it has been employed to create custom abutments and surgical guides, improving precision in implant placement. [5]In orthodontics, CAD/CAM has enabled the design and production of clear aligners and brackets, providing more personalized treatment plans.[6]Additionally, CAD/CAM systems are increasingly used in prosthodontics for fabricating full-mouth restorations, dentures, and partial dentures with greater speed and accuracy. [7]Today, CAD/CAM is a cornerstone of modern dental practices, contributing to enhanced patient outcomes, shorter treatment times, and a higher level of precision in dental restorations.[8]

CAD/CAM Technology and Workflow

Computer-aided design (CAD) and computer-aided manufacturing (CAM) are the two main stages of all CAD/CAM systems, and they can be roughly summed up as follows:
1)Optical/contact scanning that records the patient's extraoral or intraoral state using software to create a digital model from the taken photos so that a dental prosthesis can be created and ready for production.
2)Instruction for tools that, depending on the CAD/CAM system being used, can help turn a design into a product through milling or 3D printing.[9]

Intraoral scanning

There are several intraoral scanners available in the market. These systems capture a three-dimensional virtual image of the prepared tooth or teeth, along with the surrounding structures, directly within the patient's mouth. Subsequently, these images are transferred to computer-aided design (CAD) software for the prosthesis design process[10]. A comparison between intraoral scanning, also known as digital impression, and traditional impression techniques is provided below. However, despite the benefits associated with digital impression methods, certain considerations must be taken into account when obtaining digital impressions. The dentist responsible for capturing intraoral images must ensure effective moisture control. Additionally, attention should be given to soft tissue retraction and hemostasis [11].

The relationship between restorations, soft tissue, gums, and the opposing teeth, that form suitable contacts, is considered in a basic manner during the design process. A CAD/CAM machine that mills completed ceramic blocks to create tooth restorations that are exact duplicates of the 3D design completed by the dentist using CAD/CAM software. The factory produced ceramic blocks used for milling come in a variety of hues to meet patient specifications and adhere to high aesthetic standards.

Contact and Non-Contact Digitizing

This technique involves creating a conventional impression, followed by the production of a model, from which data is transferred to CAD using either probe digitization (contact) or laser light (non-contact). In contact digitizing or scanning, a contact probe traces the anatomy of the model by adhering to the contours of the physical structure. Conversely, non-contact scanning employs laser light, optics, and charged-coupled devices, eliminating the need for physical contact with the model. This method is generally quicker in data collection compared to contact scanning, although it requires a high level of precision in detail recording[12]. Numerous studies and CAD-CAM technology have produced a formula for creating incredibly accurate restorations that are not only biocompatible but also have exceptional aesthetic qualities. It's a ceramic that isn't metal. These materials can be used to create dental veneers, crowns, bridges, and special fillings, depending on the tooth defect. These restorations are created in dental technology labs fitted with CAD-CAM (computer) technology, ensuring exceptional accuracy and beauty. The dentist can use a cursor to create an extremely accurate and suitable anatomical design of the missing tooth substance by creating a 3D image of teeth and gums on the screen. The 3D models that are produced offer the perfect foundation for restoration.

Fixed prosthetic restorations can now be made in the office in just two to three hours thanks to the use of contemporary machines of the MC XL type for grinding finished ceramic and zirconia blocks. This machine has several benefits. The milling precision is within the range of +/- 25 microns, and the grinding time for a circular bridge is no more than 6 minutes. Prosthetic restoration surfaces made in this manner undoubtedly adhere better than those made conventionally because of the 7.5 micron grinding resolution.

CT scan / MRI

Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) represent advanced techniques for data acquisition in CAD/CAM applications. Through these methods, individual images can be captured and subsequently transferred to CAD systems. While CT scans utilize radiation for data acquisition, MRI does not. MRI data is particularly suitable for soft tissue modeling, whereas CT data is preferred for hard tissue (bone) modeling [13].

CAD/CAM in Restorative Dentistry

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Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) technology has significantly transformed restorative dentistry, enhancing the precision, efficiency, and quality of dental restorations. This integration allows for the digital design and fabrication of various dental prostheses, including crowns, inlays, onlays, and veneers, streamlining workflows and improving patient outcomes.

Advancements in CAD/CAM Materials

The evolution of CAD/CAM materials has been pivotal in restorative dentistry. A recent study by Khan (2025)[14] evaluated and compared the mechanical properties and clinical outcomes of different CAD/CAM materials, utilizing advanced simulation and data analysis software, while considering real-world clinical data from diverse populations. The study emphasized that the choice of material directly influences the clinical success of restorations, with options ranging from traditional feldspathic ceramics to modern resin-based composites suitable for permanent restorations.

Further, a comprehensive review by Tomer et al. (2021) [15] detailed the classification and properties of chairside CAD/CAM materials. The authors noted that the continuous development of these materials has expanded their clinical applications, offering enhanced esthetics and durability. This evolution has enabled practitioners to select materials tailored to specific restorative needs, thereby optimizing treatment outcomes.

Clinical Workflow Integration

Integrating CAD/CAM technology into clinical practice has revolutionized the restorative workflow. Traditionally, the fabrication of dental prostheses involved multiple appointments and manual laboratory processes. With CAD/CAM systems, clinicians can now capture digital impressions, design restorations virtually, and fabricate them in-office, often within a single visit. This shift not only reduces treatment time but also enhances the accuracy of the fit and morphology of restorations.

Mechanical Properties and Longevity

The mechanical properties of CAD/CAM materials are critical for the longevity and functionality of restorations. A study by Prause et al. (2023)[16] utilized microcomputed tomography and scanning electron microscopy to investigate the microstructure of hybrid CAD/CAM materials. The findings revealed that millable hybrid materials exhibited a homogeneous distribution of ceramic particles, contributing to their strength and wear resistance. In contrast, 3D-printed materials showed some agglomerations and irregularities, indicating the need for further refinement in additive manufacturing processes.

Patient Outcomes and Satisfaction

The adoption of CAD/CAM technology has positively impacted patient satisfaction by reducing chair time and the number of visits required for restorative procedures. A systematic review by Alotaibi (2025)[17] compared CAD/CAM 3D-printed complete dentures with conventional ones in terms of patient satisfaction. The analysis demonstrated that CAD/CAM 3D-printed dentures are comparable to conventional dentures in overall patient satisfaction, although some concerns were noted regarding aesthetics and speech.

Additionally, a study by Saponaro et al. (2016)[18] evaluated patient experiences with digitally fabricated complete dentures using CAD/CAM technology. The results indicated high levels of patient satisfaction concerning comfort, mastication, and efficiency of the prosthesis fabrication technique.

Challenges and Future Directions

Despite its advantages, challenges persist in the widespread adoption of CAD/CAM technology. The initial investment in equipment and the learning curve associated with mastering digital workflows can pose significant barriers for some practitioners. Moreover, a study assessing the attitudes of Saudi dentists toward CAD/CAM technology revealed a high level of satisfaction and a favorable outlook; however, it also highlighted the necessity of specialized training and skill acquisition for the effective implementation of this technology in clinical practice [19].

CAD/CAM in Prosthodontics and Implantology

Computer-aided design and Computer-aided manufacturing (CAD/CAM) technology has transformed prosthodontics and implantology by increasing the efficacy and precision of dental restorations. In prosthodontics, it is used for various treatment procedures, including fabrication of crowns, inlays, onlays, fixed bridges, fixed and removable dentures, dental implants, and veneers with superior aesthetics and fit. CAD/CAM technology has advantages over conventional fabrication methods as it eliminates the need for traditional molds, casts, or analog components fabrication, making the process more hygienic and reducing the chair side time, thereby improving patient comfort.[20]

CAD/CAM technology in implant prosthodontics:

In implantology CAD/CAM technology streamlines the design and production of custom abutments and prosthetic components. It has enhanced implant planning and placement. It aids in guided implant surgery by integrating CBCT and intraoral scans for precise implant placement. CAD/CAM is used to customize implant abutments, thus providing patient-specific soft tissue adaptation and esthetics, milling and 3D printing enhance mechanical properties. Implant-supported prosthesis like hybrid dentures, overdentures and full arch restorations benefit from CAD/CAM precision. CAD designed bone scaffolds promote bone regeneration and implant integration and the bioresorbable (bioactive) coatings of implant improve osseointegration. The digital monitoring provided by CAD/CAM allows for tracking implant adaptation and bone healing.[21]

The treatment process for dental implants using digital methods begins with data collection. Data collection can be done via 3D object scanning or obtaining a digital volume, i.e. CBCT. According to Gallucci *et al.* 2019, Morton *et al.* 2019 the components of data collection give the complete treatment planning in which implant therapy is thought of as a singular entity and part of a total plan for the patient. Later to data collection, the fundamental focus is the CAD/CAM (computer aided design and computer aided manufacture) of prostheses and related processes.[21] The implant abutments are produced via milling using systems like Procera (Nobel Biocare), Encode (Biomet 3i), Etkon (Straumann) using restorative materials like Titanium, Alumina, and Zirconia.[22]

PROCEDURE:

The first step in the digital workflow for implant restoration is scanning using either laboratory-based or intraoral scanner . An intraoral scan provides a preoperative diagnosis and facilitates treatment planning of static computer-aided implant surgery. The 3D image is captured through computer-surfaced digitization techniques, followed by 3D image processing, where data is entered into the computer, here curve smoothening, data reduction and undercut blocking can be done and further designing of restoration can be carried out using CAD and fabrication of restoration using CAM via subtractive (milling) or additive (rapid prototyping or selective laser sintering) procedures.[23]

The implant abutments, milled from medical-grade titanium, exhibit superior biocompatibility and integration with implant fixtures. These abutments offer several advantages, including high precision, durability, proper coronal preparation, an optimal path of insertion, a resemblance to natural teeth, a 6° angled axis, and reduced chairside time.[23]

CAD/CAM in fabrication of surgical guides for implant placement:

Bibb *et al* described fabrication of stainless-steel surgical guides for the placement of dental implants for prosthetic retention using SLM technique. It was first given for the manufacture of custom fitting surgical guides.[23]

CAD/CAM technology in removable partial denture prostheses:

William *et al* have demonstrated a fabrication method for removable partial denture using CAD/CAM.[23] The fabrication of a complete denture included drawing on the working cast and then scanning using a laboratory scanner. It is prepared by printing a photo polymeric framework and then casting with chromium cobalt or Direct Metal Laser Sintering.[20] Cast partial dentures can be fabricated using CoCr Alloys or commercially pure Titanium and Ti-6Al-4V Alloy.[23]

CAD/CAM technology in fixed prosthodontics:

CEREC in the lab system – The tooth preparation die is fixed in the scanning platform and data is collected using the non-contact laser. Ceramic block is placed in the milling chamber and precise restoration is done using milling diamonds. Porcelain build-up is done, forming an aesthetically superior restoration, and then the fit is checked in the patient’s mouth, while doing required adjustments.[23]

CAD/CAM technology in maxillofacial prosthodontics:

It is used in fabrication of maxillofacial prostheses, extraoral radiation devices, individual radiation masks, etc. 3D surface imaging is done by using CAD software. This imaging aids in the fabrication of a resin model with the Lithographic technique, and then a wax pattern is made, and again 3D imaging is done, data is entered in the computer, the prosthesis is milled, and thus a silicone maxillofacial prosthesis is fabricated using CAD/CAM technology.[20]

CAD/CAM technology in fabrication of veneers:

CAD/CAM allows for detailed design and fabrication of dental veneers for anterior teeth, they are more natural and aesthetically pleasing.[23]

CAD/CAM in Orthodontics

Computer-Aided Design and Manufacturing (CAD/CAM) technology is increasingly utilized in orthodontics to create customized appliances, such as brackets, wires, and retainers. This technology enhances the precision and efficiency of orthodontic treatments. Recent studies have highlighted a range of orthodontic CAD/CAM applications, including diagnostic aids and treatment planning, clear aligner therapy, lingual appliances, titanium Herbst appliances, customized brackets with patient-specific torque, machine-milled indirect bonding jigs, and robotically bent archwires. One of the latest advancements in this field is the use of digital models.

In addition to the precise, customized milling of orthodontic appliances, 3D technology allows both practitioners and patients to utilize virtual treatment planning software. This software enhances the identification of treatment objectives and improves visualization of expected outcomes. Practitioners can evaluate various treatment options, such as extraction versus non-extraction approaches or substitution versus prosthetic replacement in cases of missing teeth. Multiple orthodontic systems—including labial and lingual fixed appliances, as well as removable clear aligner systems—are successfully integrating this technology. The ultimate goal of using CAD/CAM technology in orthodontics is to enhance the reproducibility, efficiency, and quality of orthodontic treatments[24].

The intraoral scanners capture images through the projection of laser light or structured light, without direct interaction with biological tissues[25]. The speed, resolution, and accuracy of the scanner depend on the technology used by the sensor to capture the image [25,26]. These devices are equipped with specialized software that processes the data to create a 3D virtual image of the dental arches [25,26,27].

In orthodontics, the digital workflow is primarily used for digital setups and the fabrication of clear aligners, although this is just one aspect of its clinical applications. Digital setups offer enhanced predictability, regardless of the type of orthodontic appliance used[28]. Traditionally, the orthodontic setup uses plaster models to separate and reposition the crowns in wax. With digital technology, the treatment simulation process has become faster and more practical. The models corresponding to the various treatment stages are automatically generated by the setup software and used for aligner production[28].

Digital indirect bonding and virtual bracket removal can reduce treatment time, eliminate clinical and laboratory steps, and enhance patient comfort, accuracy, and predictability. However, CAD/CAM technology in orthodontics requires a higher financial investment and professional training.

Future Trends and Challenges & conclusion

In light of the significant changes brought about by CAD/CAM and 3D printing in dental diagnosis and treatment planning, manufacturing techniques, and materials employed in this domain, it is important to consider the challenges that currently exist and the potential opportunities that may emerge in the future. Currently, 3D printing technology is used to produce physical models of a patient's dental and jaw anatomy from digital scans. AI algorithms are also employed to analyze dental images, such as X-rays and intraoral scans. Moreover, augmented reality (AR) applications enhance patient education by allowing individuals to visualize potential treatment outcomes through the overlay of virtual dental restorations on real-world images of their mouths.

Looking ahead, AI-driven treatment plans will leverage patient data, including dental images, medical history, and genetic information, to create tailored treatment strategies for orthodontics and oral surgery, enhancing both the efficiency and predictability. Additionally, advancements in 3D printing technology will allow for the production of biocompatible dental implants directly from digital designs, leading to implants that are customized for optimal fit and aesthetics. AI in CAD/CAM restorative dentistry uses numerical reasoning, virtual simulation, machine learning algorithms, and deep modeling to replicate human brain function. These technologies can improve patient satisfaction, reduce restorative fabrication time, and enhance design analysis and machining flexibility. Interpretable and traceable AI technologies can aid in clinical decision-making with high accountability. Teledentistry is also expected to expand, facilitating remote consultations and diagnoses through telecommunications, image sharing, and patient monitoring. This development will enable dentists to provide advice, triage emergencies, and manage non-urgent dental care from a distance. Real-world examples include MouthWatch TeleDent and Denteractive, which have already demonstrated success in remote dental care. Lastly, personalized prosthodontics will advance through by the integration of digital scanning, CAD/CAM software, and 3D printing, allowing for the production of highly customized and precise dental prostheses that improve both function and aesthetics.[29]

Artificial Intelligence (AI) is increasingly being incorporated into dentistry, offering significant potential to improve diagnostic accuracy, treatment planning, and patient outcomes. AI algorithms can analyze large datasets, including radiographic images and clinical histories, facilitating the early identification of oral and dental diseases and the development of personalized treatment plans. Moreover, digital marketing has become essential for effective dental practice management. With the growing use of the internet and social media, dental practices must establish a strong online presence to attract and retain patients while providing educational resources. Tactics such as search engine optimization (SEO) and targeted advertising can boost online visibility and enhance brand recognition. Additionally, video marketing is a powerful tool for sharing educational content, showcasing the practice and its services, and introducing the dental team. These videos can be shared through the practice’s website and social media platform, further engaging potential and existing patients.[30]

Teledentistry:

Teledentistry, which represents a branch of telemedicine, utilizes digital technologies to provide dental care and consultations remotely, thereby allowing patients to receive consultations, screenings, and even certain treatments without physically visiting a dental office; this innovation not only enhances convenience and reduces costs but is particularly advantageous for individuals living in remote, isolated, or underserved areas with limited access to dental services. Furthermore, teledentistry can support follow-up appointments, consultations, and monitoring of patients who have undergone dental procedures. In the aftermath of the COVID-19 pandemic, this practice has rapidly gained traction within the realm of digital dentistry, significantly enhancing access to care and treatment outcomes while simultaneously reducing the risk of disease transmission by facilitating early detection and intervention for oral and dental health issues.[30]

Challenges and Implications:

While digital dentistry offers many benefits, dental professionals face several challenges and limitations. These include the significant costs of advanced technologies, the need for specialized training to use these tools effectively, and the possibility of technological errors or failures during procedures. Understanding these issues is vital for practitioners as they incorporate digital solutions into their practices. Furthermore, concerns about cybersecurity breaches and patient privacy violations are prominent, as digital images and sensitive patient data can be vulnerable to cyberattacks, highlighting the necessity for strong security measures.

Some dental professionals also worry about the potential for job loss due to automation and technological progress. However, it's important to note that digital dentistry is designed to enhance practitioners' abilities and improve patient care rather than replace them. The field is continuously evolving, with future developments expected to include augmented reality (AR), virtual reality (VR), and machine learning (ML) technologies, which could further enhance patient outcomes and treatment experiences.

Conclusion:

CAD/CAM technology in dentistry represents a pivotal evolution in the dental care sector, fundamentally altering diagnostic and treatment planning methodologies. The integration of Computer-Aided Design(CAD) and Computer-Aided Manufacturing(CAM), along with 3D printing, has optimized dental workflows and significantly enhanced the accuracy and precision of restorative procedures. These advanced technologies empower dental practitioners to fabricate highly personalized prosthetics, implants, and orthodontic devices, ultimately enhancing patient outcomes and satisfaction.

The introduction of CAD/CAM systems enables clinicians to design and produce restorations on-site, minimizing turnaround times and enhancing the overall patient experience. Additionally, 3D printing facilitates the creation of intricate structures and bespoke solutions that were previously unattainable, thus expanding the possibilities of digital dentistry. However, the transition to digital dentistry presents several challenges. The substantial initial investment required for cutting-edge equipment, the need for specialized training, and concerns surrounding cybersecurity and patient data confidentiality represent significant obstacles. Additionally, some dental professionals may resist adopting these innovations due to concerns about job security and the implications of automation.

Despite these hurdles, the prospects for digital dentistry remain bright. Continuous advancements in artificial intelligence and machine learning are anticipated to enhance diagnostic and treatment planning capabilities further. While challenges persist, the advantages of digital dentistry are compelling. The ongoing integration of CAD/CAM and 3D printing technologies is poised to redefine dental practice, creating new avenues for innovation and improved patient care. To fully harness the potential of digital dentistry, dental professionals must embrace these technologies, engage in lifelong learning, and adapt to the ever-evolving landscape of dental care. The transition towards a wholly digital dental practice is already in motion, heralding a future characterized by enhanced precision, efficiency, and a focus on patient-centered care.

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