Evolution of 3D Printing in Complete Dentures: Materials, Techniques, and Clinical Advancements -A Review

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***Abstract*—Three-dimensional (3D) printing has revolutionized dentistry by providing unprecedented accuracy, repeatability, and efficiency in prosthodontic fabrication. In complete denture production, additive manufacturing has replaced traditional manual methods with digitally driven, highly customizable workflows. This review explores the evolution of 3D printing technologies in complete denture fabrication, with a detailed discussion on materials used for denture bases and artificial teeth. It highlights the transition from subtractive to additive techniques, advancements in photopolymer and resin formulations, and their clinical implications for function, fit, and patient comfort. The review also addresses current limitations and future directions for achieving full digital integration in prosthodontics.**

***Index Terms*—3D printing, complete denture, additive manufacturing, dental materials, digital dentistry**

I. INTRODUCTION

Complete dentures restore form and function in edentulous patients, serving both aesthetic and functional purposes. Conventional methods of denture fabrication are time-consuming and dependent on operator skill, often leading to variability in quality. The emergence of computer-aided design and computer-aided manufacturing (CAD/CAM) has marked a paradigm shift, and within this, 3D printing (additive manufacturing) has become a pivotal innovation. [1]

3D printing allows layer-by-layer construction of dental prostheses based on digital data, ensuring enhanced precision, reproducibility, and reduced human error. [2] the integration of digital scanning, virtual design, and automated printing minimizes clinical and laboratory visits, promoting patient satisfaction and workflow efficiency. [3]

This review aims to trace the evolution of 3D printing in complete denture fabrication, examine the materials used, and highlight how these technologies have advanced prosthodontic practice.

II. EVOLUTION OF 3D PRINTING IN DENTISTRY

The origins of 3D printing date back to the 1980s with stereolithography (SLA), a process that uses light to cure liquid resin layer by layer. [4] Initially adopted for prototyping, it entered dentistry in the early 2000s for surgical guides and later evolved to fabricate crowns, bridges, and dentures. [5]

The first CAD/CAM complete denture systems emerged in the 2010s, with companies such as Ava Dent and Dentca introducing digitally designed and milled dentures. [6] However, the subtractive milling approach had limitations—material wastage, tool wear, and inability to fabricate complex geometries. This led to increased focus on additive manufacturing, where dentures could be printed directly from digital files using various resin formulations. [7]

Recent advancements in printing accuracy, biocompatible materials, and mechanical strength have made 3D printed dentures clinically viable. [8] the ongoing development of multi-material printers and high-resolution photopolymerization has further refined fit, comfort, and aesthetics. [9]

III. APPLICATION OF 3D PRINTING IN COMPLETE DENTURE FABRICATION

The complete denture digital workflow involves several stages:

1. Digital Impression: Obtained using intraoral or extraoral scanners.
2. Digital Design: Performed using CAD software, allowing virtual tooth setup and occlusal adjustment.
3. 3D Printing: Using SLA, digital light processing (DLP), or material jetting.
4. Post-processing: Cleaning, curing, and polishing the denture.

The major advantage lies in the ability to replicate dentures accurately from stored digital files, enabling easy replacement and repair. [10] Printing also allows monolithic fabrication of denture bases and teeth, reducing bonding failures and improving mechanical integrity. [11]

IV. MATERIALS USED IN 3D PRINTING FOR COMPLETE DENTURE FABRICATION

Photopolymer Resins

Photopolymer resins constitute the foundational material group used in stereolithography (SLA), digital light processing (DLP), and other vat photopolymerization-based additive manufacturing technologies. These materials rely on the controlled polymerization of acrylate or methacrylate monomers initiated by photo initiators activated under specific light wavelengths. Contemporary research emphasizes optimizing cross-link density, polymer chain mobility, and molecular weight distribution to enhance fracture toughness, reduce polymerization shrinkage, and improve dimensional accuracy. Advanced formulations incorporate multifunctional oligomers, urethane methacrylates, and tailored photo initiators to achieve predictable polymerization kinetics and uniform curing depth. Despite significant improvements, photopolymer resins still exhibit limitations in water sorption, long-term mechanical stability, and resistance to cyclic fatigue. Studies increasingly focus on nanofiller incorporation—such as silica nanoparticles or nano clays—to reinforce the polymer matrix and mitigate crack propagation.

Polymethyl Methacrylate (PMMA)

PMMA remains the benchmark material for conventional denture bases due to its reliable mechanical and biocompatible profile. The adaptation of PMMA for 3D printing involves engineering photoactivated PMMA-based resins that replicate the polymer network generated through traditional heat-curing or auto-polymerizing processes. Current research examines the influence of resin viscosity, initiator concentration, and photopolymerization depth on polymer conversion efficiency and internal porosity. Although printed PMMA typically presents lower flexural strength than milled high-density PMMA pucks, advancements such as high-molecular-weight prepolymers, multifunctional cross-linkers, and nanofiller reinforcement are reducing this performance gap. Investigations exploring polymer chain orientation, post-polymerization thermal cycling, and solvent-assisted annealing demonstrate promising improvements in strength and longevity.

Composite Resins

Composite resins intended for denture teeth consist of methacrylate matrices reinforced with micro- or nano-scale ceramic, silica, or zirconia fillers. These fillers enhance mechanical durability, occlusal wear resistance, and surface hardness, making them suitable for long-term functional loading. Material jetting technologies enable voxel-level deposition of composite materials, providing the ability to print multilayered structures that mimic enamel–dentin gradation. Current research focuses on optimizing filler–matrix bonding through silane coupling agents, evaluating filler distribution uniformity, and improving wear mechanisms under simulated masticatory loading. Studies also investigate thermal expansion coefficients, colour stability under UV exposure, and resistance to hydrolytic degradation—properties essential for preserving aesthetics and functional integrity.

Thermoplastic Polymers

Thermoplastic polymers such as polyamide (nylon), polycarbonate (PC), and thermoplastic polyurethane (TPU) are emerging as viable alternatives for flexible dentures, particularly produced through selective laser sintering (SLS). Their semicrystalline molecular structure imparts notable impact strength, resilience, and adaptability to undercut anatomical regions. Nylon-based materials provide reduced brittleness, whereas TPU offers elastic properties favourable for pressure distribution. However, these polymers present challenges including printing warpage, limited colour r options, and difficulties achieving uniform layer fusion. Experimental work continues to refine crystallization kinetics, laser absorption profiles, and powder particle morphology to enhance printability and dimensional stability.

Biocompatible and Medical-Grade Resins

The rise of long-term intraoral applications has prompted the development of Class IIa and Class IIb medical-grade photopolymer resins. These materials undergo rigorous ISO 10993 biocompatibility evaluation, including cytotoxicity, genotoxicity, and mucosal irritation testing. Formulations aim to minimize unreacted monomers, leachable components, and incomplete polymerization residues. Antimicrobial advancements include the incorporation of quaternary ammonium monomers, zinc oxide nanoparticles, and silver-based agents to inhibit microbial adherence, reduce biofilm formation, and limit Candida albicans colonization. Molecular-level engineering focuses on enhancing hydrophobicity, reducing surface free energy, and improving resistance to enzymatic degradation in the oral environment.

Experimental and Future Materials

Emerging research explores next-generation materials intended to overcome the inherent limitations of current resin systems. Nanocomposite resins employing carbon nanotubes, graphene derivatives, or nano-hydroxyapatite aim to enhance elastic modulus and provide controlled crack deflection pathways. Bio-based polymers derived from renewable resources are being engineered to achieve PMMA-like mechanical performance while improving environmental sustainability. Resin–ceramic hybrid systems seek to combine ceramic-level durability with polymer-level flexibility and bond ability. Beyond traditional 3D printing, 4D printing materials capable of responding to thermal, mechanical, or moisture stimuli represent a transformative innovation, enabling self-adjusting borders, adaptive internal liners, and functionally responsive dentures that adjust to intraoral changes over time.

Advantages of 3D Printed Complete Dentures

- Precision and Fit: Digital design ensures accurate adaptation to tissues. [12]
- Reduced Chairside Time: Minimal adjustments and faster turnaround. [13]
- Reproducibility: Digital storage allows easy duplication of dentures. [14]
- Customization: Individualized tooth morphology and gingival contouring. [15]
- Patient Comfort: Lightweight materials and improved occlusal balance. [16]

Limitations and Challenges

Despite rapid progress, several limitations persist:

- Material Properties: Printed resins often exhibit lower fracture toughness compared to conventional PMMA. [17]
- Post-Processing Requirements: Incomplete curing can affect biocompatibility. [18]
- Printer Calibration and Accuracy: Small discrepancies can lead to misfit. [19]
- Regulatory Challenges: Standardization across resin formulations and printer systems remains under development. [20]

Future Perspectives

Future research will likely focus on multi-material printing, enabling simultaneous fabrication of denture bases and teeth with varying hardness. [12] Integration of AI-assisted design and intraoral scanning will further personalize dentures to individual anatomy and function. [12] Additionally, advances in bioprinting may allow direct printing of soft tissue–compatible liners or living cell layers for improved comfort and integration. [12]

As materials evolve to meet long-term clinical requirements, 3D printed dentures are expected to become a standard of care in digital prosthodontics. [13]

V. CONCLUSION

The evolution of 3D printing has transformed the landscape of complete denture fabrication, bridging the gap between traditional craftsmanship and digital precision. From early stereolithography systems to modern multi-material printers, additive manufacturing has provided a scalable, customizable, and efficient alternative to conventional techniques. With ongoing research into high-strength, biocompatible materials and smarter digital workflows, 3D printed dentures are poised to redefine prosthodontic standards in the coming decade.

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