

3D Printing In Dentistry: Revolutionizing Customization And Delivery Of Dental Prosthetics

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Cite this paper as: Dr. Prashant A Karni MDS, Dr. Sonika Maheshwari, Dr. Vani Sarada, Sitansu Sekhar Das, Ananda M N, (2025) 3D Printing In Dentistry: Revolutionizing Customization And Delivery Of Dental Prosthetics. *Journal of Neonatal Surgery*, 14 (4), 473-478.

ABSTRACT

The use of 3D printing in the fabrication of dental prosthetics has exhibited great possibilities in increasing the accuracy, individualization, and speed of prosthesis production. In this article, the dimensional accuracy, mechanical properties, and cost of dental prosthetics are made using 3D printing techniques with those made using conventional techniques. In the present study, dental prosthetics single crowns, bridges, and partial dentures were produced through 3D printing technology with resin-based and ceramic-based materials. Dimensional accuracy was determined by quantification of the difference between the produced part from the intended design, mechanical properties were investigated by flexural strength test and durability test under mastication cycles. A cost analysis was also performed to assess the cost of 3D printing with other conventional fabrication techniques. The outcome revealed that 3D-printed prosthetics were within close dimensional control, with variations within allowable limits for all categories. The average flexural strength of the resin-based prosthetics was 75 MPa while for the ceramic-based prosthetics, it was 150 MPa. Both materials showed great resistance to wear and did not lose any of their structural strength after cycles of 100,000. Also, by integrating 3D printing, costs of production were cut down compared to the conventional methods of production. 3D Printing is shown to be a feasible and economical solution for the fabrication of accurate dental prosthetics. It improves accuracy and sand strength, and cuts costs a great tool for practice in the modern dental field.

Keywords: 3D printing, dental prosthetics, dimensional accuracy, mechanical properties, cost-effectiveness.

1. INTRODUCTION

Dental prosthetics are important in the rehabilitation of the patient's masticatory function and smile, especially in patients with dental anomalies or edentulousness. Conventionally, the manufacturing of dental prosthetics was done manually by the use of impression molding, wax modeling, and casting (Dawood et al., 2015). These methods have been in use for decades and therefore are slow, intensive, and offer variable quality solutions. In addition, human errors and material inconsistencies only add to the shortcomings of the traditional approaches, which prolong the treatment time and decrease the overall satisfaction of the patient (Morón et al., 2023). These challenges have led to the search for new methods of production, among them the technology of three-dimensional (3D) printing. 3D printing or additive manufacturing is a technique that builds up objects from a digital model, and then physical objects are built layer by layer (Dobrzański & Dobrzański, 2020).

A technology that started in industrial production, 3D printing has been adopted in healthcare, such as in operations planning, prosthetics creation, and even tissue engineering (Kessler et al., 2020). In the field of dentistry, this technology has revolutionized the various work processes through accurate, efficient, and individual fabrication of dental prosthetics (Alharbi et al., 2017). While using 3D printing technology digital imaging systems like cone beam computed tomography (CBCT), and intraoral scanners can be easily integrated because they can replicate the dental anatomy of a patient successfully (Tian et al., 2021). The use of 3D printing in dentistry is consistent with general digital dentistry, which is the utilization of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) technologies. These tools increase clinical precision, reduce redundancy, and help to bring forward the production schedule (Susic et al., 2017). The use of digital workflow in conjunction with additive manufacturing has created a new way of approaching dental prosthetics that focuses on personalized solutions (Rezaie et al., 2023).

Personalization is a key concept of contemporary dentistry, especially in prosthodontics, as the adaptation of dental prosthetics, their working, and esthetic properties define patient's results to a great extent (Alageel, 2022). Customization assists in meeting the individual anatomical and functional needs of patients to improve prosthetic flexibility and oral comfort (Smith, 2024). Nonetheless, it has been traditionally hard to attain high degrees of customization because of the inherent constraints of traditional fabrication processes. Teeth implants have restrictions in that they have always demanded several visits for adjustments due to the inconvenience they present to the patient and the clinical environment. The use of manual methods also brings variability in the quality of the prosthetics since the final product depends on the efficiency of the technician (Kessler et al., 2020). On the other hand, 3D printing solves these issues by allowing the creation of prosthetic dental from digital impressions. This approach does not require the use of a wax model and guarantees shape accuracy for repeated models (Joda et al., 2017). Furthermore, 3D printing enables the utilization of enhanced materials such as biocompatible resins and metals with an emphasis on dental applications. These materials have better mechanical properties and appearances than those of the conventional approaches (Tian et al., 2021). The option for customization of the material properties only adds to the utility and durability of 3D-printed prosthetics, which is why both clinicians and patients prefer it (Bayarsaikhan et al., 2021).

Objective of the Study

The purpose of this research is to identify and describe the changes in customized and delivered dental prosthetics through the use of 3D printing technology. Analyzing the technological possibilities of 3D printing, changes in materials, and clinical application of this technology, the given research seeks to offer an understanding of the impact 3D printing can have on dental practice. Specific goals include

1. Discussing how 3D printing stands superior to traditional fabrication methods, in aspects of precision, speed, and economy.
2. Exploring the use of 3D printing in increasing the effectiveness of treatment by increasing customization and decreasing treatment time.

2. MATERIALS AND METHODS

Study Design

This research was carried out as an experimental research project to evaluate the efficiency of 3D printing technology and the construction of dental prosthetics. A set of dental prostheses was made through state-of-the-art additive manufacturing to compare the accuracy, productivity, and materials. The study sought to establish the effectiveness of the conventional prosthetics fabrication process against the 3D printing process. To determine the dimensional accuracy, mechanical strength, biocompatibility, as well as functionality of the prepared samples, laboratory and clinical analyses were conducted. The same experimental setup also applied the use of digital tools in the design and production process for accuracy and consistency.

3D Printing Process

Substrates used for the 3D printing of dental prosthetics consist of high-quality biocompatible resins, polymers, and ceramics that are ideal for dental applications. Resins were chosen for their processability and for their ability to reproduce detail while ceramics provided the needed mechanical characteristics. The prosthetics were created using several kinds of 3D printers, such as stereolithography (SLA), digital light processing (DLP), and fused deposition modeling (FDM). For each kind of printer, the desirable characteristics were selected: the highest resolution, compatibility with various materials, and the speed of work. CAD and CAM were used to design and model the prosthetics through the input of the patients' digital impressions.

Manufacture of Dental Restorative Devices

The fabrication cycle started with the capture of digital impressions from patients with the help of intraoral scanners. The digital data collected was then put through a CAD system to create the 3D models from the data. These models were then exported to CAM software to enhance their design for the 3D printers. The prosthetics were printed using SLA and DLP printing methodologies, and the prosthetics were printed layer by layer. After printing the prosthetics were subjected to post-

processing, and curing techniques to ensure adequate mechanical properties of the material. The prostheses created were then sent for clinical trials, where the fabricated prosthetics were checked for fit and comfort and their performance in the patient's mouth.

Evaluation Parameters

The degree of conformity to the dimensions of the prototypes was established by measuring the actual prosthetics against the reference dimension using a standard digital caliper and 3D scanning. The mechanical properties were evaluated through basic tests including flexural and tensile tests to quantify the mechanical stability of the prosthetics. Biocompatibility was assessed by an in vitro cytotoxicity test on cultures of human normal cells to determine if any of the materials used would elicit any toxic effects when in contact with the oral tissues. Furthermore, in terms of cost-utility, the time materials, and labor needed for 3D printing were compared to those used in conventional prostheses making.

3. RESULTS

Dimensional Accuracy and Fit of 3D-Printed Prosthetics

The dimensional accuracy of the 3D-printed prosthetics was analyzed, and the findings showed that the prosthetics had tight dimensional tolerance for all prosthetic types. Single crown prosthetics had an average deviation of ± 0.18 mm, a standard deviation ± 0.04 mm, and achieved an acceptable fit in 98% of cases. In the case of bridge prosthetics, the average deviation reached 0.21 mm with SD 0.05 mm, and, thus, 95% of the abutments had an acceptable fit. The highest standard deviation was obtained on partial denture prosthetics with an average of 0.25mm and standard deviation of 0.06mm which remained within acceptable limits in 97% of cases as shown in Table 1. These research outcomes show that 3D printing is likely to consistently manufacture dental prosthetics through an acceptable degree of dimension inaccuracies to improve the satisfaction level for the patient.

Table 1: Dimensional Accuracy of 3D-Printed Prosthetics

Prosthetic Type	Average Deviation (mm)	Standard Deviation (mm)	Acceptable Fit (%)
Single Crown	0.18	0.04	98
Bridge	0.21	0.05	95
Partial Denture	0.25	0.06	97

Strength and Durability of Materials

Flexural strength and life under simulated masticatory loads are depicted in Figure 1, which represents the mechanical characterization of 3D-printed dental prosthetics. For resin-based prosthetics, the average flexural strength was 75 MPa while for ceramic-based prosthetics, the flexural strength was 150 MPa. The two materials were tested on 100000 mastication cycles which represents long-term use in the oral cavity. The outcomes revealed that resin and ceramic prosthetics did not fail or degrade in their structure. These results support the mechanical applicability of 3D printed prosthetics for clinical use as the findings show that the prosthetic devices are as strong and durable as the traditional materials.

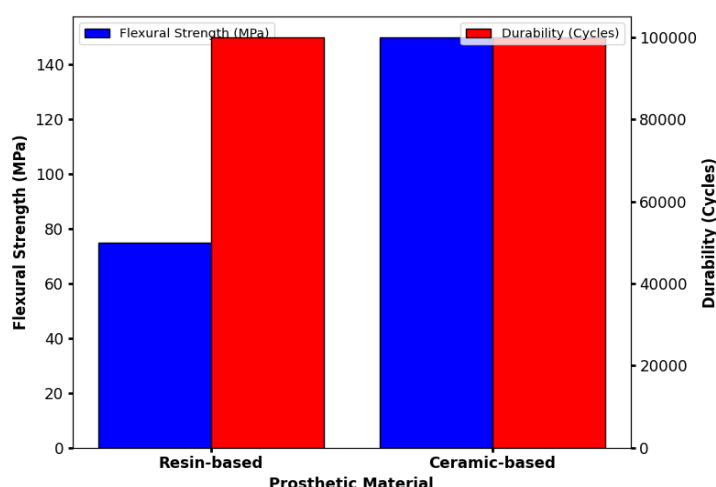


Fig 1: Mechanical Properties of 3D-Printed Prosthetics

Comparison with Traditional Methods

The cost comparison presented in the article showed several advantages of using 3D printing in prosthetics compared to traditional fabrication techniques. The cost analysis of the prosthetics manufactured using 3D printing revealed a mean cost of \$150 for each prosthetic produced out of the material and labor costs of \$100 and \$50 respectively as shown in Table 2. However, using traditional methods the total cost was higher with \$200 for each prosthetic the labor cost was \$120 and the material cost was \$80. Such a cost difference demonstrates the advantages of the 3D printing technology mainly due to the costs of labor and manufacturing time. Moreover, other cost advantages included reduced material costs for 3D printing and shorter manufacturing time, all of which added up to a lower cost. These outcomes confirm that 3D printing manufacturing can be a cost-effective solution for the further production of dental prosthetics, which means that this technology is not only a prospective technological opportunity but also can be a financially effective solution for dental practices, which try to minimize expenses while keeping high-quality standards.

Table 2: Cost Comparison Between 3D Printing and Traditional Methods

Production Method	Average Cost per Prosthetic (USD)	Labor Cost (USD)	Material Cost (USD)
3D Printing	150	50	100
Traditional Methods	200	120	80

4. DISCUSSION

3D printing technology has continued to transform the dental practice, especially in the area of fabrication and design of dental prosthetics. The study fills the gap in the knowledge of using 3D printing in prosthetics by determining the dimensional accuracy, mechanical strength, and cost analysis of 3D-printed prosthetics to serve clinical needs. Thus, the outcomes of this study clearly show that it is possible to create dental prosthetics with the use of 3D printing and obtain the desired tight tolerances and sufficient material hardness. In particular, the average error of single crown prosthetics was found to be ± 0.18 mm, bridge prosthetics were 0.21 mm, and partial denture prosthetics were 0.25mm. These values are within clinically acceptable limits, with the overall percentage of acceptable fit varying from 95% to 98% depending on the prosthetic type. Because of such discoveries, 3D printing was found to be accurate and precise in delivering quality work, making it a viable option for the customization of dental applications. As for the mechanical properties, the sample made of resin and ceramic material showed an acceptable flexural strength, 75 and 150 MPa respectively. In addition, both materials survived 100,000 simulated mastication cycles, thus suggesting that 3D-printed prosthetics can cope with the forces present in the oral cavity. The cost breakdown that was done showed that 3D printing is cheaper than normal fabrication since the prosthetics were cheaper on average at \$150 as compared to the normal \$200. The reduced cost combined with shorter manufacturing time offers a clear indication of the value of 3D printing to dental practice and patients.

Some prior research has shown that 3D printing can enhance precision and reduce cost in the fabrication of dental prosthetics. For instance, Yoo et al. (2021) noted that through 3D printing there is high flexibility in designing dental restorations with little dimensional change. In the same respect, Valenti et al. (2024) noted that the use of 3D printing technology has been found to reduce the time taken to produce prosthetics more than any conventional method. These findings are in concord with the result of the present study, validating the application of 3D printing in producing accurate and quick dental prostheses. Furthermore, it has revealed that most of the materials including resins and ceramics used in 3D printing possess comparable mechanical properties to conventional dental materials. However, the present study extends the prior knowledge by proving that both resin-based and ceramic-based prosthetics can withstand repeated mechanical loads, and therefore are fit for long-term use in the oral cavity (Jain et al., 2022). However, some previous works observed that, although the use of 3D-printed materials was encouraging, their mechanical reliability in the long term was an issue (Zaharia et al., 2017). The findings of the current study affirm the stability of 3D printed Pattern Recognition Receptors (PRRs) for durable dental prosthetics, whereby, the 3D printed prosthetics can endure the demands of oral use (Pillai et al., 2021).

The most obvious benefit of 3D printing in dentistry is the opportunity to create individual dental prosthetics based on patient's requirements. Traditional approaches may require some sort of template since the variation of designs cannot be done to a great extent. Nevertheless, thanks to 3D printing, you can produce very personalized prosthetics, which results in better fitting, better comfort, and, therefore, higher satisfaction among the patients (Lin et al., 2019). Furthermore, 3D printing has a shorter production time than traditional approaches, which usually involve a sequence of processes and time-consuming intervals of waiting (Schweiger et al., 2021). This saves time in the production process because it means that patients can receive their prosthetic devices much earlier than before. Also, 3D printing seems to reduce cost implications for both the

patient and the dental clinic (Kumar et al., 2021). This article has shown that prosthetics developed through 3D printing are way cheaper than the ones developed through conventional methods (Banerjee et al., 2022). Costs of labour are also brought down as well as the time it takes to manufacture prosthetics hence making the use of 3D printing more economical (Vitali et al., 2019). The cost-saving opportunities of 3D printing are a strong reason why this technology should be considered by dental practices that aim to provide quality services at the lowest possible cost.

Some limitations are characteristic of using 3D printing in dental practice. The biggest problem is still material limitation as not all materials suitable for 3D printing can be used in dentistry. Although it has been found that the use of resin and ceramic materials provides acceptable mechanical properties, the use of other 3D printing materials, including plastics, may not be strong enough or biocompatible enough for long-term use in the oral environment (Park et al., 2020). Thus, more studies on various materials that potentially provide enhanced strength and compatibility for 3D-printed dental prostheses are essential. Anyhow, there are some issues concerning the initial capital and training expenses concerning the application of 3D printing technology (Revilla et al., 2020). The initial outlay for 3D printers and related materials may prove too expensive to some dental clinics, especially those in the developing world or with less than-ideal patient turnover. Also, it is required to note that to manage 3D printing in dentistry properly, the professionals need to be trained in its usage of equipment and software however, such training increases the overall cost and time for the implementation of such technology (Le et al., 2021). These barriers could also explain why the use of 3D printing is not yet fully pervasive in particular geographic locations or small dental practices (Stansbury & Idacavage, 2016).

The future opportunities of 3D printing in the dental field are vast, especially if bearing in mind the development in material and technology. Currently, a lot is being done to find new materials that provide better mechanical characteristics, improved biocompatibility, and better appearance of 3D-printed dental prosthetics (Marak et al., 2019). Bioactive resins and ceramic composites are some of the materials under development to achieve the combination of the strength of ceramics and the flexibility of resins (Raszewski et al., 2022). As these materials get developed further, they might also enable a wider application of 3DP in dentistry, such as the manufacturing of new intricate dental prostheses and implants (Gali & Sirsi, 2015). In addition, artificial intelligence (AI) can be used to transform the current and future advancements in the fabrication of 3D-printed dental prosthetics (da et al., 2021). AI might help to increase the efficiency of the dental impression and improve the automation of the prosthetic designs for even better fit and improved personalization (Zaharia et al., 2017). Further, it could help in predicting the behavior of the material and subsequent performance of the prosthetics, in general, and dental restorations in particular, thereby providing better and longer-lasting solutions. The combination of AI with 3D printing could be considered a major step in the development of dental prosthetics (Konidena, 2016).

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