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MATERIALS FOR 3D PRINTING IN PROSTHODONTICS: ADVANTAGES AND DISADVANTAGES

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ABSTRACT

Three-dimensional (3D) printing is a major innovation in digital prosthodontics, enabling the creation of accurate, customized dental restorations. The success of this technology relies heavily on the materials used, as their properties—physical, mechanical, biological, and aesthetic—directly impact how well they perform in the mouth. This paper looks at the three main types of materials currently used for 3D printing in prosthodontics: photopolymer resins, metal alloys (especially titanium and cobalt-chromium), and advanced ceramics like zirconia. We discuss their pros and cons regarding strength, biocompatibility, appearance, how easy they are to manufacture, and cost. Current findings suggest photopolymer resins are good for temporary restorations and diagnostic tools because they are accurate and quick to produce. On the other hand, metal alloys and ceramics are more durable and last longer clinically but need more advanced equipment, extra steps, and higher costs. Recent developments in material science, like ceramic-reinforced hybrid resins, are expected to broaden the use of additive manufacturing. As digital workflows continue to advance, 3D printing is becoming a standard part of prosthodontics, leading to more predictable treatments, increased efficiency, and better patient care.

KEYWORDS: 3D printing, prosthodontics, photopolymer resins, zirconia, biocompatibility.

INTRODUCTION

Digital technologies have rapidly transformed many areas of dentistry, with prosthodontics experiencing some of the most significant shifts. Traditional methods using impressions, stone models, wax patterns, and casting have been the standard for making dental prostheses. While still reliable, these methods are often labor-intensive, time-consuming, and heavily dependent on the skills of both the dentist and the dental technician. The increasing demand for more precision, faster production, and personalized treatment has led to the widespread adoption of digital workflows in prosthodontics today.[1]

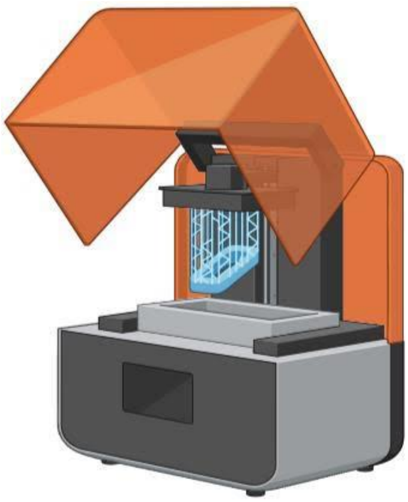
One of the most significant developments in digital dentistry is 3D printing, also known as additive manufacturing. Unlike traditional subtractive manufacturing, where restorations are milled from solid blocks, additive manufacturing builds an object layer by layer from a digital design. This method reduces material waste, allows for complex shapes, and creates restorations that closely match a patient's anatomy. As a result, 3D printing has become an increasingly valuable tool in prosthodontic treatment planning and laboratory production.[4] The combination of intraoral scanners, cone-beam computed tomography (CBCT), facial scanning, and CAD/CAM systems has further accelerated the use of additive manufacturing in daily clinical practice. Digital workflows now let clinicians design, modify, and produce restorations with a level of accuracy that was hard to achieve with older methods. Beyond improving precision, these technologies also improve communication between dentists and labs, reduce the number of appointments, and make patients more comfortable by eliminating many traditional impression procedures.[1,5] The clinical success of 3D printing, however, depends not only on the printing technology itself but also on the materials used. Significant advances in biomaterial science have led to a wide range of printable materials, including photopolymer resins, cobalt-chromium and titanium alloys, and advanced ceramics like zirconia. Each group has distinct physical, mechanical, biological, and aesthetic properties that determine its suitability for different clinical situations. While photopolymer resins are commonly used for diagnostic models, surgical guides, and temporary restorations due to their excellent accuracy and rapid production, metallic alloys and ceramic materials offer superior mechanical performance and long-term durability for permanent restorations.[6] Despite remarkable progress over the last decade, no single material meets all clinical needs. Each material has specific advantages and limitations concerning strength, aesthetics, wear resistance, biocompatibility, manufacturing complexity, or cost. Therefore, selecting the right material remains a critical decision in the digital workflow, directly impacting the longevity, biological safety, and overall success of prosthetic treatment. Understanding these characteristics helps clinicians and dental technicians choose materials based on individual clinical needs, rather than just what technology is available.[1] As additive manufacturing technologies continue to advance, research is focusing on developing new biomaterials that combine high mechanical strength with better aesthetics and biological compatibility. Ceramic-reinforced hybrid resins, printable zirconia, and bioactive materials show promise for expanding the clinical applications of 3D printing. These innovations are expected to improve the quality and durability of prosthetic restorations and support more personalized, efficient, and minimally invasive patient care.[8] For these reasons, understanding the properties of current 3D-printing materials is essential for prosthodontists in the era of digital dentistry. As technology progresses, material selection will continue to be a key factor in treatment outcomes, long-term performance, and patient satisfaction. This paper aims to provide a critical overview of the materials used in 3D printing for prosthodontic applications. It will focus on the advantages and disadvantages of photopolymer resins, metallic alloys, and advanced ceramic materials, emphasizing their mechanical properties, biocompatibility, aesthetic performance, clinical uses, and costs. Additionally, the paper will discuss the challenges of their clinical and lab use and highlight recent developments that may shape the future of additive manufacturing in prosthodontics. By comparing these materials, this review seeks to support evidence-based material selection and improve clinical decision-making in contemporary prosthodontic practice.

3D PRINTING TECHNOLOGIES IN DENTISTRY

The effectiveness of any 3D-printed prosthetic restoration depends on both the material selected and the manufacturing technology used. Different printing techniques use different methods to build an object, which affects accuracy, surface quality, mechanical properties, production time, and the overall clinical outcome. Although many additive manufacturing methods have been introduced over the past two decades, only a few have been widely accepted in dentistry because they provide the necessary precision for intraoral applications. Among the technologies currently used in prosthodontics, stereolithography (SLA), digital light processing (DLP), and selective laser melting (SLM) are the most common. Each technology has unique strengths and weaknesses, making it suitable for specific clinical situations rather than being a universal solution.

Stereolithography (SLA)

Stereolithography (SLA) was the first commercially available 3D-printing technology and is still considered one of the most precise additive manufacturing methods used in dentistry. The process works by selectively hardening a liquid photosensitive resin using a focused ultraviolet laser. As the laser cures each layer, the object is built up from the bottom until the complete restoration or model is produced. One of SLA printing's biggest advantages is its exceptional dimensional accuracy and excellent surface finish. These qualities make it especially suitable for applications where precision is critical, such as diagnostic casts, implant surgical guides, orthodontic models, and detailed anatomical replicas. The smooth surface produced by SLA often requires minimal finishing before clinical use, improving the fit and accuracy of the final restoration. Despite these benefits, SLA printing (Pict.1) is generally slower than some newer additive manufacturing technologies because the laser cures each layer point by point rather than hardening an entire layer at once. Consequently, production time increases with the complexity and size of the printed object. However, its outstanding precision continues to make SLA a preferred technology for applications where accuracy is more important than speed.[1,3]



Pict.1 Stereolithography (SLA)

Digital Light Processing (DLP)

Digital Light Processing (DLP) is similar to stereolithography as both technologies use liquid photopolymer resins. The main difference is how the resin is hardened. Instead of tracing individual points with a laser, DLP uses a digital projector to cure an entire layer of resin with a single flash of light. This significantly reduces printing time without sacrificing dimensional accuracy. Because every layer is cured simultaneously, the production time depends mainly on the object's height, not the number of restorations being printed. This means multiple prosthetic components can be made in the same printing cycle, making DLP particularly attractive for busy dental labs and clinics. Today, DLP (Pict.2) is widely used for making temporary crowns and bridges, complete denture bases, occlusal splints, custom impression trays, and surgical guides. Its combination of speed, precision, and relatively low operating costs has made it an important part of modern digital prosthodontics. However, like all resin-based technologies, thorough washing and post-curing are essential to ensure complete hardening and adequate biocompatibility of the printed restorations.[2,4,5]

Pict. 2: Digital Light Processing.

Selective Laser Melting (SLM)

Unlike SLA and DLP, which use liquid resins, Selective Laser Melting (SLM) is designed specifically for manufacturing metal restorations. In this process, a high-powered laser selectively melts thin layers of metal powder according to a digital design. Successive layers fuse together until the final restoration is completed. SLM has fundamentally changed the production of metal frameworks in prosthodontics. The technology allows direct fabrication of cobalt-chromium and titanium restorations without the need for traditional wax patterns, investing, or casting. This digital workflow reduces many inaccuracies associated with traditional lab procedures while producing restorations with excellent density, mechanical strength, and dimensional stability. Metal restorations made with SLM (Pict.3) are commonly used for implant-supported prostheses, custom implant abutments, fixed partial denture frameworks, removable partial denture frameworks, and other restorations that need to withstand high functional loads. Titanium, in particular, is highly valued for its excellent corrosion resistance, superior biocompatibility, and ability to integrate successfully with surrounding tissues. Despite these advantages, SLM remains one of the most expensive additive manufacturing technologies. The equipment requires a substantial financial investment, specialized maintenance, controlled operating conditions, and trained staff. Furthermore, printed metal restorations need additional post-processing, including support removal, heat treatment, polishing, and surface finishing, before they are ready for clinical use. These factors continue to limit the widespread availability of SLM technology, especially in smaller dental labs.[6,8]

Pict. 3: Selective Laser Melting – SLM.

Choosing the Appropriate Technology

No single printing technology is ideal for every clinical situation. The choice depends on several factors, including the material being processed, the intended clinical application, the required accuracy, production time, and cost. SLA remains the preferred option for highly detailed models and surgical guides due to its outstanding precision. DLP offers a good balance between speed and accuracy, making it the technology of choice for routine resin-based prosthetic applications. SLM, while significantly more expensive, provides unmatched mechanical performance for metallic restorations and plays an essential role in advanced prosthodontic treatment. As digital manufacturing continues to evolve, improvements in printing hardware, software, and biomaterials are expected to increase production efficiency and expand the range of clinical applications for additive manufacturing in dentistry. Rather than completely replacing conventional manufacturing, these technologies are increasingly being integrated into comprehensive digital workflows that combine precision, efficiency, and personalized patient care.

ANALYSIS OF MATERIALS USED FOR 3D PRINTING IN PROSTHODONTICS

Selecting the right material is one of the most important steps in the digital workflow because it directly affects the quality, longevity, biological safety, and aesthetic outcome of the final prosthetic restoration. While advances in 3D-printing technologies have significantly expanded possibilities in digital dentistry, treatment success still largely depends on choosing a material that meets the specific clinical requirements of each case. No single material is ideal for every indication, and each has distinct physical, mechanical, and biological characteristics that determine its clinical performance. Currently, materials used for additive manufacturing in prosthodontics can generally be divided into three major groups: photopolymer resins, metallic alloys, and advanced ceramic materials. Each group has unique advantages and limitations that should be carefully considered during treatment planning.

PHOTOPOLYMER RESINS

Photopolymer resins are currently the most commonly used materials in dental 3D printing because they are compatible with both stereolithography (SLA) and digital light processing (DLP) technologies. Their relatively low cost, ease of processing, and excellent printing accuracy have made them indispensable in everyday prosthodontic practice. Depending on their chemical composition and certification, these materials may be intended for short-term intraoral use or for manufacturing laboratory devices. Today, photopolymer resins are routinely used for producing diagnostic casts, surgical guides, temporary crowns and bridges, complete denture bases, custom impression trays, occlusal splints, and various auxiliary prosthetic appliances. Their versatility has significantly contributed to the widespread adoption of digital workflows in dental laboratories and clinical practice.

ADVANTAGES

Excellent Dimensional Accuracy

One of the biggest strengths of photopolymer resins is their ability to reproduce fine anatomical details with remarkable precision. High printing accuracy allows restorations and dental models to fit closely to the digital design, reducing discrepancies that might otherwise require chairside adjustments. This precision is especially important when manufacturing implant surgical guides and provisional restorations, where even small inaccuracies can affect treatment outcomes.[1,2]

Rapid Manufacturing

Compared to conventional laboratory procedures, resin-based 3D printing significantly reduces production time. Temporary restorations, study models, or surgical guides can often be fabricated within a single working session, allowing clinicians to provide treatment more efficiently while reducing lab workload. Faster production also improves communication between clinicians and technicians, especially when modifications are needed during treatment.[3]

Favorable Esthetics

Modern dental resins are available in multiple shades that closely match natural tooth color. This makes them suitable for provisional restorations, allowing patients to maintain an acceptable appearance while awaiting definitive prostheses. Their smooth surface finish also contributes to good aesthetic results immediately after printing and polishing.

Cost-Effectiveness

Photopolymer resins are among the most economical materials available for digital dentistry. Both the material itself and the associated printing equipment are considerably less expensive than systems designed for metal or ceramic printing. As a result, resin printing has become accessible not only to large dental laboratories but also to many private dental clinics.

DISADVANTAGES

Limited Mechanical Performance

Despite continuous improvements, photopolymer resins still have lower fracture resistance and wear resistance than metals or ceramics. Their mechanical properties are generally sufficient for temporary restorations but are inadequate for restorations that must withstand long-term occlusal loading. Patients with severe bruxism or heavy biting forces may experience premature wear or fracture of resin restorations.[4]

Color Instability

Long-term aesthetic stability is another limitation. Resin materials tend to absorb pigments from drinks like coffee, tea, and red wine, as well as from tobacco smoke. As a result, discoloration may gradually develop over prolonged intraoral use, affecting the appearance of provisional restorations.

Polymerization-Related Concerns

Successful clinical performance greatly depends on proper post-processing. Inadequate washing or insufficient ultraviolet post-curing can leave residual monomers within the printed restoration. These substances have been linked to local tissue irritation, allergic reactions, and cytotoxic effects. Strict adherence to manufacturers' recommendations for cleaning and post-curing is therefore essential before placing printed restorations in the mouth.[5]

METALS AND ALLOYS

Metal additive manufacturing has become increasingly important in prosthodontics because it allows for the direct fabrication of strong and highly accurate restorations without relying on traditional casting methods. The most frequently used materials are cobalt-chromium alloys and commercially pure titanium, both of which have excellent mechanical properties and long-term clinical reliability. Unlike resin printing, metallic restorations are produced using Selective Laser Melting (SLM), where successive layers of metal powder are fused by a high-energy laser. This process allows complex prosthetic frameworks to be manufactured directly from digital files while minimizing many of the inaccuracies associated with traditional laboratory techniques. Common clinical uses include fixed partial denture frameworks, implant-supported prostheses, custom implant abutments, removable partial denture frameworks, and various retention components.

ADVANTAGES

Outstanding Mechanical Strength

Metal restorations produced via SLM show excellent resistance to fracture, deformation, and cyclic loading. Their ability to withstand high occlusal forces makes them particularly suitable for posterior restorations and extensive implant-supported reconstructions.

Excellent Biocompatibility

Titanium is one of the most biocompatible materials available in dentistry. It has exceptional corrosion resistance, excellent tissue compatibility, and a remarkable ability to integrate with surrounding bone. Allergic reactions are extremely rare, making titanium an excellent choice for implant-supported prosthetic treatment.

Efficient Material Utilization

Compared to subtractive manufacturing techniques, additive manufacturing significantly reduces material waste. Only the amount of powder needed to fabricate the restoration is used, improving production efficiency and lowering unnecessary material loss.

DISADVANTAGES

High Financial Investment

Although SLM offers remarkable manufacturing precision, the technology requires expensive equipment, specialized facilities, regular maintenance, and trained personnel. These factors continue to limit its availability, especially in smaller dental laboratories.

Complex Post Processing

Printing is only one stage of manufacturing. After fabrication, restorations need support removal, stress-relieving heat treatment, surface finishing, polishing, and quality control before clinical delivery. These additional procedures increase production time and overall cost.

Limited Esthetics

Metal frameworks lack the natural translucency needed for highly aesthetic restorations. Therefore, cobalt-chromium and titanium frameworks typically require ceramic layering when used in visible areas of the mouth.

ADVANCED CERAMIC MATERIALS (ZIRCONIA)

Ceramic materials have long been considered the gold standard for highly aesthetic prosthetic restorations. For many years, zirconia restorations were made almost exclusively using CAD/CAM milling systems. More recently, however, advances in additive manufacturing have made it possible to fabricate ceramic restorations through 3D printing, opening new opportunities for digital prosthodontics. While ceramic printing hasn't become as widespread as resin printing, continuous improvements in printing accuracy and material formulations suggest considerable potential for future clinical use. Unlike photopolymer resins, ceramic restorations are produced from highly concentrated ceramic suspensions or pastes that undergo a complex manufacturing process. After printing, the restoration is dried and sintered at very high temperatures, allowing the ceramic particles to fuse into a dense and mechanically stable structure. This extra step is essential to achieve the strength and durability required for permanent prosthetic restorations. Currently, zirconia remains the ceramic material most extensively studied for additive manufacturing due to its outstanding mechanical properties, excellent biological behavior, and highly favorable aesthetic characteristics. It is increasingly used for permanent crowns, fixed partial dentures, veneers, inlays, and onlays, particularly where superior aesthetics and long-term clinical performance are needed.

ADVANTAGES

Superior Esthetic Performance

One of zirconia's greatest advantages is its ability to closely mimic the optical properties of natural teeth. Modern generations of zirconia show improved translucency while maintaining high strength, allowing restorations to blend seamlessly with adjacent teeth. These optical improvements have significantly expanded the uses for zirconia in the anterior aesthetic zone, where appearance is often as important as function.[1,2]

Excellent Biocompatibility

Ceramic materials have excellent tissue compatibility and are considered biologically inert. Their smooth surface discourages bacterial plaque buildup, which contributes to healthier periodontal tissues and reduces the risk of inflammatory complications around prosthetic restorations. Unlike certain metal materials, zirconia does not corrode in the oral environment and has a very low potential for allergic reactions, making it suitable for patients with metal sensitivities.[3]

High Mechanical Strength

Although ceramics have traditionally been associated with brittleness, modern yttria-stabilized zirconia exhibits exceptional fracture resistance and flexural strength. These properties enable zirconia restorations to withstand considerable functional loading while maintaining long-term structural stability. Continuous improvements in microstructure and manufacturing techniques have further enhanced the reliability of zirconia for both single-unit and multi-unit restorations.[4]

Improved Material Gradients

Recent developments have led to the introduction of multilayer zirconia materials with gradual changes in translucency, color, and mechanical properties throughout the restoration. These gradient materials more closely resemble the natural structure of enamel and dentin, improving aesthetics without compromising strength. Such innovations represent an important step toward more lifelike prosthetic restorations.

DISADVANTAGES

Fragility Before Sintering

A major challenge with ceramic printing occurs before the sintering process. During this stage, known as the green state, printed zirconia has very limited mechanical strength and can easily fracture or deform if handled improperly. Careful handling throughout the manufacturing process is therefore essential to prevent damage before final densification.[2]

Shrinkage During Sintering

A characteristic feature of zirconia is the significant dimensional shrinkage that occurs during sintering. Depending on the material, shrinkage can be about 20–25%, requiring sophisticated compensation algorithms within CAD software. Accurate prediction of this contraction is essential to ensure that the final restoration fits precisely after sintering. Even small inaccuracies in compensation can compromise marginal adaptation and overall clinical success.[5]

Technological Complexity

While remarkable progress has been made, ceramic additive manufacturing remains more technically demanding than resin printing and, in many cases, conventional milling. Specialized equipment, carefully controlled processing conditions, and long sintering cycles contribute to increased manufacturing time and higher production costs. Consequently, ceramic printing has not yet become routine in many dental laboratories.

COMPARATIVE ANALYSIS OF 3D-PRINTING MATERIALS

Choosing the most appropriate material involves balancing several factors rather than focusing on just one property. Mechanical strength, aesthetics, biological compatibility, manufacturing complexity, production time, and cost all influence the final decision. Since each material has a unique combination of advantages and limitations, the best choice depends on the clinical situation and the functional demands on the restoration. Photopolymer resins remain the preferred option for diagnostic models, surgical guides, and temporary restorations because they offer high printing accuracy, rapid production, and relatively low cost. Their excellent dimensional precision makes them particularly useful during treatment planning and temporary rehabilitation. However, their limited mechanical strength restricts their use in long-term restorative applications. Metallic materials, especially titanium and cobalt-chromium alloys, continue to provide the highest level of mechanical reliability. Their ability to withstand substantial functional loads makes them essential for implant-supported prostheses, extensive fixed restorations, and removable partial denture frameworks. Nevertheless, the high cost of manufacturing equipment and the need for extensive post-processing remain significant drawbacks that limit widespread adoption. Advanced ceramics, especially zirconia, offer the best balance between aesthetics and biological compatibility. Their natural appearance, excellent tissue response, and long-term durability make them the preferred material for permanent restorations in both anterior and posterior regions. Despite these benefits, ceramic printing continues to present technical challenges related to sintering shrinkage, manufacturing complexity, and higher production costs. Rather than competing with each other, these materials should be seen as complementary components of modern digital dentistry. Each material serves a distinct clinical purpose, and successful treatment depends on selecting the one that best meets the functional, biological, and aesthetic requirements of the individual patient. As additive manufacturing technologies continue to mature, future biomaterials may combine the favorable characteristics of current polymers, metals, and ceramics, offering restorations that are simultaneously strong, aesthetic, biologically compatible, and economically accessible.

DISCUSSION

The rapid development of digital dentistry has fundamentally changed the principles of modern prosthodontic practice, shifting clinical workflows from traditional, manual procedures to integrated digital systems. Current literature shows considerable advantages of digital technologies in terms of accuracy, efficiency, patient comfort, and treatment predictability. However, interpreting these findings requires a balanced perspective, as the available evidence includes both promising clinical outcomes and significant limitations regarding long-term validation, cost-effectiveness, and technological dependency. Several authors have reported that digital workflows using intraoral scanning and CAD/CAM technologies provide accuracy comparable to, and in some clinical situations superior to, conventional impression techniques. These findings are particularly relevant for single-unit restorations and short-span fixed prosthodontics, where digital impressions have demonstrated high trueness and precision. Eliminating impression materials, reducing the risk of dimensional distortion, and immediate visualization of scanned structures offer important clinical benefits. Conversely, some studies suggest that the accuracy of digital impressions may decrease in more complex situations, especially in full-arch rehabilitations, extensive implant-supported restorations, and cases with challenging soft tissue conditions. These differences indicate that the effectiveness of digital scanning is strongly influenced by clinical complexity, scanner technology, operator experience, and scanning protocols. Current evidence suggests that intraoral scanners have significantly improved patient acceptance compared to conventional impression procedures. Many patients experience less discomfort, reduced gag reflex stimulation, and greater confidence with digital procedures. This is especially important for elderly patients and those needing extensive prosthodontic rehabilitation. However, improved patient experience does not automatically guarantee better clinical outcomes. The clinician's ability to interpret digital data, manage occlusal relationships, and consider biological factors remains essential. Digital technology should therefore be viewed as an advanced diagnostic and manufacturing tool, not a replacement for clinical expertise. The literature on subtractive and additive manufacturing shows an ongoing transition in dental production methods. Several authors have reported that subtractive CAD/CAM milling provides highly predictable restorations due to the use of industrially manufactured materials with controlled mechanical properties. Materials like zirconia and lithium disilicate continue to be the standard for many definitive prosthetic applications because of their strength, durability, and well-established clinical performance. In contrast, additive manufacturing offers unique advantages, including reduced material consumption, greater design flexibility, and the ability to produce complex structures that are difficult to achieve with traditional milling. Nevertheless, additive manufacturing is still an evolving technology. While laboratory studies have shown promising accuracy and surface characteristics, long-term clinical evidence on the durability and biological performance of 3D-printed definitive restorations is still limited. Concerns remain regarding material aging, mechanical resistance, polymerization stability, surface treatment protocols, and long-term intraoral behavior. Therefore, while additive manufacturing represents a major step toward sustainable and personalized dentistry, further prospective clinical studies are needed before it can fully replace established manufacturing techniques. The comparison between digital and conventional workflows also highlights important differences regarding sustainability. Several authors have emphasized that digital dentistry can contribute to environmentally responsible dental practice by reducing impression materials, gypsum models, laboratory transportation, and unnecessary material consumption. Additive manufacturing, in particular, has been recognized for its ability to optimize material use by depositing only the required amount during fabrication. In contrast, traditional subtractive manufacturing generates considerable waste because a restoration is made by removing material from prefabricated blocks. However, sustainability in dentistry is complex, and the environmental impact of digital technologies should not be assessed solely by material waste. Energy consumption of digital equipment, production of electronic devices, software requirements, and disposal of technological components must also be considered. The role of artificial intelligence (AI) is another significant development within digital prosthodontics. Several authors have reported that AI-based systems can improve diagnostic accuracy, automate repetitive tasks, and assist clinicians in treatment planning and restoration design. AI-supported applications show potential in tooth recognition, segmentation of digital models, aesthetic analysis, and prediction of treatment outcomes. Conversely, concerns have been raised regarding algorithm transparency, validation across different populations, data security, and the risk of over-reliance on automated recommendations. Current evidence suggests that AI should function as a supportive clinical assistant rather than an autonomous decision-maker. Human expertise remains crucial, especially in complex cases requiring individualized judgment and consideration of patient expectations. The integration of multiple digital technologies, including intraoral scanners, CBCT, facial scanning, virtual articulation, and AI, has led to the development of comprehensive digital workflows. Several authors have reported improved communication between clinicians, technicians, and patients through digital visualization and virtual treatment planning. These approaches can enhance patient understanding and facilitate shared decision-making. However, implementing fully digital workflows remains challenging in many clinical settings due to high initial costs, the need for specialized training, and differences in technological accessibility across healthcare systems. Another important consideration is education and professional adaptation. Current evidence suggests that digital dentistry requires a new approach to dental training, where future clinicians must develop not only traditional clinical skills but also digital literacy. Dental professionals need to understand software limitations, scanning principles, manufacturing technologies, and data management. Without adequate education, technology adoption may increase the risk of workflow errors rather than improve treatment outcomes. Therefore, digital dentistry should be incorporated into undergraduate and postgraduate dental curricula in a structured and evidence-based manner. Despite significant progress in digital prosthodontics, several questions remain unanswered. Long-term clinical evidence is still limited, especially regarding the survival of digitally manufactured restorations over extended periods, the biological response to new materials, and the cost-effectiveness of complete digital workflows. Many available studies are laboratory-based or involve relatively short follow-up periods, making direct comparison with conventional techniques difficult. Future research should focus on well-designed randomized clinical trials, multicenter investigations, and long-term observational studies to provide stronger evidence on clinical effectiveness. Furthermore, future developments should not only focus on technological advancement but also on responsible integration into clinical practice. The most successful approach will likely involve combining digital innovation with established prosthodontic principles rather than replacing conventional knowledge. Digital tools can improve accuracy and efficiency, but successful treatment continues to depend on proper diagnosis, treatment planning, material selection, and an understanding of biological factors. Overall, current evidence indicates that digital dentistry is a major advancement in prosthodontics, offering significant benefits in precision, workflow optimization, patient experience, and sustainability. However, the enthusiasm surrounding digital transformation must be balanced with a critical evaluation of limitations and unanswered questions. The future of digital prosthodontics will depend on continuous scientific validation, ethical implementation of artificial intelligence, environmental responsibility, and the ability of dental professionals to integrate technological innovation with clinical expertise.

CONCLUSION

Three-dimensional (3D) printing has become one of the most influential innovations in contemporary prosthodontics, fundamentally changing how prosthetic restorations are designed and manufactured. By combining digital technologies with advanced biomaterials, additive manufacturing has created new opportunities for producing restorations that are more accurate, personalized, and efficient than those made with many conventional techniques. As digital workflows continue to expand, 3D printing is becoming an increasingly important part of everyday prosthodontic practice, rather than just an emerging technology. This review shows that the clinical success of additive manufacturing largely depends on selecting the right printing material for each specific use. Photopolymer resins remain essential for diagnostic models, surgical guides, temporary crowns, and other provisional restorations because they offer excellent dimensional accuracy, rapid production, and relatively low manufacturing costs. However, their limited mechanical strength, susceptibility to discoloration, and need for complete polymerization restrict their long-term clinical application. Metallic materials, especially cobalt-chromium alloys and titanium, continue to play an essential role in prosthodontics due to their outstanding mechanical properties, durability, and excellent biocompatibility. Additive manufacturing has simplified the production of complex metal frameworks while reducing many of the inaccuracies associated with traditional casting methods. However, the significant cost of printing equipment, along with the need for specialized post-processing, still limits widespread use in smaller labs. Among currently available printable materials, zirconia is the most promising option for definitive aesthetic restorations. Its excellent translucency, favorable biological response, and high fracture resistance have made it a preferred restorative material in modern prosthodontics. Although ceramic additive manufacturing still faces challenges related to sintering, dimensional stability, and manufacturing complexity, ongoing technological developments are expected to improve both accuracy and clinical predictability in the near future. A key finding from current literature is that no single material can meet every clinical requirement. Material selection should therefore be guided by the intended clinical application, functional demands, aesthetic expectations, patient-specific factors, and the available manufacturing technology. A thorough understanding of the properties, advantages, and limitations of each material allows clinicians and dental technicians to make informed decisions that ultimately improve the quality and longevity of prosthetic treatment. The future of additive manufacturing appears highly promising. Continuous advances in biomaterial science, artificial intelligence, digital workflow integration, and printing technologies are expected to further expand the uses for 3D printing in prosthodontics. The development of ceramic-reinforced hybrid materials, bioactive printable polymers, smart materials, and bioprinting technologies may eventually overcome many of today's limitations. Such innovations have the potential not only to improve restorative procedures but also to support regenerative approaches that could transform the future of oral rehabilitation. In conclusion, additive manufacturing should not be seen as a replacement for conventional prosthodontic techniques but rather as a complementary technology that broadens therapeutic possibilities and supports more personalized patient care. As clinical evidence continues to grow and new materials become available, 3D printing is expected to play an increasingly central role in prosthodontics, contributing to more predictable treatment outcomes, improved patient satisfaction, and higher standards of oral healthcare.

FINAL REMARKS AND RECOMMENDATION

Although significant progress has been made in dental 3D printing, more long-term clinical studies are still needed to evaluate the durability, biological safety, and cost-effectiveness of newly developed printable materials. Establishing internationally accepted standards for material testing, manufacturing protocols, and quality assurance will be crucial for ensuring consistent clinical performance and facilitating broader adoption of additive manufacturing in everyday dental practice. Future research should also focus on optimizing ceramic printing technologies, improving the mechanical properties of printable polymers, and exploring the clinical potential of hybrid biomaterials and regenerative printing techniques. These developments are expected to further strengthen the role of digital dentistry and contribute to safer, more efficient, and increasingly patient-centered prosthodontic care.

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