REVIEW ARTICLE

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3D Printing in Restorative Dentistry: A Review of Materials, Accuracy, and Clinical Applications

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ABSTRACT

Three-dimensional (3D) printing has become a revolutionary technology in restorative dentistry which has brought new possibilities to the design and fabrication of dental prostheses. Additive manufacturing offers better customization, material efficiency, and integration of digital workflow as compared to the traditional subtractive methods. Several categories of printable materials such as photopolymer resins, ceramics and metals are now offered temporarily and permanently in restorations, denture bases and implant-supported structures. The clinical performance and accuracy of 3D-printed restorations is based on the technology of the printer, its resolution, post-processing procedure, and properties of the materials. Recent findings show that there are good results in terms of marginal fit, mechanical stability, and esthetics; however there are still issues with long-term durability, surface finishing, and inter-system standardization. In addition to prosthesis, there are also clinical uses of the technology in surgical guides, occlusal splints, and customized trays, which underlines the versatility of the technology. Further multi-material printing, bioactive material, and optimization of workflow investigations will likely increase the 3D printing application in restorative dentistry that can enhance personalized and efficient patient care.

Keywords: 3D printing, additive manufacturing, restorative dentistry, dental materials, accuracy, clinical applications, prosthodontics.

1. INTRODUCTION

The use of digital technologies in the field of dentistry has transformed dental practice, and computer-aided design and computer-aided manufacturing (CAD/CAM) is the key to the modern restorative procedures. Three-dimensional (3D) printing, or additive manufacturing, is one of these innovations that have therefore generated a lot of interest because it is capable of producing complex dental-structures with great precision and efficiency. In contrast with traditional subtractive manufacturing, where the material is removed, 3D printing is a technology where objects are created by adding layers to digital models, thus allowing much greater customization, less material usage, and easier integration with digital impressions and design software.

The flexibility of 3D printing has increased its application in various fields in restorative dentistry. Examples of these uses are the manufacturing of provisional and final restorations, implant surgical guides, removable prostheses, occlusal splints and customized trays. These developments not just enhance the efficiency of the workflow of clinicians and laboratories but also the patient outcomes with personal and esthetic solutions.

One of the most important things about 3D printing in dentistry is the optimization and advancement of materials. Dental use of photopolymer resins, hybrid composites, ceramics, and metal alloys is now being customized to have certain mechanical and biological properties that are particularly applicable in restorative modes. Nevertheless, the clinical efficacy of 3D-printed restorations is not only limited to the performance of materials but also to the accuracy and reproducibility of printing. The choice of parameters like type of printer, resolution, orientation, and post-processing operations are decisive to obtain an acceptable marginal and internal fit, mechanical strength and long term stability.

Even with these encouraging advances, there are still issues of standardization, cost-effectiveness, regulatory acceptance and long-term clinical validation. With further research, the combination of high-tech materials, multi-material printing and artificial intelligence-

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inspired processes is likely to increase the range and dependability of 3D printing in restorative dentistry.

This review aims to provide an overview of 3D printing technologies in restorative dentistry, with a particular focus on the materials employed, the accuracy achieved, and their clinical applications.

2. 3D Printing Technologies in Dentistry

Three-dimensional (3D) printing, also known as additive manufacturing, is a layer-by-layer fabrication process that enables the production of highly customized dental restorations and appliances. Various technologies have been introduced into restorative dentistry, each with unique principles, advantages, and limitations. The most widely adopted systems include stereolithography (SLA), digital light processing (DLP), fused deposition modeling (FDM), and selective laser sintering (SLS) (Table 1).

2.1. Stereolithography (SLA)

SLA is one of the earliest 3D printing technologies applied in dentistry. It employs a laser beam to selectively cure liquid photosensitive resin layer by layer. SLA is known for its high accuracy, fine resolution, and smooth surface quality, making it suitable for applications such as surgical guides, temporary crowns, bridges, and castable resin patterns. However, it requires post-curing, has material limitations, and may involve time-consuming support removal.

2.2. Digital Light Processing (DLP)

DLP is closely related to SLA but uses a digital light projector to cure entire layers of resin simultaneously. This significantly improves printing speed compared with SLA while maintaining high precision. DLP printers are widely used for dental models, aligner molds, denture bases, and temporary restorations. Limitations include resin shrinkage and the need for meticulous calibration.

2.3. Fused Deposition Modeling (FDM)

FDM is a cost-effective technique that extrudes thermoplastic filaments layer by layer. Although FDM is widely used in prototyping, its application in restorative dentistry is limited due to relatively low accuracy, poor surface finish, and restricted biocompatible material options. It is mainly used for educational models, custom trays, and mock-ups rather than definitive restorations.

2.4. Selective Laser Sintering (SLS) / Selective Laser Melting (SLM)

SLS and its variant, SLM, employ a high-power laser to sinter or melt powdered materials, such as metals or polymers, to form solid structures. These technologies are especially valuable in fabricating metal frameworks for removable partial dentures, implant components, and substructures for fixed prostheses. They offer high mechanical strength and complex geometry capabilities but are relatively costly and require sophisticated post-processing.

2.5. Emerging Technologies

Recent developments include MultiJet Printing (MJP) and PolyJet systems, which deposit photopolymer droplets that are cured by UV light, enabling multi-material printing with high accuracy. These hold promise for advanced dental applications such as hybrid restorations and bioprinting in tissue engineering.

3. Materials Used in Restorative Dentistry

The advancement of three-dimensional (3D) printing technologies has been closely linked to the development of materials with properties suitable for restorative applications. The choice of material is critical, as it directly influences the mechanical performance, biocompatibility, esthetics, and long-term clinical success of restorations. Current 3D printing in dentistry primarily employs polymers, ceramics, and metals, each with distinct advantages and limitations.

3.1. Polymers and Resins

Photopolymer resins are the most widely used materials in restorative dentistry due to their compatibility with stereolithography (SLA) and digital light processing (DLP) systems. They are applied in the fabrication of temporary crowns and bridges, denture bases, occlusal splints, and custom trays. Advances in resin chemistry have led to improved mechanical properties, color stability, and biocompatibility. However, concerns remain regarding their long-term wear resistance, brittleness, and susceptibility to aging in the oral environment.

3.2. Ceramics and Hybrid Materials

Ceramic-based 3D printing is gaining increasing interest due to the superior esthetics, hardness, and chemical stability of these materials. Techniques such as stereolithography with ceramic slurries and binder jetting are being explored to produce crowns, veneers, and inlays with enhanced translucency and biocompatibility. Hybrid resin-ceramic composites have also been introduced, offering a balance between mechanical strength and printability. Limitations include complex processing steps, shrinkage during sintering, and the current lack of widespread clinical validation.

3.3. Metals

Metal additive manufacturing, primarily through selective laser melting (SLM) and selective laser sintering

Table 1: Comparison of 3D Printing Technologies in Restorative Dentistry

Technology	*Working principle*	*Materials used*	*Advantages*	*Limitations*	*Common dental applications*
SLA (Stereolithography)	UV laser cures resin point by point	Photopolymer resins	High accuracy, smooth surface, detailed structures	Limited materials, requires post-curing	Surgical guides, temporary crowns, resin patterns
DLP (Digital Light Processing)	Projector cures whole resin layer simultaneously	Photopolymer resins	Faster than SLA, good accuracy	Shrinkage issues, calibration-sensitive	Dental models, dentures, temporary restorations
FDM (Fused Deposition Modeling)	Extrudes thermoplastic filament layer by layer	Thermoplastics (PLA, ABS, biopolymers)	Low cost, simple workflow	Poor accuracy, rough surface, limited biocompatibility	Study models, custom trays, mock-ups
SLS/SLM (Selective Laser Sintering/Melting)	Laser sinters or melts powdered material	Metals (Co-Cr, Ti), polymers	High strength, complex geometries, durable	High cost, requires post-processing	Metal frameworks, implant parts, substructures
PolyJet/MJP (Emerging)	Inkjet head jets resin droplets cured by UV	Multiple resins, hybrid materials	Multi-material, high resolution, smooth finish	Expensive, limited availability	Hybrid restorations, prototypes, research

(SLS), enables the fabrication of high-strength restorations and frameworks. Commonly used alloys include cobalt-chromium (Co-Cr) and titanium, which are well established in prosthodontics for implant bars, removable partial denture frameworks, and substructures for fixed prostheses. These materials provide excellent strength and biocompatibility, but challenges such as surface roughness, post-processing requirements, and high equipment costs limit their broader use in routine restorative practice.

3.4. Biocompatibility and Regulatory Considerations

The suitability of 3D printing materials is closely tied to their safety in clinical use. Regulatory approval processes require rigorous evaluation of cytotoxicity, mechanical durability, and stability under intraoral conditions. While many resins and metals have been validated for temporary or permanent use, ongoing research is essential to ensure consistent performance and compliance with international standards.

In summary, the materials currently available for 3D printing in restorative dentistry demonstrate considerable potential, though each category presents unique benefits and limitations. Ongoing developments in resin chemistry, ceramic formulations, and metal processing are expected to broaden clinical applications and enhance restorative outcomes.

4. Accuracy and Fit of 3D Printed Restorations

The accuracy and fit of restorations are critical determinants of their clinical success, influencing longevity, esthetics, and patient comfort. In the context of 3D printing, accuracy refers to the degree of agreement between the printed object and the original digital design, while fit primarily concerns the marginal and internal adaptation of restorations.

Several factors affect the precision of 3D-printed dental restorations. Printer technology plays a decisive role: stereolithography (SLA) and digital light processing (DLP) generally produce higher-resolution outcomes compared with fused deposition modeling (FDM), owing to their finer layer thicknesses and superior surface quality. Selective laser sintering (SLS) and selective laser melting (SLM) are also employed for metal frameworks, providing robust mechanical properties with clinically acceptable fits.

Marginal fit remains a major focus in the literature, as inadequate adaptation can lead to microleakage, secondary caries, or periodontal complications. Studies consistently report that the marginal discrepancies of 3D-printed crowns, bridges, and provisional restorations fall within the clinically acceptable range of 50 - 120 μm, though variations exist depending on the material, printing orientation, and post-processing protocols. Internal fit is similarly influenced by these factors, with certain studies demonstrating results comparable to or better than conventional CAD/CAM milling techniques.

Post-processing, including washing, curing, and thermal treatment, significantly influences final accuracy. Over-curing or improper finishing can distort margins, while insufficient curing may compromise strength and dimensional stability. Additionally, design parameters such as cement space settings in CAD software can impact the adaptation of the printed restoration.

Although promising, challenges remain in achieving consistent accuracy across different systems. Variability between printers, resins, and laboratory workflows underscores the need for standardized protocols and quality assurance measures. Despite these limitations, current evidence supports the reliability of 3D printing for producing restorations with acceptable clinical accuracy, particularly in provisional and implant-supported applications.

5. CLINICAL APPLICATIONS

The integration of 3D printing into restorative dentistry has expanded the range of clinical applications, offering efficiency, precision, and customization in patient care. Its versatility spans from provisional to definitive restorations, as well as adjunctive devices that support treatment planning and execution (Table 2).

5.1. Provisional and Permanent Restorations

3D-printed resins are widely used for temporary crowns, bridges, and veneers, enabling rapid chairside fabrication with acceptable marginal adaptation and esthetics. Emerging high-performance resins and hybrid materials are being explored for permanent restorations, though long-term clinical evidence is still limited.

5.2. Implant-Supported Prostheses and Surgical Guides

Additive manufacturing has become an essential tool in implantology, facilitating the fabrication of accurate surgical guides and frameworks for implant-supported prostheses. These guides enhance surgical precision, reduce chair time, and improve patient outcomes.

5.3. Removable Prosthodontics

Custom denture bases, try-in dentures, and complete dentures can be fabricated using 3D printing. The digital workflow reduces the number of clinical visits, ensures reproducibility, and allows easy duplication of prostheses in case of loss or fracture.

5.4. Occlusal Devices and Splints

Occlusal splints, night guards, and orthodontic retainers can be manufactured with improved fit and comfort. 3D printing provides rapid turnaround and reduces the labor intensity of conventional fabrication techniques.

5.5. Auxiliary Tools

Customized impression trays, diagnostic models, and educational aids are additional areas where 3D printing streamlines clinical and laboratory workflows. These applications improve efficiency and support patient communication.

6. CHALLENGES AND LIMITATIONS

Despite the growing adoption of 3D printing in restorative dentistry, several challenges limit its widespread clinical application. One of the primary concerns relates to the mechanical strength and long-term durability of printed restorations. Many photopolymer-based resins exhibit reduced fracture resistance and wear properties compared with conventional ceramics or CAD/CAM-milled materials, raising questions about their suitability for definitive restorations.

Another limitation is the accuracy and reproducibility of printed prostheses. Factors such as printer resolution, material shrinkage, build orientation, and post-curing protocols significantly influence the marginal and internal fit of restorations. While some studies report clinically acceptable outcomes, variability across different technologies and manufacturers remains a concern.

Surface quality and esthetics also present challenges. Printed restorations often require extensive post-processing, including polishing and glazing, to achieve smooth

Table 2: Clinical Applications of 3D Printing in Restorative Dentistry

Application area	*Examples of 3D-Printed Devices/Restorations*	*Clinical advantages*
Provisional Restorations	Crowns, bridges, veneers	Rapid fabrication, acceptable esthetics, digital customization
Permanent Restorations	Hybrid resin-based crowns, inlays, onlays	Potential for high precision, ongoing material development
Implant Dentistry	Surgical guides, frameworks, abutments	Enhanced accuracy, improved surgical safety, predictable outcomes
Removable Prosthodontics	Denture bases, try-ins, complete dentures	Fewer appointments, reproducibility, cost-effectiveness
Occlusal Devices	Splints, night guards, retainers	Comfortable fit, fast turnaround, reduced manual labor
Auxiliary Tools	Custom trays, diagnostic models, teaching aids	Streamlined workflow, better patient education and communication

surfaces and natural optical properties. This not only increases chairside or laboratory time but may also affect dimensional stability.

From a practical standpoint, cost-effectiveness and workflow integration are critical barriers. Although printers have become more accessible, the initial investment, ongoing maintenance, and training requirements can be substantial, particularly for smaller practices. Moreover, differences in software compatibility and material availability may complicate adoption.

Finally, the field faces regulatory and standardization issues. A lack of universally accepted guidelines for evaluating 3D-printed dental materials and devices hampers direct comparison between studies and restricts large-scale clinical validation. Long-term clinical data remain limited, emphasizing the need for further research before routine use of 3D printing for permanent restorations can be recommended.

7. FUTURE PERSPECTIVES

The integration of 3D printing into restorative dentistry is expected to evolve further as technological innovations and material developments continue to emerge. Multi-material printing represents a key frontier, enabling the fabrication of restorations that combine esthetic surfaces with strong substructures in a single build process. Advances in ceramic and hybrid materials may provide improved mechanical strength, translucency, and biocompatibility, expanding indications for permanent restorations.

Another promising direction lies in the incorporation of bioactive and antibacterial materials, which could enhance the biological performance of restorations and reduce complications such as secondary caries. Parallel progress in printer resolution, software algorithms, and automated post-processing will improve accuracy, surface quality, and workflow efficiency.

The convergence of 3D printing with artificial intelligence and intraoral scanning technologies is anticipated to facilitate fully digital, chairside workflows, offering same-day fabrication of highly customized restorations. Standardization in testing protocols, regulatory frameworks, and long-term clinical data will be crucial to ensure reliability, safety, and widespread adoption.

Ultimately, the future of 3D printing in restorative dentistry is oriented toward achieving a balance of precision, durability, efficiency, and biological compatibility, with the potential to redefine patient-specific treatment approaches and transform clinical practice.

8. CONCLUSION

The process of restorative dentistry has integrated the 3D printing methodology in bridging the digital and clinical practices. The development of new technology in printers and material science has made it possible to produce accurate patient-specific restorations, including provisional crowns or implant frameworks and entire dentures. Recent sources show that 3D-printed restorations may be as accurate and clinically effective as other types and have an advantage in efficiency, customization, and integration of workflow. However, such issues like lack of long-term evidence, differences in material properties, and the necessity of standardized protocols continue to be obstacles to broad adoption. Further innovation in the field of multi-material systems, bioactive and biocompatible materials, and simplified chairside procedures promises to diversify the range of applications of 3D printing in restorative dentistry. In general, additive manufacturing is a revolutionary instrument that has a profound ability to improve clinical practice and patient-centered care.

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