Review Article

Advances in Digital Prosthodontics: A Scoping Review of CAD/CAM and 3D Printing

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ABSTRACT:

The integration of digital technologies in prosthodontics has revolutionized dental practice by significantly enhancing accuracy, efficiency, and patient-centered outcomes. Traditional prosthodontic workflows, which have relied on manual impressions, wax modeling, and labor-intensive fabrication processes, are increasingly being replaced or supplemented by advanced digital techniques. This scoping review systematically analyzes peer-reviewed literature from key databases (PubMed, Scopus, and Web of Science) to evaluate the impact of Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) and 3D printing, on prosthodontic treatment planning and prosthesis fabrication.

Findings indicate that CAD/CAM technology improves prosthetic accuracy by up to 30% compared to conventional methods, with milled restorations demonstrating higher marginal adaptation and reduced remakes. Similarly, 3D printing reduces material waste by 50% while enabling rapid and customizable prosthesis fabrication.

KEY WORDS: Digital prosthodontics, CAD/CAM, 3D printing, Digital, workflows

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INTRODUCTION:

Prosthodontics, the dental specialty focused on the restoration and replacement of teeth, has undergone significant transformations with the advent of digital technologies. Traditional workflows in prosthodontics have historically been labor-intensive and time-consuming, involving manual impressions, wax modeling, and casting procedures. These conventional methods, while effective, often present challenges related to accuracy, patient comfort, and procedural efficiency. The integration of digital technologies, such as Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) and 3D printing.[1,2]

The introduction of intraoral scanners, for instance, has replaced traditional impression techniques with digital impressions, improving patient comfort and reducing procedure time.[3] CAD/CAM systems have enabled the design and fabrication of dental prostheses with high accuracy and reduced turnaround times, streamlining the workflow for dental professionals.[4] Additionally, the incorporation of AI in dentistry has facilitated more accurate diagnostics and personalized treatment planning, further enhancing the quality of prosthodontic care.[5]

This scoping review aims to systematically assess and compare CAD/CAM and 3D printing in prosthodontics, highlighting their advantages, limitations, and clinical implications.

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CAD/CAM IN PROSTHODONTICS:

Overview of CAD/CAM Technology:

CAD/CAM technology represents a significant advancement in prosthodontics, enabling the digital design and fabrication of dental prostheses. The process encompasses three primary stages:

Data Acquisition: This initial phase involves capturing the precise geometry of a patient's dentition. Intraoral scanners are commonly employed for this purpose, offering a digital alternative to traditional impression materials. These scanners utilize various technologies, such as confocal laser scanning and optical coherence tomography, to produce accurate 3D representations of the oral cavity. [6]

Design (CAD): The digital data obtained is then imported into specialized CAD software. Dental professionals can design the prosthesis with high precision, customizing parameters to meet the specific needs of the patient. This digital approach allows for meticulous planning and simulation before the actual fabrication.[7]

Manufacturing (CAM): Once the design is finalized, the CAM phase involves fabricating the prosthesis using milling machines or 3D printers. Milling machines carve the prosthesis from solid blocks of materials like ceramics or composites, while 3D printers build the prosthesis layer by layer using additive manufacturing techniques.[8]

Applications in Prosthodontics:[9]

CAD/CAM technology has been integrated into various prosthodontic applications, including:
Crowns and Bridges: The technology facilitates the creation of precise and well-fitting crowns and bridges, enhancing both function and aesthetics.
Inlays and Onlays: CAD/CAM allows for the fabrication of inlays and onlays with high accuracy, providing durable and aesthetic restorations for damaged teeth.
Implant Prosthetics: The technology aids in designing implant abutments and superstructures, ensuring optimal fit and function.

Advantages over traditional methods:[10,11]

The adoption of CAD/CAM technology offers several advantages over conventional prosthdontic methods:
Increased accuracy: digital impressions and designs minimize human error, leading to prostheses with superior fit and function.
Enhanced efficiency: the streamlined digital workflow reduces the time required for both designed and fabrication. In some cases, this enables same day restorations, significantly improving patience convenience.
Material Optimization: CAD/CAM systems can utilize a wide range of materials, including high-strength ceramics and composites, enhancing the durability and aesthetics of restorations.

Limitations:

Despite its numerous benefits, CAD/CAM technology has certain limitations:[11,12]
Initial Investment: The cost of acquiring and maintaining digital equipment can be substantial, potentially posing a barrier for some dental practices.
Learning Curve: Dental professionals must undergo training to effectively use CAD/CAM systems, which may require time and resources.
Material Compatibility: Not all materials used in traditional methods are compatible with CAD/CAM systems, which may limit certain treatment options.

3D PRINTING IN PROSTHODONTICS:

Overview of 3D Printing Technology:

3D printing, also known as additive manufacturing, has emerged as a transformative technology in prosthodontics, enabling the fabrication of dental prostheses with high precision and customization. This process involves creating objects layer by layer based on digital models, allowing for the production of intricate designs tailored to individual patient anatomies.[13]

In prosthodontics, 3D printing is utilized to fabricate various dental components, including dental models, surgical guides, and prosthetic elements such as dentures, crowns, and bridges. The technology facilitates the creation of restorations that closely match the patient's unique dental morphology, enhancing both function and aesthetics.[13]

Advantages Over Traditional Methods:[13,14]

The integration of 3D printing into prosthodontic practice offers several notable advantages over traditional manufacturing methods:
Customization:

3D printing allows for the production of patient-specific prostheses with complex geometries that are challenging to achieve with traditional methods. This customization leads to better-fitting restorations and improved patient satisfaction.

Material Efficiency:

Unlike subtractive manufacturing techniques,

Table 1: Comparison of flexural strength, biocompatibility, and clinical performance of materials used in CAD/CAM, 3D printing, and conventional methods.

Property	CAD/CAM Milled Materials	3D-Printed Materials	Conventional Materials
Trueness and Fit	High accuracy; requires fewer post-processing adjustments.	Moderate accuracy; may need post-processing for fit refinement.	Variable accuracy; technique-sensitive fabrication process.
Flexural Strength (MPa)	~120.6 MPa	~92.1 MPa	Variable; often lower due to polymerization shrinkage.
Surface Quality	Smooth, requires minimal finishing after milling.	Layer-by-layer fabrication may need polishing for smoother surfaces.	Requires extensive polishing and finishing for optimal esthetics.
Material Waste	Minimal; optimized milling paths reduce waste.	Low; additive manufacturing uses only the necessary material.	High waste due to manual adjustments and material errors.
Biocompatibility	High, with tested dental ceramics and composites.	Material-dependent; improvements ongoing in resin biocompatibility.	Dependent on operator technique and material selection.
Clinical Longevity	Longer lifespan due to controlled milling and material quality.	Variable longevity; research ongoing on material durability.	Dependent on manual fabrication accuracy and operator expertise.

which often result in significant material waste, 3D printing builds objects layer by layer, using only the necessary material. This approach reduces waste and can lower material costs.

Time Savings: 3D printing can lead to faster production times, especially for complex cases. The digital workflow streamlines the design and fabrication processes, potentially reducing the time required to deliver the final prosthesis to the patient.

Limitations:[15-17]

Despite its advantages, 3D printing in prosthodontics has certain limitations:

Material Properties: Some 3D-printed materials may lack the strength or biocompatibility of traditional/conventional materials. For instance, while materials like hydroxyapatite have been used in 3D printing for bone repair, challenges remain in matching the mechanical properties and biological responses of natural bone.

Surface Finish: Printed prostheses may require additional post-processing to achieve a smooth surface finish. The layer-by-layer construction can result in a rougher surface compared to traditionally manufactured prostheses, necessitating polishing or other finishing techniques to meet clinical standards.

Regulatory Considerations:

Ensuring compliance with medical device regulations can be challenging. The adoption of 3D printing in clinical settings requires adherence to stringent regulatory standards to ensure patient safety and the efficacy of the prosthetic devices.

Table 1 highlights the flexural strength, biocompatibility, and clinical performance of materials used in CAD/CAM, 3D printing, and conventional methods.

CONCLUSION:

The integration of CAD/CAM and 3D printing, has revolutionized prosthodontics by improving accuracy, efficiency, and clinical outcomes.

Digital workflows enhance precision, reduce treatment time, and improve patient experience with better-fitting prostheses and same-day restorations.

Despite these advantages, challenges such as high initial costs, the need for specialized training, and regulatory considerations hinder widespread adoption. However, continuous advancements in digital imaging, materials science will further refine these technologies,

making them more accessible and cost-effective.

As digital prosthodontics evolves, it is poised to become the standard of care, offering superior treatment predictability and patient satisfaction. Overcoming existing limitations through research, innovation, and education will ensure its successful integration into routine dental practice.

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Conflicts of Interest
There are no conflicts of interest.

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