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REVIEW

The Use of 3D Printers for the Manufacture of Complex Multi-Component Dentures in Dentistry

El uso de impresoras 3D para la fabricación de prótesis complejas multicomponente en odontología

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ABSTRACT

Introduction: three-dimensional (3D) printing has transformed dentistry by enhancing precision, efficiency, and reducing material waste in prosthesis manufacturing. The objective of this study is to evaluates (3D) printing effectiveness and operational parameters by assessing technology used, workflow efficiency, patient outcomes and complications in dental procedures, focusing on its clinical applicability and impact on patient care.
Method: a systematic literature review was done for articles from 2015 to 2024. A systematic search of multiple databases, including PubMed and Google Scholar, yielded 3785 studies, which were narrowed to 15 studies that focused on 3D printing technology in multi-part dental prostheses.
Results: the 3D-printed material was compared with conventional rapid prototyping material, and good strength characteristics of the prostheses were achieved. 3D-printed prostheses' long-term performance depends on constantly developing techniques and technologies. 3D-printed prosthesis accuracy was relatively high, but patient throughput, complexity, and limited precision needed to be more satisfactory. Literature reviews, randomized controlled trials, single-centre clinical trials, and in vitro and observational studies were also included in this study.
Conclusions: although limitations about material properties, production costs, and accuracy still exist, the prospects of 3D printing for clinical application in dental prosthetics are very encouraging. Enhanced digital workflows have positively impacted patient engagement, yet additional research is needed to improve such practices in the clinic for maximal patient satisfaction.

Keywords: Dental Prosthesis; 3D Printing; Prosthetic Dentistry; Patient-Specific Prostheses; CAD/CAM Technology.

RESUMEN

Introducción: la impresión tridimensional (3D) ha transformado la odontología al mejorar la precisión, la eficiencia y reducir el desperdicio de material en la fabricación de prótesis. El objetivo de este estudio es evaluar la eficacia de la impresión (3D) y los parámetros operativos mediante la evaluación de la tecnología utilizada, la eficiencia del flujo de trabajo, los resultados de los pacientes y las complicaciones en los procedimientos dentales, centrándose en su aplicabilidad clínica y el impacto en la atención al paciente.

Método: se realizó una revisión sistemática de la literatura para artículos de 2015 a 2024. Una búsqueda sistemática en múltiples bases de datos, incluyendo PubMed y Google Scholar, arrojó 3785 estudios, que se redujeron a 15 estudios que se centraron en la tecnología de impresión 3D en prótesis dentales multiparte.
Resultados: el material impreso en 3D se comparó con el material convencional de prototipado rápido, y se obtuvieron buenas características de resistencia de las prótesis. El rendimiento a largo plazo de las prótesis impresas en 3D depende del desarrollo constante de técnicas y tecnologías. La precisión de las prótesis impresas en 3D era relativamente alta, pero el rendimiento para el paciente, la complejidad y la precisión limitada debían ser más satisfactorios. En este estudio también se incluyeron revisiones bibliográficas, ensayos controlados aleatorizados, ensayos clínicos unicéntricos y estudios in vitro y observacionales.
Conclusiones: aunque todavía existen limitaciones sobre las propiedades de los materiales, los costes de producción y la precisión, las perspectivas de la impresión 3D para la aplicación clínica en prótesis dentales son muy alentadoras. La mejora de los flujos de trabajo digitales ha repercutido positivamente en el compromiso de los pacientes, aunque se necesita más investigación para mejorar estas prácticas en la clínica y lograr la máxima satisfacción de los pacientes.

Palabras clave: Prótesis Dental; Impresión 3D; Odontología Protésica; Prótesis Específicas Para el Paciente; Tecnología CAD/CAM.

INTRODUCTION

In various sectors, 3D printing has become a revolutionary technology. Dentistry is one of the most promising areas of application. Making complex multi-component prostheses with the help of a 3D printer is a revolutionary change in dental practice, which creates more effective and accurate prosthetic solutions.[1]

This literature review aims to examine the contributions of 3D printing in prosthesis making, including its methods, materials, advantages and limitations.

Additive manufacturing, also known as 3D printing, is a technology that builds three-dimensional objects based on their digital models layer by layer. This technology has found applications in dentistry while revolutionising traditional manufacturing methods.[2]

Traditional techniques often adopt the subtractive methodology, which is labour and time-inefficient. In the same breath, 3D printing combines advantages such as efficient material usage, minimal wastage, and the ability to manufacture complex designs that are impossible to produce using standard methods.[3]

Incorporating new technologies like 3D printing into dentistry demands a compromise between technological development and the emphasis on human-centred practices. It is imperative to develop philosophical underpinnings on the connection between technology and humanitarianism, pertinent to developments such as CAD/CAM in dentistry.[4]

This is particularly so in the area of prosthesis production where CAD/CAM technologies are already advanced; 3d printing has an advantage of accuracy and speed, yet such advancement concurrently brings about ethical concerns such as data security, inequality and a need for appropriate structures to be in place.[5]

As with firsthand CAD/CAM technologies, incorporating these into dentistry requires interventional strategies to balance technological advancement with humanitarianism. In addition, the present focus on sustainability and green investment helps give ESG targets and tactical financial management, which are vital in deploying green technologies to dentistry.[6]

Further, targeting future immune-modulating therapies alongside discovering oral disease biomarkers will support the success of such 3D-printed prostheses.[7] In a broader scope, such as the fight against COVID-19, studies stress the relationship between preparedness in health services and public response along the lines of education, fund management, and an upgraded healthcare system.[8]

In addition, based on their research work, other authors have contributed to the colour-based methods targeting the improvement of the learning processes of medical students, which shows that such attempts can also be attempted in training programs for dental practitioners.[9] Emerging management paradigms necessitate appropriate leadership competencies and styles, critical for executing best practices using advanced 3D printing technology in dental clinics.[10] Ethical aspects, including the necessity to develop ethical standards, are essential when implementing virtual and digital tools, arguing that such developments will enhance the quality of patient care in dental restoration processes.[11]

The development of computer-aided design (CAD) and computer-aided design (CAM) systems has made it possible to incorporate digital workflows into a dental practice. These systems assist in gathering and processing patient information so that the clinician can design prostheses that suit the prosthesis/bio/prosthetic bone interface. Digital techniques are more accurate, reduce the time required for manufacturing, and enable the production of prostheses in one visit.[12] There are many advantages to using 3D printing in dental prosthesis

fabrication. One of the most notable is freedom to design; practitioners can design complicated shapes that improve the accommodation and function of the prosthesis. In this regard, multi-component prostheses are essential for adequately integrating different parts for optimum performance.[13]

In addition, 3D printing makes mass personalization possible, enabling dentists to customize each prosthesis to the specific patient's needs. This customization improves patient comfort and can result in improved clinical outcomes.[14] the production time has also improved significantly; processes that could take several days or weeks to complete can now be completed within hours, which decreases patient waiting time.[15]

The other benefit is the impact on material waste. Traditional manufacturing processes waste More than needed materials, while 3D printing uses only the required material for the part. Thus, this reduces costs and is appropriate to the environmental issues raised concerning the waste problem in the healthcare industry.[16]

Despite its many advantages, applying 3D printing technology in dental settings raises some red flags. One of the major hurdles is the precision and consistency of printed models compared to conventional ones. However, many studies have shown that 3D models can be made with acceptable clinical errors. However, further doubt exists about its activities in actual practice.[17]

For example, components such as the type of printer used, the materials, and the post-processing processes can heavily impact on the quality of the finished product. In addition, the properties of the materials used for 3D printing could be more problematic. Although high-performance resins and polymers are developed for dental applications, polymerization shrinkage and surface roughness issues adversely affect the strength and aesthetic of the constructed prostheses.[18]

An area requiring more studies is whether those materials can serve their purpose in a clinical environment for prolonged periods. When considering the future of the dental industry, it is essential to factor in the factors that will continue to improve 3D printing. The availability of new materials with superior mechanical traits and more excellent biocompatibility may lead to a broader range of uses in 3D-printed prostheses.

Furthermore, advancements in printing technology have the potential to increase accuracy and decrease production time even more than it currently is [19]. The prospect of hybrid manufacturing strategies which integrate subtractive and additive approaches may also help augment the functions of dental labs. Such procedures provide enhanced design decisions and more control than necessary to meet the required level of quality.[20]

They shall then ensure that in situations where these technologies are necessary, practitioners can effectively use them as digital workflows in dentistry become more ingrained. To sum up, the application of 3D printers in fabricating complicated multiple prosthesis components in dentistry is a significant advancement.

This technology's positive aspects, such as the possibility for almost unlimited variations in design, mass customization, waste elimination, and enhanced productivity, emphasize its radical nature. Nevertheless, limitations regarding precision, material characteristics and clinical usage of these prostheses need to be solved by further R&D. In this digital age of surgical intervention, comprehending these dynamics will be pivotal in exploring 3D printing modalities in dentistry to their fullest potential.

Research Aim

The objective of this study is to evaluate (3D) printing effectiveness and operational parameters by assessing technology used, workflow efficiency, patient outcomes and complications in dental procedures, focusing on its clinical applicability and impact on patient care.

METHOD

Study design

A systematic literature review (SLR) from 2015 to 2024.

Search strategy and databases used

Figure 1 depicts the systematic review process that was carried out to address the targets set. This review aims to investigate the use of 3D enlargement for making complex multi-component prostheses in Dentistry. First of all, the search was made quite a broad one. The search covered such words as "3D Printing" AND "Dental Prostheses", "Prosthetic Dentistry", "Multi-Component Prosthetics", "Custom Dental Implants" OR "Patient-Specific Prostheses" AND "Digital Dentistry" OR "CAD/CAM in Dentistry" Thus, this process resulted in a total of 13,785 records identified from database searches with 11,775 in PubMed and 2,010 in Google Scholar. Specific objectives for this level resulted in the development of specific inclusion and exclusion criteria: A total of 3030 records were not published between the years 2015 and 2024, 5721 records were deleted because the free full length was not available, and 4121 records did not fit into the best-fitted article type.

Additionally, 6 records were excluded based on language restrictions, as only English-language studies were considered. After duplicates were removed, 16 unique records remained, screened for relevance, excluding 580 records that needed to meet the criteria. Ultimately, 313 records were deemed eligible for further

assessment, identifying 15 highly relevant studies that contributed significantly to the understanding of 3D printing in the context of dental prosthesis manufacturing. Such a meticulous selection process demonstrates the methodological approach to ensure that the review contains only the most relevant and highest quality studies, thus increasing the reliability and validity of the overall findings concerning the engagement of 3D printing technologies in the dental profession.

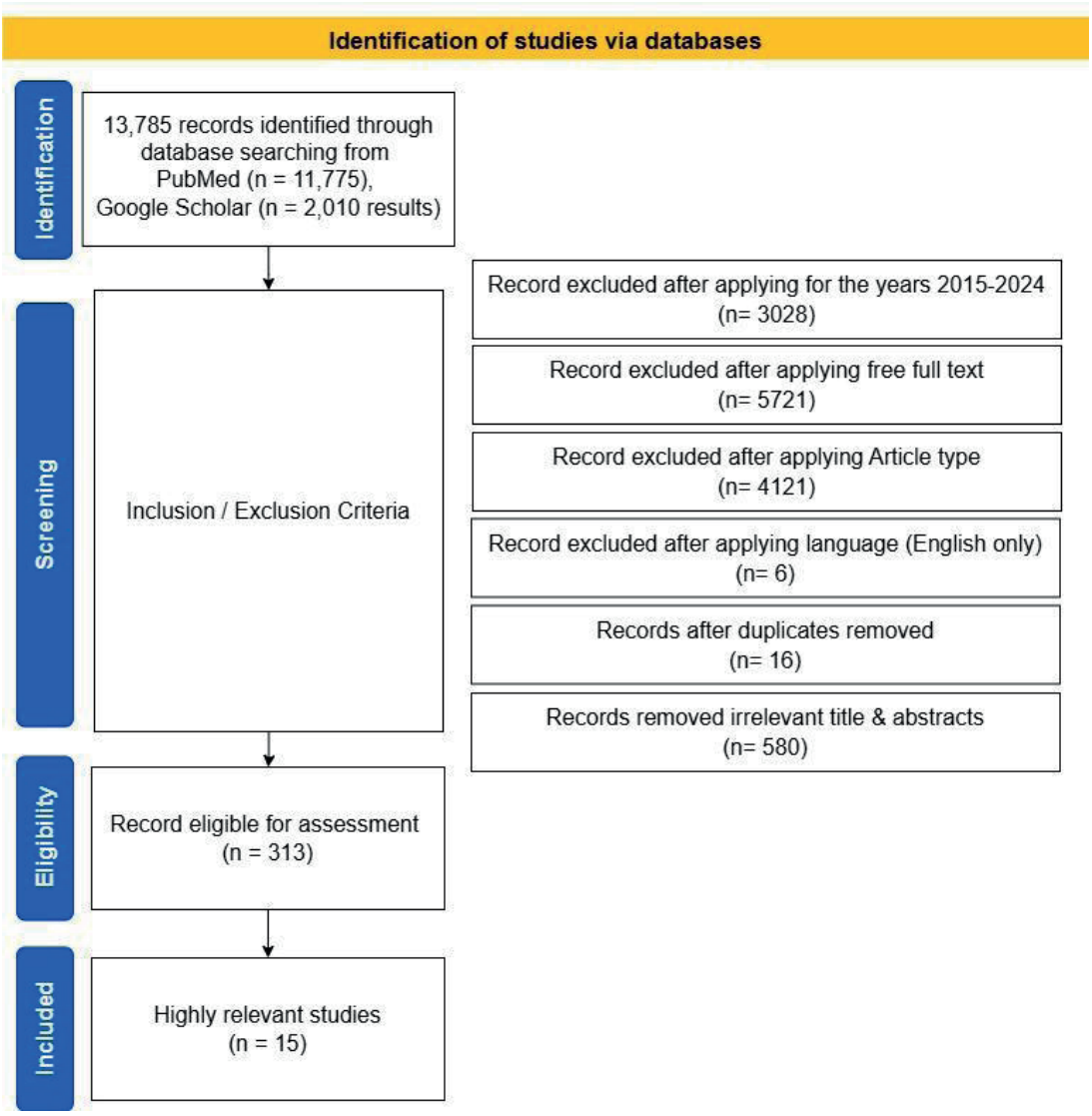

Figure 1. PRISMA Flow Diagram

Inclusion and Exclusion Criteria

In performing this systematic review, particular inclusion criteria were set so that relevant studies and literature related to the theme of the systematic review, which is the application of 3d printing technology in the production of multi-part prostheses in the field of dentistry, were included in the review. The years of the included studies were 2015-2024, which limited the review period only to advanced development in dental prosthetics. Articles written in English were included to allow ease of understanding and for the consistency of the materials. The study explored the focus papers, review papers and clinical studies which dealt with the terms 'Dental Prostheses', 'Prosthetic Dentistry', 'Multi-component prosthetic Southern Cross', 'Custom Dental Implants', and 'Patient-Centric Prosthesis'. It was also preferred to include studies on digital dentistry, CAD/CAM integration with digital printing technologies, and the most recent and modern approaches in this area.

In contrast to these inclusion criteria, several exclusion criteria were introduced to make the selection more specific. The research perimeter was set, excluding records issued earlier than 2015, to emphasize more recent developments and results. Moreover, studies lacking the free full-text version were deleted as such studies would restrict detailed examination of the methodology and outcomes. Further, articles not concerned with dental prosthetics and did not constitute a research article, such as non-research articles and

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editorials, opinions and biomedical studies unrelated to the topic, were excluded. Lastly, all other foreign languages were also deleted from the analysis to enhance the review process. Following the guidelines as set above, the review sought to incorporate a wide range of representative studies in understanding the role of 3D printing in the fabrication of dental prostheses.

Data Extraction

For the systematic review, the data extraction process considered a few variables considered a few variables related to the advantages of using 3D printing in constructing complex multi-component prostheses in dentistry. Specific aspects of each study included were the author (s) and year of publication so as not to omit citation of such particulars; the design of the study in order to determine its methodological quality; the number of cases or samples employed to ascertain the statistical power and generalizability of the study; and the specific technology employed detailing the different methods of 3D printing and the materials used. Some additional information on the details of the prostheses was assigned, too, such as types and customization options to determine the range of practices in prosthetic dentistry. However, some metrics were related to efficiency, including production time and resource use, which were recorded to determine the practical advantages of the 3D printing technologies. Additionally, information on patient outcomes, including measures of patient satisfaction and quality of life, was sought to evaluate the effect of the prosthesis on the patient. Last, clinical insights were also reviewed to obtain some complications, such as survival and durability, which were important in evaluating the efficacy and safety of the approach. This structured analysis of the available literature helps understand the current trends and prospects of 3D printing for the fabrication of dental prostheses.

DEVELOPMENT

The adoption of 3D printing technology in dentistry has dramatically revolutionized the manufacturing of intricate multi-component prosthetics by eliminating the drawbacks posed by the conventional approaches that were usually time-consuming, wasteful and not tailor-made. The application of additive material to Computer-aided design and computer-aided manufacturing (CAD/CAM) has made it possible to design and manufacture prostheses in efficient and effective ways regarding time and material usage. The development of new 3D printing methods such as stereolithography (SLA), digital light processing (DLP) and fused deposition modelling (FDM) and the improvement of biocompatible resins, metal and ceramic materials allowed for the extension of the functional and aesthetic possibilities of the dental prosthesis. Advances in the digital workflow allow for the more straightforward creation of an impression of a patient's mouth and aid in designing a prosthesis that fits onto the patient's mouth with minimal need for adjustments and fewer outpatient clinics. There are issues such as the concern over the long-term strength of the implants, high cost and the need for specialized assistance; however, looking at the potential future of 3D printing, these developments are directed towards enhancing the attributes of materials, the prices involved and the outcome.

RESULTS

As summarized in table 1, several research studies have been carried out regarding 3D printing technology in dental prosthetics. The specific study methods employed, and the total number of respondents are indicated. Many of these studies are literature reviews, synthesizing findings from [21],[36], and[37] studies.[21,22,23] These reviews provide a broad understanding of the advancements and trends in 3D printing technologies applied in dentistry.

Several studies used randomized controlled trials (RCTs), with sample sizes ranging from 15 to 46 patients.[24,25,26,27] These RCTs provide evidence of clinical efficacy and patient outcomes related to 3D-printed dental prostheses compared to other methods, making them valuable for evaluating real-world applicability.

Other studies follow clinical trial designs with smaller patient groups of 11 and 15, respectively.[28,29] These trials focus on the practical application of 3D printing in specific scenarios, providing insights into how these technologies perform in patient care settings.

The table also includes in vitro studies that assess the performance of 3D-printed materials and techniques in controlled laboratory conditions.[30,31,32] For instance, one study evaluated 30 prostheses to determine the precision of 3D-printed versus milled dental prostheses, while another compared digital models with traditional stone models.[31,32]

Additionally, an observational study with 118 patients offers insights into patient responses and the feasibility of using 3D printing in routine clinical practice without the controlled structure of an RCT.[33] Such studies help to identify trends and potential challenges in real-world settings.

The table 1 presents a clear overview of the various research strategies employed in 3D printing for dental prosthetics. It may be worthwhile to consider each study design in isolation, be it literature, RCT, in vitro, or

observational studies. This would help build a substantial perspective on the evolution of 3D printing in the domain of dental restoration and its potential future applications.

Table 1. Overview of Studies on 3D Printing in Dental Prosthetics

Author(s) and Year	Study Design	Sample Size
Anadioti et al. 2020 [21]	Literature review	21 studies
Takeuchi et al. 2018 [34]	Literature review	NA
Tanveer et al. 2023 [22]	Literature review	36 studies
Saravi et al. 2021 [35]	Literature review	18 studies
Srinivasan et al. 2021 [24]	RCT	15 patients
Gintaute et al. 2023 [25]	RCT	20 patients
Zinelis et al. 2022 [30]	In vitro	NA
Lv et al. 2022 [28]	Clinical	11 patients
Schwärzler et al. 2023 [27]	RCT	46 patients
Kveller et al. 2024 [33]	Observational	118 patients
Ohara et al. 2022 [26]	RCT	20 patients
Domysche et al. 2024 [23]	Literature review	37 studies
Igreț et al. 2023 [31]	In vitro	30 prostheses
Sim et al. 2019 [32]	In vitro	8 models
Brenes et al. 2023 [29]	Clinical	15 patients

Table 2 presents several studies that deal with 3D printing and its related technologies for producing complex multi-component dentures in the dental practice. Among them are 3D printing, CAD/CAM, additive manufacturing, and digital impression systems like intraoral scanners CEREC, iTero, etc. These digital technologies make it possible to manufacture high-quality and bespoke dental prostheses, including complete removable dental prostheses, fixed dental prostheses, orthodontic aligners, etc., enhancing patient service and clinical efficiency.

The studies cover a broad spectrum of prosthetic uses, including but not limited to full and partial dentures, crowns, bridges, orthodontic appliances and surgical guides, and even craniofacial implants. This variety highlights the broad scope of 3D printing in various applications in dental restoration. Hence, it can provide simple crowns to more intricate and sophisticated multi-element constructions. The capacity for personalized design solutions using these digital processes represents an evolutionary step forward in dental prosthetics.

The efficiency of the studies is highlighted as most of them report benefits including fewer clinic visits, faster working processes and improved patient satisfaction from better fitting prostheses. For example, CAD/CAM milled dentures are known to be more efficient in aftercare than 3D-printed dentures, which may require more adjustment during the post-operation restoration phase. Nevertheless, challenges persist, such as the development of materials that are better and sophisticated types of equipment that are expensive, which slow down the adoption of these technologies by the broader population.

The studies also look into how different 3D printing processes are related, for example, how different types of 3D Resin, which might be LCD or DLP, work differently. Other areas of study included comparisons of the various resin types, while others included comparing 3D printing processes to traditional fabrication, in this case, conventional denture making. These comparative studies, for example, explain why choosing the right technology regarding precision, durability, and patient comfort is essential. Each of these processes has advantages and disadvantages that affect clinical activity results.

Even though 3D printing and digital workflows have brought an overwhelming improvement in clinical processes and patient care, some constraints are visible. A few of the technologies still need improvement in terms of material resistance, biocompatibility, and low cost so that they can be regularly used in dental practices. Furthermore, it was noted that digital modalities. However, they enhance patient-centeredness and expedite clinical processes, and they tend to use more digital alterations, especially the fabrication of digital dentures, than traditional dentures. In general, the table depicts the potential of 3D printing in transforming the structure of the disciplines in which dental prosthesis is produced, indicating at the same time some shortcomings that need to be addressed to achieve the desired clinical efficiency.

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Table 2. Technology and Methodology Used

Author(s) and Year	Technology Used	Prosthesis Details	Efficiency
Anadioti et al. 2020 [21]	3D printing, CAD/CAM	Complete removable dental prostheses	Cost-effective, shorter workflows
Takeuchi et al. 2018 [34]	Digital scanners, CAD/CAM	Dental restorations, fixed prostheses	Reduced impression time
Tanveer et al. 2023 [22]	CAD/CAM, 3D scanning	Auricular prostheses	High equipment costs.
Saravi et al. 2021 [35]	CAD/CAM, zirconia & lithium disilicate	All-ceramic FDPs	High survival rates
Srinivasan et al. 2021 [24]	CAD/CAM milling, 3D printing	CRDP	3D-printed require more adjustments.
Gintaute et al. 2023 [25]	CAD/CAM, digital impression systems	3-unit ZrO2 implant FDPs	High satisfaction, ease of use
Zinelis et al. 2022 [30]	3D printing (LCD, DLP)	Orthodontic aligners	LCD-printed aligners more durable
Lv et al. 2022 [28]	3D treatment simulation	Esthetic rehabilitations	Improved engagement, high equipment costs
Schwärzler et al. 2023 [27]	CAD/CAM, 3D-printed trays	Orthodontic brackets	Preferred for comfort
Kveller et al. 2024 [33]	3D printing	PAM and PSI in surgeries	Reduced surgery time
Ohara et al. 2022 [26]	3D-printed vs. conventional dentures	Complete dentures	Fewer clinic visits
Domysche et al. 2024 [23]	SLA, DLP, FDM printing	Various restorations, guides	High satisfaction
Igreț et al. 2023 [31]	CAD/CAM milling, SLA printing	Provisional FDPs	Milled offers better fit
Sim et al. 2019 [32]	Digital impression, 3D printing	Crowns, bridges, inlays	Digital models precise but
Brenes et al. 2023 [29]	3D printing, lab scanner	Implant-supported prostheses	Quality of life improved

Table 3 summarizes studies focusing on patient outcomes and clinical performance in the use of 3D printing for dental prosthetics, highlighting key findings from each. Most studies explore how 3D printing technologies, including CAD/CAM systems, impact patient satisfaction, treatment efficiency, and the durability of prosthetic devices.

Milled complete removable dental prostheses (CRDPs) offer good retention, while 3D-printed dentures show promising short-term results but require material improvements for better long-term stability.[21] Digital impression systems yield clinically acceptable outcomes with reduced impression times and less patient discomfort compared to traditional methods, though the results depend on the scanner and impression material used.[34]

Digital navigation for accurate implant placement leads to predictable clinical outcomes and reduced patient visits, while CAD/CAM systems streamline the fabrication of auricular prostheses, enhancing clinical efficiency.[22] High survival rates of CAD/CAM all-ceramic fixed dental prostheses (FDPs) have been demonstrated, although further studies are needed to improve material properties for better long-term outcomes.[35]

Both milled and 3D-printed CRDPs perform similarly, but milled CRDPs require fewer adjustments, leading to better aftercare efficiency.[24] Patients rated digital workflows positively, with slightly higher satisfaction for specific systems like Trios regarding accuracy and comfort.[25]

Aligners printed using LCD technology are more durable than those printed with DLP technology.[30] Additionally, 3D digital simulations significantly improve patient engagement and understanding of their treatment, although further technological developments are needed to enhance efficiency.[28]

Hard and soft resin trays for orthodontic brackets show reliable transfer accuracy, with soft trays preferred for patient comfort.[27] Increased patient understanding and improved interdisciplinary cooperation were reported when using in-house 3D-printed models and surgical instruments, along with moderate reductions in surgical time.[33]

Digital dentures reduce clinic visits but may require more adjustments than conventional dentures, with patients often prefer traditional options for comfort and stability.[26] The precision and reduced procedural time associated with 3D printing methods like SLA and DLP enhance the customization of dental prosthetics.[23]

Milled provisional fixed dental prostheses (PFDPs) have superior marginal fit compared to 3D-printed versions, with GC resin suitable for clinical use. In contrast, other resin types like Prusa may be less ideal.[31] While digital

and stone models achieve similar accuracy, 3D-printed models exhibit lower precision, particularly in complex restorations.[32]

Generally, positive outcomes have been reported with 3D-printed prostheses, including improvements in oral health-related quality of life (OHIP scores). However, some durability concerns, complications and catastrophic failures have been noted. The study highlighted the cost-effectiveness and patient satisfaction of 3D printing for temporary prosthetic solutions.[29] This compilation of studies illustrates the varied outcomes and performance metrics associated with using 3D printing in dental prosthetics, providing a comprehensive perspective on its advantages and areas for further improvement. Each study contributes unique insights into the practical application and patient experiences related to digital and 3D-printed prostheses.

Table 3. Patient Outcomes and Clinical Performance

Author(s) and Year	Patient Outcomes	Clinical Performance
Anadioti et al. 2020 [21]	Positive satisfaction, short-term performance	Good retention with milled CRDP; limited stability in 3D-printed dentures
Takeuchi et al. 2018 [34]	Reduced discomfort and impression time	Acceptable marginal gaps, good fit in digital restorations
Tanveer et al. 2023 [22]	Predictable outcomes, fewer visits	Accurate implant placement
Saravi et al. 2021 [35]	High survival rates, fewer complications	3-year survival: 94,66 %; 5-year: 91,1 %; 10-year: 82,2 %
Srinivasan et al. 2021 [24]	Higher willingness to pay for milled CRDPs	Similar performance; milled CRDPs need fewer adjustments
Gintaute et al. 2023 [25]	High comfort, preferred digital workflows	Comparable satisfaction across workflows
Zinelis et al. 2022 [30]	Focused on mechanical properties	Higher hardness in LCD-printed aligners
Lv et al. 2022 [28]	Enhanced patient engagement	Effective communication, high VAS scores
Schwärzler et al. 2023 [27]	Better comfort with soft trays	Reliable accuracy for hard and soft trays
Kveller et al. 2024 [33]	Increased patient understanding	Improved surgical planning, reduced time
Ohara et al. 2022 [26]	Higher comfort with conventional dentures	Fewer clinic visits with digital dentures
Domysche et al. 2024 [23]	High satisfaction, better fit and aesthetics	High precision with SLA and DLP
Igreț et al. 2023 [31]	Focused on marginal adaptation	Superior marginal fit in milled PFDPs
Sim et al. 2019 [32]	Focused on prosthetic accuracy	Stone and digital models show similar accuracy
Brenes et al. 2023 [29]	Improved OHIP scores	9 complications, 3 catastrophic failures

Table 4 outlines the complications associated with various types of prostheses in the context of 3D printing and dental restoration, categorized into specific issues. One significant category is High Costs and Technical Requirements, which include complications related to the high costs of equipment, the need for trained technical staff, and the time required for maintenance and adjustments. Studies emphasize these challenges, indicating that while 3D printing offers numerous advantages, financial and technical barriers can limit accessibility and efficiency in clinical settings.[22,23,24,28]

Accuracy and Fit Issues represent another critical area of concern. This category highlights variations in accuracy, challenges with achieving precise fits, and more significant marginal gaps that can lead to complications in prosthetic performance. Studies indicate that achieving optimal accuracy in prostheses remains challenging, affecting overall patient satisfaction and clinical outcomes.[23,27,31,32,34]

The Material Properties and Durability category addresses complications such as variations in material properties, the risk of prosthesis fractures, secondary caries, chipping, and framework fractures. The research underscores the importance of material selection and durability, as these factors significantly impact the longevity and functionality of dental prostheses.[24,29,30]

Esthetics and Patient Satisfaction highlight issues related to the printer's low resolution, unsatisfactory aesthetic results, colour instability, and comfort and phonetics. According to the research, attaining the set aesthetic goals or appearing desirable is vital for the patient's acceptance and satisfaction; hence, this is a critical aspect that requires improvement in 3D printing technologies.[21,26]

Lastly, complications such as preference differences in workflow or model deformation during surgery are mentioned in Workflow and Ease of Use. Donoway et al. show that attention to smoother workflows is significant in the clinical setting regarding effectiveness and usefulness.[25,33]

The table depicts a comprehensive picture of the different types of complications encountered with different types of prostheses in 3D printing, which indicates that integrating these technologies into dental practices is not that easy. The different categories highlight aspects that require additional research and development to improve the patient's overall performance and dental prosthetic work.

Table 4. Complications Associated with Different Prostheses

Category	Complications	References
High Costs and Technical Requirements	High equipment costs, need for trained technical staff, maintenance, and adjustment time	(22, 23, 24, 28)
Accuracy and Fit Issues	Variation in accuracy, accuracy challenges, larger marginal gaps, fit issues	(23, 27, 31, 32, 34)
Material Properties and Durability	Variation in material properties, prosthesis fractures, secondary caries, chipping, framework fractures	(24, 29, 30)
Esthetics and Patient Satisfaction	Low printer resolution, poor esthetics, color instability, comfort and phonetics issues	(21, 26)
Workflow and Ease of Use	Minor differences in workflow preference, model deformation during surgery	(25, 33)

The current study explores in depth the aspects related to the application of 3D printing technology in creating dental prostheses, paying attention to its universality and advantages in clinical practice. Much of this is from varied research designs, ranging from RCTs to observational studies, that lend themselves to patient outcomes, material performance, and efficient operation. However, as they point out, substantial resistances, such as cost implications, skills intensity, and material longevity, accentuate the need to improve these challenges to increase scope and acceptance within the clinical setting.

DISCUSSION

The present analysis of existing literature on the use of 3D printed structures in the fabrication of dental prostheses indicates that some progress has been made, and some issues remain to be solved. The variety of research methodologies- from literature reviews and randomized controlled trials to clinical trials, in vitro studies, and observational studies—offers a thorough understanding of the efficacy, efficiency, and patient outcomes of 3D-printed dental prostheses.

The current study reviews various findings on applying 3D printing and digital technologies in creating complex dental prostheses. These technologies, particularly CAD/CAM and intraoral scanners, facilitate customized solutions that significantly enhance patient care. The versatility of 3D printing allows for a broad spectrum of restorations, from simple crowns to complex craniofacial implants, marking substantial progress in the field.

Supporting Findings from recent studies confirm that 3D printing technologies, such as SLA, DLP, and FDM, offer better precision and lower error rates than traditional methods. This aligns with findings that emphasize the efficiency of 3D printing in reducing clinic visits and improving patient satisfaction due to better-fitting prostheses.[36]

Furthermore, the ability to utilize various materials, including polymers, metals, and ceramics, enhances the customization potential of dental prostheses and is supported by evidence showing that 3D printing can produce complex geometries with high accuracy, thereby meeting diverse clinical needs.[37]

Additionally, regarding clinical Performance, initial studies on digital dentures have indicated promising short-term clinical Performance and positive patient-related outcomes, suggesting that 3D printing can modernize denture fabrication techniques effectively.[38] While 3D-printed dentures demonstrate significant advancements, other studies indicate that CAD/CAM-milled dentures often provide superior aftercare efficiency. This highlights a critical area where traditional methods still hold advantages over newer technologies.[39]

Despite advancements, material durability, biocompatibility, and cost-effectiveness persist. Some studies note that 3D-printed materials may require more adjustments than conventional approaches, suggesting that while promising, these technologies need further refinement for optimal clinical implementation.[2]

Comparative analyses reveal that while 3D printing shows potential for improved fit, there are instances where traditional methods yield higher accuracy in specific applications. For example, research indicates that CAD/CAM milled prostheses exhibit superior dimensional stability over time compared to their 3D-printed counterparts.[40]

In conclusion, integrating 3D printing in dental prosthetics represents a transformative shift towards customization and efficiency in patient care. However, ongoing research is crucial to address existing material properties and procedural efficiency limitations. Future developments should focus on enhancing the capabilities of 3D printing technologies while also leveraging traditional methods where they excel to ensure optimal

clinical outcomes for patients.

The present SLR integrates reviews and research studies on the patient outcomes, clinical performance and implant considerations of the 3D printing technology in the dental field, considering the patient comfort, efficiency, time of treatment, and prosthesis life, among other factors. There is good retention of the milled, complete, removable dental prostheses. At the same time, some 3D-printed dentures have produced favourable outcomes in the short term but will require some improvements in the materials used to obtain better service longevity.

Digital impression systems enhance comfort and reduce impression times but vary in effectiveness. Digital navigation for implant placement improves clinical outcomes and reduces patient visits. Comparisons between milled and 3D-printed CRDPs reveal similar performance, though milled options need fewer adjustments. Patient satisfaction with digital workflows is generally high, particularly with specific systems. While digital dentures reduce clinic visits, they may necessitate more adjustments, and many patients still prefer traditional options for comfort.

Current SLR also emphasizes that patient satisfaction with 3D-printed dental prosthetics has generally been positive, particularly regarding digital workflows. Studies indicate that patients appreciate the reduced number of clinic visits associated with digital denture fabrication, although some still prefer traditional options for comfort reasons. For instance, a study involving 35 edentulous patients reported significant improvements in oral health-related quality of life after receiving 3D-printed complete removable dental prostheses (CRDPs).[41]

Another review noted that initial patient-related outcomes for digital dentures were favourable, although long-term satisfaction may be affected by material degradation over time.[42] Other studies also emphasize that treatment efficiency has markedly improved by introducing digital impression systems and 3D printing technologies. Digital impressions enhance patient comfort and significantly reduce the time required for traditional impressions. However, the effectiveness of these systems can vary.[43]

A meta-analysis shows that digital navigation for implant placement has also been shown to improve clinical outcomes and decrease the number of patient visits needed for successful treatment.[44] This efficiency is further supported by evidence suggesting that 3D printing can streamline workflows, allowing for quicker turnaround times in prosthetic production.[45]

While milled CRDPs have demonstrated good retention and lower adjustment needs, 3D-printed dentures show promising short-term results but face challenges regarding long-term stability. Research indicates that 3D-printed dentures are initially effective but may require material enhancements to ensure durability over time. A comparative study highlighted that CAD/CAM milled dentures exhibited superior dimensional stability compared to their 3D-printed counterparts after prolonged use.[46]

The aesthetic quality of 3D-printed prostheses may decline over time due to colour changes in acrylic resins, which could impact patient satisfaction in the long run.[47] While comparing milled and 3D-printed CRDPs, studies reveal similar clinical performance; milled options typically require fewer adjustments. This aspect is crucial for dental practices that optimize patient care and operational efficiency. The body of research suggests that while both methods have their advantages, continuous improvements in materials for 3D printing could bridge the gap in performance between these two approaches.[48]

In conclusion, integrating 3D printing technology in dental prosthetics transforms patient care by enhancing satisfaction through improved comfort and reduced treatment times. However, further research into material properties and long-term performance remains needed to realise the potential of this technology. As advancements continue, patient outcomes and clinical efficiencies will likely improve, making 3D printing an increasingly viable option in prosthodontics.

This review underscores the importance of ongoing studies to validate these findings and explore new materials that could enhance the durability and aesthetic longevity of 3D-printed dental prosthetics. The current SLR also specified the difficulties of using different prostheses in three-dimensional printing and dental restoration. High costs, coupled with the technical difficulties involved, cover such things as the high cost of the equipment, the requirement of skilled personnel, and the maintenance, which takes much time.

These financial and technical challenges can hinder accessibility and efficiency in clinical settings despite the advantages of 3D printing technologies. The issues of accuracy and fit are also of paramount importance, showing the inconsistencies, the difficulties of fitting prostheses to the patient's contours, and narrow joints possibly impacting the functioning of the prosthetics. The interrelations of the material properties and their durability eliminate the problems of material heterogeneity and possible fractures and chipping that stress the need for suitable materials for durability.

Additionally, aesthetics and patient satisfaction focus on achieving high aesthetic standards, while workflow and ease of use emphasize the need for streamlined processes to improve clinical efficiency. Each category highlights areas for further research to enhance patient outcomes in dental prosthetics.

Similarly, other studies also show the findings regarding complications related to 3D printing in dental restoration, highlighting several critical challenges that align with recent studies. High costs and technical

requirements remain significant barriers to the widespread adoption of 3D printing technologies in dentistry. A Delphi study identified the lack of knowledge among dental professionals as a primary obstacle, alongside the high training effort required for staff and a preference for traditional methods such as milling.[49]

This aligns with the concerns about expensive equipment and the need for trained personnel, which can hinder accessibility and efficiency in clinical settings. Recent studies emphasize that while 3D printing offers cost-effective solutions in the long term, initial investments are substantial. For example, a study on 3D-printed temporary crowns reported a production cost of approximately €0,40 per crown, suggesting potential economic benefits if practices overcome initial financial hurdles.[50] However, the necessity for ongoing maintenance and training continues to pose challenges.

Accuracy and fit are critical concerns in dental prosthetics. Research shows that the standard procedures for crown fabrication result in marginal discrepancies that may lead to complications such as bacterial colonization and decay. On the other hand, 3D printers fabricate objects in layers, which enhances their accuracy. A research study established that the edge and internal gap values on the 3D printed restorations were significantly lower than those performed on a milling machine, indicating an improvement in fit. Nonetheless, variability in the material's properties sometimes results in problems with fit and performance, which warrants more research on uniformity and quality.[51]

Material selection is essential in providing the patient with a durable dental prosthesis. Some studies have shown that while certain 3D-printed resins have good mechanical strength, others may have cytotoxicity or low-strength properties. Additives such as zirconia have been reported to enhance flexural strength, which is essential in extending restorative structures' life span.[52] This emphasizes the need for further investigation of the materials' compositions to improve the mechanical properties and biocompatibility.

Another aspect where 3D printing may be beneficial is workflow efficiency. Conventional approaches involve multiple visits and lengthy procedures. On the other hand, technically advanced centres employing 3D printing take one visit to manufacture, design, and implant the crowns. Nevertheless, some factors still act as barriers to implementation due to practitioners' lack of knowledge of Chichester's adoption of the technology into regular practice.[53]

In summary, studying challenges accruable to 3D printing in dental restoration offers both opportunities and challenges. Though the evolution of technology improves accuracy, customization, and patient satisfaction, several hurdles, such as resource constraints, the variability of materials and their practical application, should be addressed. These technologies should be adopted more generally in practice by advancing the standardization of materials and processes and improving the orientation of dentists towards innovative technologies.

CONCLUSIONS

This research is aimed at assessing the applicability and operational characteristics of 3D printing technology with the focus on its actual use in dental procedures and its effect on patients. All the components of the systematic literature review (SLR), which included analysis of various types of studies, literature review, randomized controlled trials, clinical and observational studies and in vitro research, are of help in elucidating the strengths and weaknesses of the technology.

The application of 3D printing technology has ensured a better scope of care to the patient by improving the workflow, minimizing clinic visits, and providing an option for customized treatment. The ability of tailoring the services, and optimizing the technological processes has had a positive effect on the patients' appeasement. Still, there are some challenges such as increased costs, technical specifications, and the material characteristics that restrain the accuracy, fit, and strength of the endoskeletal prostheses.

The clinical performance and long-term reliability of the 3D-printed prostheses are, however, affected by issues such as material degradation and poor durability. Aesthetic aspects should also be addressed as the current printers have a narrow resolution that does not meet patient satisfaction. Such aspects point out the need for further improvement of the materials and technology used in practice for better clinical outcomes and patient experience.

Looking into the future, it is suggested that efforts should be made to further enhance the material properties, increase the effectiveness of the workflow and make it affordable in order to continue embedding 3D printing in daily dental practice. Addressing these challenges would propel 3D printing to emerge as a paradigm shift in the field of dental prosthetic engineering which would eventually serve the patients better, and transform the world of dentistry.

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