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Revolutionizing Dental Prosthetics: Unveiling the Impact of CAD/CAM Technology

Rada Kazakova [a,b]*

[a] *Department of Prosthetic Dentistry, Faculty of Dental Medicine, Medical University–Plovdiv, 4000 Plovdiv, Bulgaria*
[b] *CAD/CAM Center of Dental Medicine, Research Institute, Medical University–Plovdiv, 4000 Plovdiv, Bulgaria*
Email address: rada.kazakova@mu-plovdiv.bg

A B S T R A C T

This review aims to comprehensively outline the methods and advancements in CAD/CAM technology for dental restorations, including scanning, designing, and fabrication techniques, alongside emerging classifications. PubMed was systematically searched using specific terms, with articles limited to those in English published from 2001 to 2024, supplemented by manual searches of relevant journals. Advantages of CAD/CAM include digital impressions and expanded design software applications, yet implementation remains costly and requires trained personnel. Notably, 5-axis milling units provide optimal restoration accuracy, while 3D printing is primarily limited to polymers. Future developments may see ultrasound impressions replacing optical impressions, offering non-invasive gingival penetration. It is anticipated that practitioners will increasingly utilize acquisition cameras connected to computers for image transmission to laboratories.

Keywords: CAD/CAM, dental restorations, digital impressions, 3D printing, digital dentistry

1. Introduction

The rapid evolution of CAD/CAM (Computer Aided Design, Computer Aided Manufacture) technology has had a profound and far-reaching impact across all disciplines of dentistry, with prosthodontics and restorative dentistry experiencing particularly dramatic transformations. These technological advancements, coupled with the continual development of biomaterials like high-strength ceramics such as zirconia, have ushered in a new era in dental education and patient care. Notably, the integration of CAD/CAM systems has revolutionized various aspects of clinical practice, offering benefits in terms of economics, time efficiency, and the ability to predict postoperative clinical outcomes. Within this context, three key protocols stand out: digital impressions, digital models, and the use of virtual articulators and facebows. These protocols represent the cornerstone of modern CAD/CAM-assisted dentistry, facilitating precise and efficient treatment planning and execution [1-4].

Moreover, the provision of prosthodontic care has evolved into a multifaceted process that involves collaboration between patients, student clinicians, faculty clinicians, and commercial laboratories at various levels. This collaborative approach underscores the complexity of modern prosthodontic treatment and highlights the importance of seamless integration between different stakeholders. Against this backdrop, the objective of this study is to comprehensively review the current body of literature on the methods and techniques employed in the scanning, designing, and fabrication of CAD/CAM-generated restorations. Additionally, the study aims to explore the latest classifications of CAD/CAM technology, recognizing the significant variability in acquisition systems, CAD design mechanisms, and CAM fabrication processes. It is important to acknowledge that while CAD/CAM technology offers remarkable capabilities, not all systems may possess the capacity to fulfill the diverse range of restorative needs required for individualized prosthetic solutions. Therefore, this review seeks to provide insights into the current landscape of CAD/CAM technology in prosthodontic practice, addressing both its potential and its limitations in shaping the future of dental care [4-5].

2. Materials and Methods

A systematic review of the literature was conducted on PubMed utilizing targeted search terms encompassing "CAD/CAM, 3D printing, scanner, digital impression, and zirconia." Subsequent to the initial search, identified articles underwent rigorous screening to ascertain relevance to the investigation at hand. The scope of the search was delimited to English-language articles published within the timeframe spanning from 2001 to 2024. Additionally, a supplementary manual search was performed, scrutinizing both articles and reference lists retrieved from the electronic search as well as from reputable peer-reviewed journals.

3. Results

CAD/CAM systems represent a sophisticated integration of technology within the realm of dentistry, comprising a multifaceted array of components that collectively streamline and enhance the process of dental restoration. At the core of these systems lies the data acquisition unit, a pivotal component responsible for capturing intricate details of the dental anatomy. This unit operates through intraoral scanners or conventional impression methods, translating physical structures into digital impressions. The captured data undergoes intricate processing, facilitated by specialized software, which transforms it into a virtual working environment where restorations can be meticulously designed and customized to meet individual patient needs [1-4].

The classification of CAD/CAM systems further underscores the diversity and complexity within this domain, with distinctions drawn between laboratory and chairside systems. Laboratory systems, equipped with both scanning and milling capabilities, offer comprehensive solutions for restoration fabrication, while CAD-only systems focus primarily on digital scanning. Within these classifications, a myriad of manufacturers contribute to the market landscape, each offering unique features and functionalities tailored to specific clinical requirements and preferences [6-8].

Intraoral scanners, as integral components of CAD/CAM systems, play a fundamental role in capturing accurate digital impressions. These scanners are categorized into two main types: single-image cameras and continuous scanning devices. Single-image cameras, exemplified by devices such as iTero and Trios, capture individual images of the dentition, while continuous scanning devices employ a series of overlapping images to create a comprehensive digital representation. These scanners serve as the primary interface between the physical and digital realms, enabling clinicians to capture precise data for subsequent digital processing and restoration design [9-11].

Scanning protocols, integral to the CAD/CAM workflow, offer clinicians flexibility in capturing data intraorally, accommodating both preoperative and postoperative scanning approaches. Preoperative scanning allows for the incorporation of existing anatomical contours, while postoperative scanning focuses solely on the preparation site, streamlining the digital workflow and enhancing efficiency.

Virtual articulators and facebows play a crucial role in ensuring accurate articulation of digital models, facilitating comprehensive treatment planning and execution. These mechanical devices provide a framework for aligning the maxillary arch with the axes of the condylar hinge, enabling clinicians to simulate occlusal relationships and ensure optimal functional outcomes.

Design software, provided by manufacturers, empowers clinicians to create and customize a wide range of dental restorations, from simple copings to complex fixed partial dentures and veneers. This software offers sophisticated tools and functionalities, allowing for precise manipulation of digital models and the creation of highly customized restorations tailored to individual patient needs [5-9].

In the digital fabrication phase, CAD models are translated into physical restorations using subtractive or additive manufacturing techniques. Subtractive methods involve milling or grinding processes, where restoration materials are sculpted from solid blocks to achieve the desired shape and dimensions. Additive manufacturing, on the other hand, builds up material layer by layer using 3D printing technology, offering unparalleled flexibility and precision in restoration fabrication.

Despite the remarkable advancements in CAD/CAM technology, certain limitations persist, including line-of-sight restrictions of cameras and the absence of glass-ceramics in disc form for restoration fabrication. These limitations underscore the ongoing need for innovation and research within the field, driving the evolution of CAD/CAM systems to meet the ever-changing demands of modern dentistry. Addressing these challenges and advancing technological capabilities will shape the future trajectory of CAD/CAM systems, paving the way for enhanced clinical outcomes and patient care [8-10].

4. Discussion

CAD/CAM technology offers notable advantages such as the utilization of digital impressions and models, as well as the integration of virtual articulators. These capabilities significantly enhance the precision and efficiency of dental restorations. However, the implementation of CAD/CAM technology is often hindered by its perceived expense and the necessity for highly skilled personnel to operate the equipment and software effectively. Presently, design software has expanded its capabilities to encompass various applications, including the fabrication of complete dentures and frameworks for removable partial dentures. Optimal accuracy in restoration fabrication is commonly achieved through the utilization of 5-axis milling units, which allow for intricate and precise shaping of dental restorations from various materials [8-12].

While 3D printing technology has made inroads in dentistry, its applications are currently limited to polymers, with ceramics notably absent. The limited mechanical properties and biocompatibility issues associated with polymer-based restorations restrict their widespread adoption for permanent solutions. However, 3D printing remains highly valuable for the creation of dental models, surgical guides, and temporary restorations, showcasing its potential in specific niches within the field.

One of the primary challenges in the adoption of 3D printing for zirconia restorations is the reduced mechanical properties observed in printed specimens. This is primarily due to the inherent limitations of current 3D printing techniques, such as SLA and DLP, which involve the curing of successive layers of a photosensitive polymeric binder mixed with zirconia powder. These methods, while offering high accuracy and relatively smooth surfaces, often result in lower flexural strength compared to traditional subtractive methods. Defects such as pores, cracks, and fractures at layer interfaces further compromise the mechanical integrity of the restorations [3-6].

To address these challenges, several potential solutions have been proposed. Optimization of printing parameters and material compositions can significantly enhance the mechanical properties of 3D printed zirconia. Refinement of printing processes, along with the development of new materials, can help address opacity issues and improve the overall aesthetic quality of the restorations. Advancements in printing technology, including the integration of AI algorithms, can enhance shape accuracy and reduce the incidence of defects. Improved quality control measures and post-printing treatments are also essential in mitigating common defects such as pores and cracks [7, 8].

Looking ahead, there is a prospect for optical impressions to be supplanted by ultrasound impressions, leveraging ultrasonic waves to penetrate the gingiva non-invasively. This innovation could eliminate the need for retraction cords and remain unaffected by fluids, offering a more comfortable and efficient alternative for capturing dental impressions. The potential for ultrasound technology to revolutionize the field of dental impressions underscores the continuous evolution of digital dentistry and its commitment to improving patient outcomes and procedural efficiency [8-12].

The integration of CAD/CAM technology with emerging techniques such as 3D printing and ultrasound impressions holds great promise for the future of dentistry. As these technologies advance, they are likely to overcome current limitations and expand their applications, ultimately leading to more efficient, accurate, and patient-friendly dental procedures. Continued research and development in this field are essential to realize the full potential of these innovations and to ensure their successful implementation in clinical practice.

5. Conclusion

The emerging trend in dentistry suggests a growing implementation of acquisition cameras integrated with computer systems and advanced software. This shift towards digital workflows enables efficient transmission of captured images to dental laboratories for restoration fabrication. With technological advancements, practitioners can streamline workflows, enhance communication, and improve patient outcomes. As the dental industry embraces digital solutions, the use of acquisition cameras and robust software is poised to become commonplace, ushering in an era of efficiency and precision in dental practice.

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