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Dr. Diego Tueme Mendoza
Posgrado de Prostondoncia. Facultad de Odontología. Universidad Autonoma de Nuevo León. Dr. Eduardo Aguirre Pequeño, Mitras Centro, Monterrey, NL Mexico

Corresponding Author:
Dr. Diego Tueme Mendoza
Posgrado de Prostondoncia. Facultad de Odontología. Universidad Autonoma de Nuevo León. Dr. Eduardo Aguirre Pequeño, Mitras Centro, Monterrey, NL Mexico

3D Technology: Its impact on the different fields of dentistry

Diego Tueme Mendoza

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Abstract
Introduction: The digital era has driven significant technological advances, with 3D printing emerging as a key tool in modern dentistry. This technology has optimized precision and efficiency in dental care, while reducing costs and improving access to high-quality treatments for patients.
Objective: To examine scientific literature on the advancements of 3D printing in prosthodontics, implantology, periodontics, and orthodontics.
Methodology: A comprehensive search was conducted in the PubMed, Scopus, and Google Scholar databases using terms such as "3D Printing," "Dental Cam", "Implant Guide" and "SLA".
Conclusion: 3D printing represents a paradigm shift across various fields of dentistry by enabling more precise and personalized treatments. While its advantages in efficiency and material innovations are acknowledged, ongoing clinical research is essential to validate its efficacy and ensure optimal integration into professional practice.

Keywords: 3D printing, dental materials, precision, strength, surface morphology, print orientation

1. Introduction

General Background: The digital transformation has driven notable advancements across various medical fields, particularly in dentistry, with the advent of 3D printing. This technology has been instrumental in optimizing the precision and efficiency of dental treatments while contributing to cost reduction, significantly enhancing patient access to superior-quality dental care (Balhaddad *et al*., 2023) [7].

Specific Background: 3D printing technologies have undergone rapid development in dentistry and its various specialties, enabling customized designs and the production of multiple clinical devices and applications, such as surgical guides for implants, definitive crowns, orthodontic appliances, and more (Khorsandi *et al*., 2021) [18]. These advancements have not only streamlined clinical workflows but also enriched dental education and increased patient awareness.

Detailed Background: The incorporation of 3D printing in dentistry is not only transforming traditional procedures but also opening new possibilities for more personalized dental care. Despite growing interest and improvements in applications, long-term clinical studies are crucial to establish standards and confirm the safety and efficacy of these technologies (Balhaddad *et al*., 2023) [7]. This study aims to delve into the current state of 3D printing across various dental specialties to facilitate the transition of its applications from the laboratory to clinical practice.

Justification: 3D printing is revolutionizing dentistry by enabling the design and production of tools and devices with exceptional precision and notable cost reduction. This comprehensive review highlights emerging technologies and the dental fields that benefit most from their implementation, emphasizing their impact on current dental treatments and the immense potential these advanced solutions bring to the future of modern dental practice.

1.1 Objective
To examine the literature on 3D printing and its advancements in prosthodontics, implantology, periodontics, and orthodontics.

2. Methodology
An exhaustive analysis of relevant articles was conducted through the PubMed, SCOPUS, and Google Scholar databases, focusing primarily on publications from the last three years. The quality of the studies was assessed using the PRISMA methodology, which includes identification, selection, screening, and inclusion stages. The quality of systematic reviews was evaluated with the AMSTAR-2 tool. The search strategy employed Boolean operators such as AND, OR, and NOT, along with keywords like "3D Printing", "Dental Cam", "Implant Guide" and "SLA" both individually and in combination.

3. Results
3.1 Prosthodontics
Dentistry has been a pioneer in adopting digital technologies, with 3D printing in prosthodontics serving as a clear example of its impact. This technology has radically transformed the fabrication of dental prostheses, enabling digitized processes that offer high precision and appropriate functionality (Zhou *et al*., 2021) [44].

3D printing has proven effective in manufacturing fixed prostheses, both for teeth and dental implants, achieving remarkable precision in individual or short-span implant sites within clinically acceptable limits. However, the accuracy of full-arch impressions remains a subject of debate. Some studies suggest that conventional techniques are more precise for full arches, although advancements in digital methods have progressively improved reliability (Michelinakis *et al*., 2021) [23].

For complete dentures, research indicates that digitally fabricated prostheses provide adaptation comparable to or superior to traditionally made ones. These prostheses stand out for minimal occlusal discrepancies and the precision achieved through CAD-CAM milling and 3D printing technologies (Wang *et al*., 2021) [38].

While aesthetics and biocompatibility of materials used for removable prostheses are crucial, there is still insufficient evidence regarding the biocompatibility and clinical performance of printed dentures, highlighting the need for further studies (Alhallak & Nankali, 2022) [4].

Additionally, 3D-printed crowns demonstrate high precision and minimal occlusal adjustments, enabling more predictable and cost-effective rehabilitations (Höhne & Schmitter, 2022) [15]. The resins used in 3D printing also exhibit promising mechanical and biological properties, suggesting their viability as definitive materials in clinical settings (Atria *et al*., 2022) [6].

Additive manufacturing of dental devices is influenced by multiple factors, such as the technology employed, printer, and materials selected, along with printing parameters, support structures, and post-processing techniques. Proper optimization of these elements is essential for clinical success and quality outcomes (Piedra-Cascón *et al*., 2021) [27].

In summary, the digitalization of dentistry, driven by 3D printing, has revolutionized prosthodontics by enhancing precision and functionality in prosthesis fabrication. While advances are promising, especially in fixed prostheses and complete dentures, challenges remain, such as accuracy in full arches and long-term material biocompatibility.

3.2 Implantology
In dental implantology, the integration of 3D printing has revolutionized both restorative and surgical dentistry, achieving levels of precision and accuracy previously unattainable (Yeung *et al*., 2020) [42]. The combined use of cone-beam computed tomography (CBCT) and intraoral scans has enabled professionals to plan and execute implant procedures with remarkable accuracy (Katkar *et al*., 2020) [16]. A study by Yeung *et al*. (2020) [42] evaluated the accuracy of 3D-printed surgical guides across various implant systems. Results revealed that, despite some dimensional and angular variations, deviations remained within clinically acceptable limits—a key factor for long-term surgical success.

Similarly, Al Kabany (2023) [2] compared linear and angular deviations in implant preparation sites using a novel sliding guide printed in 3D versus a conventional static guide. Findings indicated that the sliding guide significantly reduced angular deviations, enhancing implant placement precision.

In treatment planning, Papaspyridakos *et al*. (2022) [26] emphasized the relevance of a digital workflow for patients with terminal dentition. This approach, which includes digital smile design and restorative simulations, allows for prosthetically guided evaluation before implant planning, improving treatment predictability.

Li *et al*. (2020) [20] developed a patient-specific implant for mandibular reconstruction using metal 3D printing, employing topology optimization and finite element analysis. This approach demonstrated that customized implants deliver optimal biomechanical results and aesthetics in patients with severe mandibular defects.

Another study by Rouzé l'Alzit *et al*. (2022) [32] assessed the accuracy of commercial 3D printers in fabricating surgical guides. Results indicated that guide size influences accuracy, with smaller guides being more precise regardless of the printing technology used.

Neumeister *et al*. (2017) [25] examined the accuracy of 3D-printed drill guides, confirming that CAD/CAM technology produces guides with minimal deviations of only 0.25 degrees from the planned implant position. This highlights the importance of precision in guide fabrication.

Frahsek (2023) [12] discussed how digitalization, including digital volumetric tomography (DVT) and 3D printing, enhances both precision and reproducible clinical outcomes in implantology. Finally, Pradíes *et al*. (2023) [29] conducted a review on 3D printing applications in dental implantology, highlighting its potential to optimize the quality of prosthetic structures and surgical procedures. The integration of 3D printing in implantology has significantly enhanced precision and efficiency in dental prosthesis fabrication. Although challenges related to adaptation and biocompatibility persist, advanced data utilization, such as CBCT and intraoral scans, has enabled more accurate planning and execution of implants. Innovations in 3D-printed surgical guides, combined with digital workflows, are redefining treatment planning with a more aesthetic and functional focus. The customization of implants through CAD/CAM technology underscores the potential of 3D printing to provide superior solutions in biomechanics and aesthetics, paving the way for more precise, efficient, and personalized dentistry.

3.3 Periodontics
Periodontics is undergoing a significant transformation with the implementation of 3D printing, a technology revolutionizing clinical and educational procedures in this

specialty. The following summarizes its most notable applications, particularly in periodontal tissue regeneration and surgical procedures such as gingivectomies, osteotomy guides, and apicoectomy guides.

3D printing allows the creation of customized three-dimensional objects from digital designs and precise manufacturing processes using specific materials. In periodontics, this technology has been applied in surgical guides, educational models, and dental reconstructions. However, its use for soft tissues such as oral mucosa and gingiva remains in its early stages. Nesic highlights the potential of 3D printing in regenerative medicine, noting its ability to create customized oral soft tissue grafts that deliver satisfactory functional and aesthetic results (Nesic, 2020) [24].

Biological 3D printing is advancing rapidly in dental regeneration, addressing the structural complexity and cellular interactions of dental tissues. According to Ma (2019) [21], 3D-printed scaffolds for dental and periodontal tissue regeneration are offering new perspectives in biofabrication and regeneration.

Tao (2020) [35] analyzed the use of 3D printing in craniofacial tissue engineering, including the periodontal complex, alveolar bone, and cartilage. While promising, further research is needed to fully integrate these techniques into clinical dentistry.

Yen and Stathopoulou (2020) [41] emphasized how CAD/CAM and 3D printing technologies have improved the customization of grafts for alveolar ridge augmentation, significantly reducing surgical time. However, long-term stability and predictability require further validation.

Laird (2021) [19] highlighted that combining 3D printing with nanotechnology enhances the properties of tissue engineering scaffolds, improving cellular interaction and their ability to stimulate periodontal regeneration.

In a biomimetic approach, Roato (2022) [31] examined how bioprinting and dynamically controlled environments can improve regeneration of the periodontal ligament, alveolar bone, and cementum, addressing major challenges in periodontal tissue engineering.

Sufaru (2022) [33] reviewed applications of 3D-printed membranes and scaffolds for periodontal regeneration, emphasizing innovative techniques such as guided bone regeneration (GBR) and guided tissue regeneration (GTR), which are setting new standards in periodontal regeneration.

Regarding biodegradable bone scaffolds, Rider (2018) [30] compared various 3D printing techniques, highlighting their potential for dental applications such as alveolar ridge augmentation.

Zhou (2023) [43] reported on the use of reverse 3D-printed guides for autogenous tooth transplantation, significantly reducing donor tooth exposure time and improving alveolus preparation accuracy.

Lastly, Gul (2019) [14] emphasized the impact of 3D printing on education and training in periodontics, as well as its utility in clinical applications for regeneration and repair.

In summary, 3D printing is enriching periodontics by offering new possibilities for tissue regeneration and surgical procedures. While its application in surgical guides and educational models is well established, its potential for soft and hard tissue regeneration remains under development. Bioprinting is emerging as a revolutionary technique, with the potential to achieve more precise and biomimetic periodontal tissue regeneration. However, further research is necessary to ensure its long-term safety and effectiveness.

3.4 Orthodontics

3D printing technology is revolutionizing the field of preventive orthodontics by introducing more precise and efficient digital fabrication of key devices, such as band-and-loop space maintainers. According to Khanna *et al.* (2021) [17], these maintainers, created through 3D printing, not only preserve dental arch integrity with superior accuracy but also significantly reduce common human errors associated with traditional methods. This represents a crucial advancement in the customization of orthodontic devices and enhances the experience for both professionals and patients.

In the realm of clear aligners, Bichu *et al.* (2022) [8] explored advancements in the materials used, emphasizing their success hinges on factors such as the strength, flexibility, and durability of the employed polymers. Recent developments in biomaterials and CAD/CAM technologies have driven these innovations. Notable examples include shape-memory polymers, which allow for more controlled dental movements, and bioactive materials that promote oral health during treatment. The authors also stressed the importance of environmentally sustainable production methods, paving the way for a greener future in orthodontic therapy.

The precision of 3D-printed dental models is another crucial aspect of modern orthodontics. Tsolakis *et al.* (2022) [36] conducted a systematic review, concluding that various 3D technologies, such as stereolithography (SLA) and fused deposition modeling (FDM), can produce models with clinically acceptable accuracy levels. However, they noted variability among technologies and materials, requiring further studies to identify the most reliable and efficient options for routine orthodontic use.

Zinelis *et al.* (2022) [45] conducted a specific analysis of the mechanical properties of aligners fabricated with different types of 3D printers, finding that LCD printers outperform DLP printers in terms of strength and flexibility. This highlights how the choice of printing technology can directly influence the effectiveness and comfort of orthodontic devices.

Maspero and Tartaglia (2020) [22] explored the possibilities of direct 3D printing for the fabrication of clear aligners. This method eliminates intermediate stages in the manufacturing process, enhancing material properties and allowing for more effective and personalized treatments. Direct 3D printing is positioning itself as a viable alternative to traditional techniques, opening new opportunities for customization and efficiency in orthodontics.

Etemad-Shahidi *et al.* (2020) [11] evaluated the precision of full-arch dental models produced through 3D printing. While they found that the technology is generally adequate for orthodontic applications, they noted that treatments requiring extremely high precision, such as complex surgical procedures, could benefit from stricter design and manufacturing standards.

Ergül *et al.* (2023) [10] offered a broader perspective on the impact of 3D printing in orthodontics, emphasizing its potential to completely transform clinical workflows through digital integration. This transformation not only enhances operational efficiency but also allows professionals to offer more personalized and reproducible solutions.

Regarding retainers, Tsoukala *et al.* (2023) [37] identified directly 3D-printed retainers as a promising alternative to traditional materials. These devices are not only more cost-effective to produce but also offer advantages in terms of comfort and fit. However, the authors stressed the need for additional clinical trials to fully assess their long-term efficacy and durability.

Francisco *et al*. (2022) [13] highlighted how 3D digital technology is revolutionizing diagnosis, treatment planning, and case monitoring in orthodontics. This digitalization allows orthodontists to perform more precise evaluations and adopt more effective treatment strategies, significantly improving clinical outcomes and the patient experience.

Finally, Alam *et al*. (2023) [3] pointed out that 3D printing, along with technologies such as CAD/CAM, biopolymers, and teleorthodontics, is shaping the future of modern orthodontics. However, they recommend adopting these technologies cautiously and based on robust research, given the rapid pace of technological evolution and the need to ensure quality standards.

In conclusion, 3D printing is redefining preventive orthodontics by introducing significant advancements in the precision, efficiency, and customization of orthodontic devices. While the benefits of these technologies over traditional methods are evident, further studies are needed to support their long-term efficacy and durability. With ongoing material and technique development, 3D printing is likely to drive a complete digital transformation in orthodontics, establishing a new standard in patient diagnosis, treatment, and follow-up.

4. Conclusions

3D printing is driving a revolution across multiple dental specialties, including prosthodontics, implantology, periodontics, and orthodontics, by introducing significant improvements in precision, efficiency, and treatment personalization. This technology offers transformative potential in areas such as the fabrication of dental prostheses, surgical implant planning, and dental and periodontal tissue regeneration. However, important challenges remain, such as achieving precision in full arches, ensuring the biocompatibility of materials, and conducting more clinical studies to validate its long-term efficacy. It is crucial to adopt these technologies cautiously, carefully evaluating their practical applications while optimizing outcomes for patients. As 3D printing continues to evolve, it will redefine the standard for dental procedures, enhancing the quality of care and fostering a more personalized approach to treatment.

Conflict of Interest

Not available

Financial Support

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