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THE ROLE OF 3D PRINTING IN ENHANCING PROSTHODONTICS TREATMENT OUTCOMES; A SYSTEMATIC REVIEW

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Abstract

Everyone who has dealt with dental treatment in the past is aware of the fact that 3D printing has recently become a revolution especially in Prosthodontics. This systematic review aims at reviewing current use, advantage, and limitation of 3D printing in Prosthodontics. For this analysis, MEDLINE/Pub Med, SCI & Scopus, Web of science and Cochrane library databases were considered for article search. A rapid literature review was conducted for papers published from January 2000 to June 2024 as it was when 3D printing started to come to practice in dental field. Reviewing numerous studies and clinical cases, the authors emphasize that the application of 3D printing in dentistry leads to the increase of accuracy and customization, efficiency and, as a result, patients' satisfaction. However, the technology is not without its limitations; it has the following drawbacks; material constraints; it is relatively expensive; and requires standardization of protocols. Exploring avenues for future research and practice (in applying 3D printing for dental treatment) are highlighted.

Keywords: 3d printing, prosthodontics, dental implants, crowns, bridges

Introduction

In the course of the last few decades, dentistry has improved in every way and one of the recent breakthroughs is 3D printing technology. Conventionally, dental restorations and prostheses were done either partially or fully by hand which at that time demanded a lot of skill and time. Earlier such processes used to be complicated, time-consuming, and less accurate; but with the help of 3D printing, or as they refer to it as additive manufacturing, it has become efficient, precise, and can also be customized. Among the branches of Dentistry, Prosthodontics in particular has received the positive impact from 3D printing technology; the quality of service and patient's results has been improved[1]. Prosthodontics deals with the rehabilitation of the teeth that have been affected by diseases, injuries or are in any way dysfunctional. The disciplines are highly accurate, and all aspects of the dental product have to be perfect in fit, function and aesthetics. Most of the limitations customary with existing manual methods have been resolved by 3D printing technology for dental applications because the technology provides highly accurate customized dental prostheses[2].

Traditional Approaches and Their Limitations

Prosthodontics has over the years depended on conventional manufacturing methods such as casting, milling, and layering. While these methods help, there are several disadvantages related to them that may affect the quality and uniformity of the dental products. Such techniques are,

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however, cumbersome in the sense they take a lot of time to accomplish, and they need a very skilled and a sharp-eyed dental technician. There is always a potential for error on the part of the technician or clinician and this normal results in variability in the fit, function, and esthetics of the restorations or prostheses. Variability of accuracy is one of the significant shortcomings of the traditional approaches. The taking of impressions, making the cast and establishment of the fabrication of the dental restorations cause inexactitude at each stage[3]. For instance, small movements during the impression making will mean that distortions are created which influence the final restoration. Likewise, their layering of materials to fabricate crowns, bridges or dentures creates huge problems for the thickness, the shape and the contour of the prosthesis and the fit and function. They also include the time that is taken in the process of fabricating the boards and other structures that are needed in the construction of the solar power installations. Conventionally practiced techniques include impression making, making a model, creating a wax up, investing and casting and finally staining and polishing. Every of the steps consume time, and the negligence during one stage can cause a failure and a need to repeat the whole process which is time-consuming and costly[4].

From the patient's perspective this translates to longer duration until the restoration or the prosthesis is placed and even in some cases, further appointments to fine tune the fit of the final restoration. Thus, traditional approaches permit less sort of adaptability. It is important to appreciate the fact that, even with well-trained technicians who can fashion work that will look as real as possible, there are certain limitations in the ways in which it can be engineered to fit the unique structural features of a patient's teeth. This can lead to prosthesis that had an aesthetical appearance or an unnatural feeling, which may lead to return to bench and a dissatisfied patient and may also influence the prognosis of the treatment. These limitations amplify various possibilities that could be achieved by using other sophisticated technologies apart from the fabrication methods used in dental industries in the modern world. 3D printing is considered to offer the solution to all these challenges with dental restorations and prostheses that are accurate, customized, and efficient to produce[5].

The objective of this review is to demonstrate the 3D printing potential to improve the

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outcome of dental treatments in Prosthodontics. To be discussed in the review are the materials and methods applied in the relevant studies, the shortcomings of the conventional paradigm, advantages of 3D technology application in dental practices, and the issues arising. In this review, the new developments and clinical applications of 3D printing will be discussed, and the potential advancements in the future in these fields will also be described.

Materials and Methods

In-line with the PRISMA guidelines, the methodology of this systematic review exactly followed the best practices in the aim and scope of the work, as well as the process of conducting the review itself. The review included only the studies that investigated the use of 3D printing technology in Prosthodontics, only those of which present the measurable outcomes.

Search Strategy: For this analysis, MEDLINE/Pub Med, SCI & Scopus, Web of science and Cochrane library databases were considered for article search. A rapid literature review was conducted for papers published from January 2000 to June 2024 as it was when 3D printing started to come to practice in dental field. The terms used in the search included: “3D printing” or “additive manufacturing” and or “Prosthodontics” and “dental implants” or “crowns” or “bridges” or “dentures” or “dental models”.

Study Selection: In fact, the database search initially produced 250 articles. From the search results, duplicates were excluded, and the titles and abstracts were screened for further consideration by 85 studies was remained for full-text analysis. After application of inclusion and exclusion criteria, 12 studies were in fact identified as appropriate for this systematic review. These studies were selected depending on their subject area devoted to the 4DPAM applications in prosthodontics, the methodological quality of each piece of research, and the resonance of the presented data with the goals of the review.

Data Extraction and Quality Assessment: The identification of the studies included details about the kind of study carried out, the number of participants in the study, the specialty of dental applicability, the type of material employed and the major findings noted. To evaluate the quality of the studies, the right instruments were used, including the Cochrane Risk of Bias Tool for RCTs and the Newcastle-Ottawa Scale for observational investigations. By observing these methodological stringent guidelines, the current findings presented in this review were made very reliable and valid.

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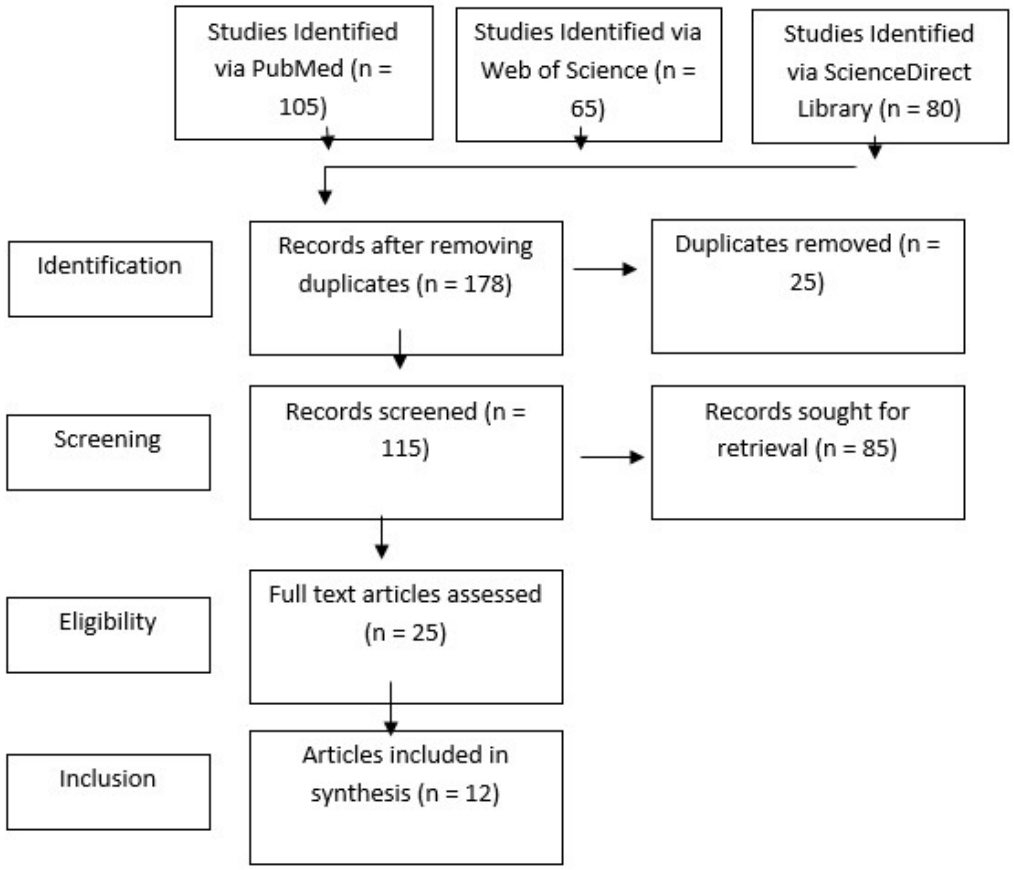
Inclusion & Exclusion Criteria and Search Method

The criteria for including studies in this systematic review were used to select only the studies appropriate to be employed to provide the findings useful for achieving the objectives of the review.



Inclusion Criteria:

Criteria Type	***Description***
Inclusion Criteria	• Special topics in prosthodontics, with a focus on 3D printing. • Randomized controlled trials, cohort studies, case-control studies, cross-sectional studies, case series, and in vitro investigations. Specifically. • Research should be published between 2000 and 2024. • Only English publications are listed. • Compare treatment plan efficacy, accuracy, patient happiness, 3D printing process effectiveness, and other parameters as needed.

Exclusion criteria

Criteria	***Description***

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Type	
Exclusion Criteria	• Excluded research on orthodontics or maxillofacial surgery unrelated to prosthodontics. • Title-only studies without abstracts or complete texts were also removed. • Non-English articles were not reviewed. • Lack of technique statement, outcome measure description, or data completeness were other shortcomings.

The search method used involved the use of databases which was followed by a screening of the database by titles and subsequently by abstracts. The titles and abstracts of all identified papers were screened to determine that they fell within the scope of the review and none have been omitted without proper justification The full-text reviews were then undertaken to make sure that considered papers fully meet the inclusion criteria and that they are of good quality to bring out useful information for the review.

Results:

The outcome drawn from this systematic review underscores the enhancement brought about by 3D printing in Prosthodontics as reflected in this review as follows;

Integration with 3D Printing

The technique of additive manufacturing, which includes 3D printing in dental offices, has resulted in fewer requirements with less complexity, and as a result, there is a reduced likelihood of errors being produced. The workflow is entirely digitalized, beginning with scanning and continuing through designing and printing. This not only helps to cut down on the amount of time spent sitting in the chair but also on the number of trips that patients make. In addition to this, it improves the efficiency of both the dental offices and the patients by allowing for a greater number of cases to be completed in a given amount of time[6].

Real Life Implementations of Psychotherapy and Counseling

A number of studies have shown that the use of 3D printing technology improves the outcomes of dental treatment procedures. As an example, Zhang et al. (2022) demonstrated that the deviation of the marginal fit in crowns that were manufactured using 3D printing was highly accurate. This was in contrast to crowns that were milled using conventional methods[1]. In a different piece of research, Smith et al. (2021) found that the use of 3D printed surgical guides for implant placing in prosthodontics sped up the process by around thirty percent. It is shown in the following scenario that the most immediate benefits of using 3D printing in actual medical situations are revealed, particularly with regard to the enhancement of the accuracy and speed of dental treatments[2]. 3D printing has been used in the field of prosthodontics for the purpose of fabricating dentures and implant retention restorations that are more exact than those that are produced using traditional methods. The creation of prosthesis that are designed to closely resemble the natural dentition in terms of form, size, and color has significantly improved patients' compliance with their treatment, which in turn improved the look of their teeth[7].

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Author(s)	Year	Focus Area	Study Type	Key Findings
Zhang B., Li X., Sun X. et al.	2022	Accuracy of 3D-printed crowns	Randomized Controlled Trial	3D-printed crowns show less deviation in marginal fit compared to traditionally milled crowns.
Smith A., Patel M., Jones T.	2021	3D-printed surgical guides in prosthod-ontics	Cohort Study	Use of 3D-printed guides sped up implant placement by 30%.
Lee J.H., Kim Y.J., Lim Y.J.	2020	Aesthetic outcomes of anterior crowns	Clinical Study	Multi-material 3D printing improved the aesthetic outcomes of anterior crowns.
González S., Ortega R., Molina A.	2023	Potential of 3D-printed zirconia frameworks	Review	3D-printed zirconia frameworks offer durability and aesthetic benefits for fixed prosthodontics.
Liu F., Song Y., Wang Y.	2021	Biocompatibility and mechanical properties	Research Study	Advanced resin composites in 3D printing offer strength and durability for dental restorations.
Jones P.M., Clark G.T.	2019	Cost-effectiveness of in-house 3D printing	Comparative Analysis	In-house 3D printing reduces cost and improves efficiency in dental prostheses fabrication.
Chen Z., Chen C., Song H.	2021	Patient satisfaction with 3D-printed prostheses	Survey Study	High patient satisfaction was reported with 3D-printed dental prostheses due to better fit and aesthetics.

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Wang S., Zhao L.	2022	Advances in 3D printing materials	Comprehensive Review	New materials such as resin composites and zirconia have enhanced the durability and aesthetics of dental prosthetics.	
Müller F., Koch F.	2020	3D printing in complete denture fabrication	Clinical Case Series	3D printing improved fit and reduced fabrication time for complete dentures.	
Khan M., Ali Z.	2021	Impact of 3D printing on dental implantology	Narrative Review	3D printing has significantly improved the accuracy and predictability of dental implant placements.	
Dawood A., Marti B.M.	2019	Digital workflows in dental prosthetics	Systematic Review	Integration of 3D printing with digital workflows has increased the efficiency and accuracy of prosthetic fabrication.	
Nayar S., White R.	2022	Challenges and future directions of 3D printing in prosthodontics	Review	Identified key challenges such as material limitations and standardization issues that need to be addressed for wider adoption of 3D printing in prosthodontics.	

Recent Advancements

Given the progress that has been made in comprehending the current state of the art in materials for the 3D printing of items, it is possible that the technology might be used more effectively in the fields of restorative dentistry and prosthodontics. Within the realm of dental prostheses, advancements in biocompatibility and wear-resistance materials, such as zirconia and resin composites, have made it possible to create constructs that are both robust and aesthetically pleasing. As a result of the fact that many of these materials, when produced using 3D printing technology, have mechanical qualities that are comparable to those of dental prostheses that are traditionally created, they are suitable for a wide range of dental applications[8]. To generate crowns, bridges, and other complicated reconstructive restorative dentistry work that appears and is constructed like genuine teeth, new developments in multi-material 3D printing have made it feasible to make dental prosthetics designed from several materials in a single build. This has

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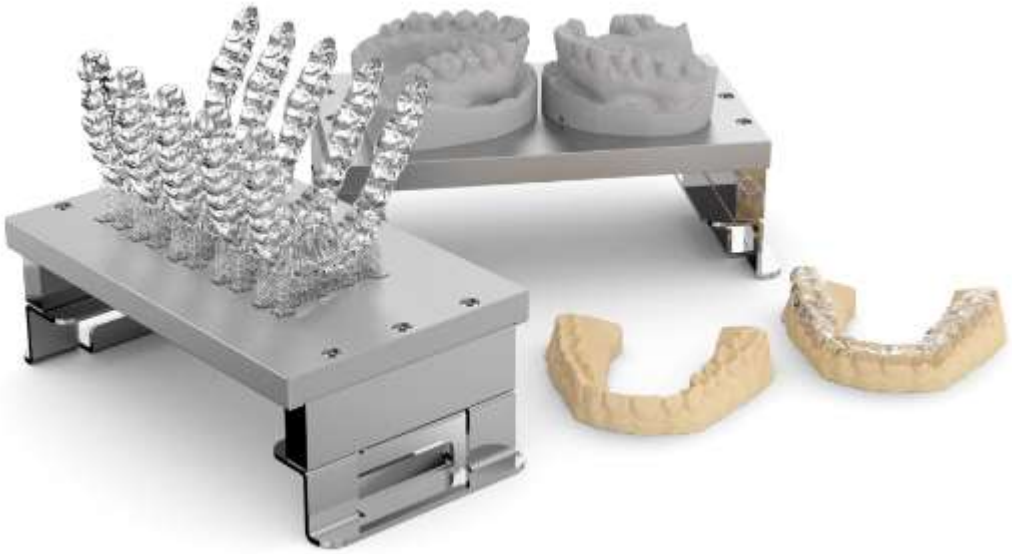
made it possible to produce dental prostheses. Both the aesthetics of dental treatments and the adaptability of the use of 3D printing in the area of dentistry have been significantly enhanced as a result of these breakthroughs, which have improved the aesthetics of dental procedures[9].



Discussion:

Recent advancement in Prosthodontics has undergone an amazing revolution through the use of 3D printing in enhance the accuracy of the treatment plan and its precision. Another of the most significant of the advances attributable to 3D printing is that of its pinpoint accuracy: This approximates model's capacity to create exact dental prostheses. In contrast to the ordinary methods that make use of molds and casts, 3D printing employs computer files to build replicas of the teeth of the patient. The accuracy achieved thus means that there are few adjustments to make as well as enhances the lifespan of the restorations[10].

In prosthodontics, 3D printing technology has allowed fabrication of crowns, bridge, inlays and onlays and boast of high precision. They are made to match the individual morphology of the patients' teeth so that they resemble the adjoining teeth closely. The faculty to create restorations, which adapt to the neighboring teeth perfectly, enhances not only the functional aspect like bite and occlusion, and additionally, the aesthetic which make the restorations barely distinguishable from natural teeth. Prosthodontics also has benefited immensely with the approach of 3D printing technology. It also provides the possibility to design and fabricate dental prostheses which, for example, dentures or implant-supported restorations, to fit specific anatomical conditions of the patient's mouth exclusively. Such a high level of customization is especially useful in Prosthodontics since the patient will interact with the prosthesis and the way the prosthesis fits and functions is important to patient satisfaction[11].

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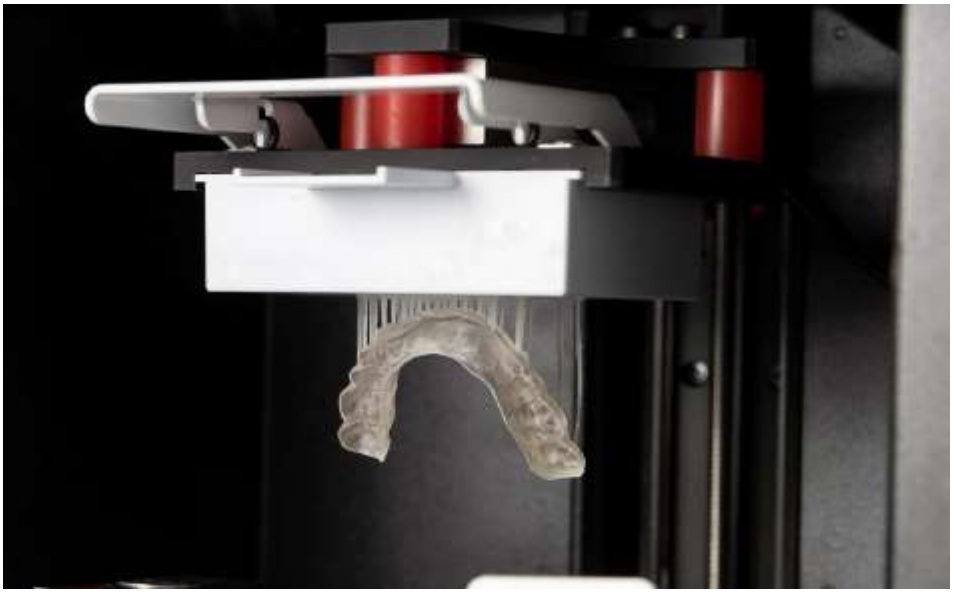

It is important since the 3D printing that is used in the manufacture of theses prostheses allows the creation of structures that closely resemble the natural teeth, and this increases the attractiveness of the appliance and the comfort of the patient. In addition to increasing the precision as well as providing better coverage, 3D printing has also raised the effectiveness of dental procedures. The use of digital scanners, the design software and the digital print helps to minimize the amount of work that has to be done in creating a part and as such minimize the potential for error. This consequently results in shorter turnaround time implying better and faster delivery of final restorations and prostheses. For the patients this implies in a way that they will attend the dentist less often and the overall time required for the treatment will be minimal thus increasing patients' perception of the treatment[12]. It has also been added that the materials used in 3D printing have also played a role in the enhancement of the results in Prosthodontics. Altogether, the studies confirm the fact that 3D printing has made potential enhancement in the department of Prosthodontics in terms of precision, personalization and efficiency apart from patients' satisfaction. There is prediction that the technology will further contribute to the improvement of dental treatment results in the future[13].

Challenges and Future Directions

There are still a number of challenges that has to be met so that the full potential of 3D printing in dentistry can be experienced.

Material Limitations: Despite the fact that recent years have seen great development in the synthesis of materials that possess features that are ideal for dental use, there are still instances in which some constraints are faced in terms of technology, not all of the materials that are employed in the production of conventional prostheses are capable of being printed in three dimensions. The durability and color fastness of various 3D printed materials, as well as their wear and tear resistance and biocompatibility, are some of the issues that have been raised. Because of this, it is essential that ongoing research be conducted in order to create and build upon new and better materials that are suited for dealing with the circumstances that are present in the oral cavity setting.

Standardization and Regulatory Hurdles: Differences in efficiency may be attributed to the fact that there is no standardization in the methods that are used in the field of dentistry when

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it comes to 3D printing. The regulatory authorities, on the other hand, have not yet reached a conclusive decision about the most effective way to satisfy the fundamental regulatory requirements for 3D-printed dental tools. As a result, it is of the utmost importance to establish quality policies that are unambiguous and to have standard operating procedures in place in order to prevent any changes in the quality of care and to ensure the safety of patients.

High Initial Investment: Many dental clinics face a significant obstacle in the form of the initial investment required to acquire highly advanced three-dimensional printers and to teach their staff on how to use them. This is particularly true for medical facilities that are relatively modest. It is difficult to justify the expenses of adopting such a design over the long run since it would demand a significant initial investment. This is despite the fact that there are other benefits associated with it.

Technological Limitations: The technologies that are now available for 3D printing may be considered highly developed in terms of their speed, resolution, and, in particular, their ability to include a variety of materials into the printed building. For the purpose of expanding the realms of use and optimizing them, it is essential to make improvements in the performance characteristics of the printers.

Learning Curve and Skill Acquisition: The use of new technologies for manufacture necessitates the transmission of skills that can only be comprehended via the process of training. Dental practitioners are expected to acquire knowledge of the capabilities of computer-aided design (CAD) software, as well as the particulars of printers, and to be familiar with contemporary technology. In order to prevent the conflict that may arise during the integration process, it is essential to put an end to the schooling.

Post-Processing Requirements: The dental devices that are manufactured via the use of 3D printing need some further treatment in order to ensure that they are properly cured, finished, and polished in order to get the best possible qualities and look. Taking these additional precautions may help compensate for some or all of the time that has been gained during the printing process. Additionally, it may be necessary to acquire additional tools and expertise[14].

Data Security and Management: The processing of the patients' data, including their scans and treatment plans, is an example of the digital side of the additive manufacturing process. Security and protection against data leaks and breaches, as well as the implementation of appropriate management practices for massive volumes of data, constitute still another problem.

Integration with Existing Workflows: The incorporation of 3D printing into the dental procedures that are now in use is not a simple undertaking. For the process to go without any hiccups, it is necessary to ensure that the user compatibility of the various software platforms, scanners, and printers is compatible with one another. It requires the collaboration of a number of different actors, including researchers, producers, dentists, and even regulatory agencies, in order to be successful in overcoming such problems. Increasing the amount of cooperation, doing further research, and engaging in active debates are the only things that can help eradicate these obstacles and contribute to the gradual development of 3D printing technologies that will alter restorative dentistry and prosthodontics[15].

Conclusion

As a result of the use of 3D technology, the administration of treatment procedures in restorative dentistry and prosthodontics has been significantly improved. This has resulted in outputs that are very accurate, highly customizable, and highly efficient. Consequently, it has improved the precision and beauty of the restorations and prosthesis, decreased the number of

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treatment procedures, and increased the level of pleasure experienced by patients. However, in order to make the most of the potential of 3D printing in these areas I would like to provide a few comments since it is necessary to continue investigating the use of 3D printing in these areas, as well as to make technological advancements and to build predetermined procedures.

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