

Review Article

3D Printing in Dentistry: A Narrative Review

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ABSTRACT

Three-dimensional (3D) printing (additive manufacturing) is a new breakthrough in the modern dentistry that is more accurate, customized, and effective than traditional methods. Initially developed as an industry-scale prototyping system, 3D printing has evolved in a very short time into a digital dentistry core product with imaging, computer-aided design (CAD), and biocompatible material developments. Its applications have since been distributed to a variety of dental specialties, such as in prosthodontics, orthodontics, implantology, oral and maxillofacial surgery, periodontics and endodontics. Crowns, bridges, dentures, surgical guides, aligners and tissue scaffolds can be manufactured using 3D printing in clinical practice and increase predictability of treatment outcome and patient satisfaction significantly. Moreover, the implementation of chairside 3D printing has reduced the dependence on the laboratory, reduced the time of treatment, and optimized the workflow. Recent progress, in bio-printing and regenerative therapies, also promises opportunities in the use of 3D printing in synthesis of scaffolds and biomaterials in bone and periodontal regeneration, and a future of biologically integrated applications. Scattered with its impressive potential, problems can still be pointed out, such as the high start-up cost, lack of long-term statistics on the performance of materials and the fact that regulatory and educational structures are necessary to facilitate safe implementation. Comparison with the literature in the past shows consistent evidence of accuracy and efficiency, and highlights current limitations in material science and standardization. In general, 3D printing is a paradigm shift in dental care, and ongoing technological and scientific advancements bring the industry to the next stage of fully personalized, cost-effective, and regenerative treatment options.

Keywords: Additive manufacturing, Bio-printing, Digital dentistry, Implantology, Orthodontics, Prosthodontics, Regenerative dentistry, Surgical guides



BACKGROUND

Modern dentistry has been transformed by the introduction of the latest digital technologies, and 3D printing is one of the most revolutionary technologies of the past decades. Also called 3D printing, additive manufacturing is the process of creating digital designs into three-dimensional objects by manual layer-by-layer printing [1]. The technology was initially popularized within the engineering and industrial production sectors but soon spread to healthcare, particularly within the dentistry industry, due to its possible ability to offer precision, customization, and efficiency [2]. Such a paradigm shift of the classical subtractive model of additive manufacturing has assisted clinicians and dental technicians in achieving results that before were thought difficult or even impossible [3]. The 3D printing in dentistry is a wide-ranging and constantly evolving domain. This has been very beneficial to prosthodontics, particularly in the production of crowns, bridges, dentures, and implant-supported prostheses [4]. Orthodontics has adopted 3D printing to design custom brackets, clear aligners, and study models that can be used to plan the treatment and communicate with patients. Surgical guides and patient-specific implants can be 3D printed to make interventions less risky and predictable in oral and maxillofacial surgery [5]. Furthermore, regenerative treatments, periodontics, and restorative dentistry are slowly starting to incorporate 3D-printed scaffolds and biomaterials in order to improve clinical outcomes [6]. The advantages of 3D printing are not confined to clinical applications only. It offers tailored care using less chairside time and greater satisfaction to patients. It can help practitioners make the workflow more efficient by minimizing lab errors, waste, turnaround time. Moreover, Internet-based design storage provides easy reproducibility and long-term storage that can be retrieved in the future [7]. These benefits highlight the fact that 3D printing is not a technical add-on but a facilitator of a more patient-centered, cost-effective oral healthcare model. The potential of 3D printing in the field of dentistry is impressive but, not surprisingly, there are challenges related to it [8]. Initial investment cost is another significant impediment to universal use, and material biocompatibility is also needed, as is regulatory approval and special training. Additionally, the questions regarding the quality and reliability of 3D-printed restorations and appliances with time remain raised and the issue needs to be researched by scientists [9]. As more technology is added, these limitations should be addressed using research, innovation, and evidence-based practices to facilitate safe and effective integration into daily dental practice [10]. It is therefore important to determine the current state of 3D printing, its applications, issues surrounding it, and the future of 3D printing in the field of dentistry.

REVIEW

Background and Historical Perspective

Additive manufacturing, or 3D printing, traces its origins to the early 1980s when Charles Hull developed the first method to make three-dimensional objects by curing liquid resin with ultraviolet light (stereolithography, or SLA) [11]. This innovation was first adopted by industry as a prototype of the various types of 3D printing technologies today, such as selective laser sintering (SLS), fused deposition modeling (FDM), and digital light processing (DLP) [12].

The rapid expansion of the field continued over the next few decades with the development of computer-aided design (CAD), digital imaging, and biomaterials science. One of the first fields of healthcare to see the possibilities of 3D printing was dentistry [13]. This was first adopted in the 1990s when CAD/CAM (computer-aided design/computer-aided manufacturing) systems started to gain prominence [14]. These systems transformed the field of restorative dentistry as they allowed digitization of impressions and automatic milling of crowns and bridges. But with increased accessibility to additive manufacturing, it has started to provide even more flexibility and accuracy than subtractive methods [15]. In the early years, dentistry was involved in producing diagnostic models as well as wax models used to make casted prosthetic components. In early 2000s, milestones were reached which indicated that 3D printing could be used in laboratories or in usual clinical practices. The implementation of 3D-printed surgical guides enabled the oral and maxillofacial surgeons to plan and perform the implant surgeries more accurately than ever before [16]. At the same time, orthodontists began using 3D-printed models to print clear aligners, changing the way orthodontic treatment is delivered across the globe. Biomimic resins further stimulated the development of functional intraoral products like splints, retainers and denture bases. Over the past few decades, the mechanical reproduction has been enhanced to develop 3D printing that is used biologically [17].

The printing of scaffolds has been demonstrated in bio-printing research and used in tissue engineering and regenerative dentistry, and has potential applications in alveolar bone regeneration and periodontal repair. This trend is a bigger dentistry trend—the transformation of restorative to regenerative and patient-specific solutions [18]. Today, one of the pillars of digital dentistry is 3D printing, supported by high-resolution intraoral scanners, other modern imaging (CBCT (cone beam computed tomography)) and strong CAD software. Its history indicates a clear development: to prototyping, to functional prosthesis, to mechanical guides, to biological scaffolding, to laboratory-based equipment, to clinical solutions at the chairside. It is against this background that we can gain insight into the transformative potential of 3D printing in the future of dental care.

Table 1: Development of 3D printing in dentistry over the years

Period	Development	Key Milestones
1980s	Generalisation of 3D printing technology	Charles Hull launched Stereolithography (SLA) in 1984, laying the basis for future usage.
1990s	Early study and evaluation in the dentistry and healthcare domains	At first, simple resin materials were used in dentistry to make prosthesis and dental prototypes.
Early 2000s	Combined with digital dentistry	3D printing and CAD/CAM technology coupled for surgical guides, dental crowns, and bridges.
2010–2015	Quick uptake and technological advancements	Biologically compatible substances for 3D printing are introduced, comprising metals, ceramics, and dental-grade resins.
2015–Present	Rise in dental applications for 3D printing	Enhanced precision and Customisation in making of surgical guides, aligners, implants, and patient-specific restorations.
Future	Progress in tissue engineering and material science	Bioprinting research for regenerative dentistry is in progress, with a view to create teeth or gums that are functional.

Modern Technology and Recent Advances

The current technological advancements with 3D printing technologies have facilitated the rapid development of digital dentistry, and modern practice is now reaping the benefits of high-resolution printers, biocompatible materials, and high-quality imaging systems that are all redefining precision, efficiency, and patient-centered care [19]. Significant developments in high-end printing technologies modified to serve dental applications, including stereolithography (SLA) and digital light processing (DLP), are both extremely precise and sufficiently detailed to produce surgical guides, aligners, and prosthetic frameworks. Selective laser sintering (SLS) enables manufacturing of metal components such as cobalt-chromium crowns and implant abutments to be produced without casting, and fused deposition modeling (FDM) has been optimized to produce cost-effective educational prototypes and models [20]. These developments have enabled dentists to create restorations and appliances that are extremely accurate, close to the patient anatomy. Meanwhile, material science has developed to accommodate biocompatible and functional applications and contemporary resins are permitted to be used intra-orally in permanent crowns, temporary restorations and splints, as well as in ceramic-impregnated polymers, which improve both esthetics and strength [21]. Titanium and zirconia prepared through powder-bed fusion procedures have now become common in long-lasting implant-supported restorations, and bio-inks and scaffold materials are spawning new opportunities in bone and soft tissue engineering. The other disruptive innovation is the creation of chairside and point-of-care solutions such that prostheses or surgical guides can be printed in the dental office. The combination of intraoral scanners and CAD/CAM software ensures same-day restorations and shortens the treatment time

considerably, increasing the level of patient satisfaction [22]. Furthermore, the efficient interconnection of digital technology with CBCT scans, digital impression scanners, and artificial intelligence has made workflows more efficient, as AI-based platforms help in planning treatment, optimizing prostheses, and forecasting the future. Probably the most niche of futuristic developments can be seen in the field of regenerative and bio-printing, where biomimetic scaffolds can be created using living cells, hydrogels, and growth factors. Dentistry is on the verge of biological replacement therapy with experimental studies actively examining the regeneration of alveolar bone, periodontal tissues and pulp-dentin complexes [23].

Clinical Applications

In the fields of prosthodontics and restorative dentistry, 3D printing has promoted the production of crowns, braces, veneers, and removable dentures, and biocompatible resins and ceramic-filled materials allow the production of restorations with accurate fit and esthetics digitally designed and 3D-printed. It can also be used to quickly produce temporary restorations, custom trays and wax patterns, simplifying lab workflows and shortening turnaround time [4]. Clear aligners, customized brackets and retainers are some of the items that are now manufactured using 3D printing in orthodontics. Through digital models generated after intraoral scans, patient comfort and accuracy are improved because traditional impressions are not required. Software-guided sequential aligner fabrication ensures effective and predictable tooth movement, which transforms the modern orthodontic practice [5]. Surgery Planning and Guidance results 3D printing is used in the field of oral and maxillofacial surgery to aid surgical planning and intraoperative

guidance by creating custom anatomical models using CBCT or CT scans to help the surgeon visualize intricate structures and plan resections or reconstructions. There are custom surgical guides, which provide greater accuracy in the placement of implants, orthognathic surgery, and tumor resections, and patient-specific implants and prosthetic reconstructions, which are more effective in maxillofacial rehabilitation than tibial-fibula indexes [24]. Surgical templates created during 3D printing enable very precise placement of implants in the body in the field of implantology to minimize errors in surgery and infection after surgery. Bespoke abutment and frames used in implant-supported restorations can be fabricated quickly, and offer great congruence to patient morphology, and current studies are evaluating 3D-printed biomaterials to assist bone growth and sinus augmentation. Biomimetic structures of 3D-printed scaffolds are also relevant to periodontics and regenerative dentistry, as they offer cell growth, vascularization, and integration frameworks that have shown promising outcomes in periodontal and bone regeneration. Bio-printing developments are also opening the door to the regeneration of periodontal ligament, alveolar bone and pulp-dentin complexes [1].

DISCUSSION

The implementation of 3D printing in the field of dentistry has greatly improved the accuracy of diagnosis, treatment planning, and patient outcomes. This review outlines the transformative potential of additive manufacturing, but it is also critical to assess the current effectiveness of the concept in the context of the existing literature.

According to a study by Dawood A et al. (2015) [25], 3D printing was termed as a revolutionary technology in the field of prosthodontics, especially the production of crowns, bridges, and surgical guides. Their findings were directed towards the saving of costs and increased accuracy as compared to the traditional practices. The latter are the conclusions that we came to at the time, specifically regarding efficiency and accuracy, but we also go further, mentioning the modern improvements to the material, such as the ability to make ceramic-filled resins or titanium printing, which were more primitive at the time.

Similarly, Revilla-Leon M et al (2018) [26] conducted a comprehensive review of additive manufacturing in dentistry and concluded that despite the important role of accuracy and speed, clinical performance was determined by the limitations of the materials. Our results support this observation, as the current advancement of the biocompatible resin and zirconia-based prints continue to enhance the reliability, yet, the factors of long-term stability remain unaddressed.

It states that despite that improvement, material science remains the key to a broader adoption. Beefathimathul H et al. (2025) [27] performed a third comparative study to assess the use of 3D printing in orthodontics and

implantology. They proved to be highly accurate in the manufacture of aligners and implant surgical guides with less treatment time. Our analysis supports these results and provides additional evidence of recent advances in AI implementation, which have contributed to improvements in design and predictive results, not previously available. This is an indication of the increasing digital ecosystem in which 3D printing is incorporated. Ramadan Q (2021) [28] recently highlighted the needs of 3D printing in regenerative dentistry and tissue engineering, which is a frontier technology rather than a standard practice. Their claim is endorsed in our review, and there is increasing clinical translation of regenerative scaffolds, especially in bone augmentation and periodontal repair. Although bio-printing is in its early developmental phases, advances during the past five years indicate a shift between conceptual and initial clinical use. Combined, these comparisons indicate that the path of 3D printing in dentistry has shifted away, though not to the point of irrelevance, from proof-of-concept uses to clinically applicable, integrated applications. Nonetheless, constraints in material strength, regulatory standards and training considerations continue to limit universal adoption. Research and evidence-based validation would be required to make 3D printing a regular standard of care in every field of dentistry and not a promising adjunct.

CONCLUSION

Being the most accurate, flexible, and fast in terms of producing dental equipment and devices, 3D printing has brought a revolution to the world of dentistry. The technique relies on high-tech digital design and additive manufacturing to create surgical guides, crowns, bridges, and aligners in a highly precise manner. 3D printing improves the quality and functionality of dental procedures by combining CAD software, different printing processes, and subsequent methods. This new technology in dental applications will continue to increase and will drive improvements in patient care and practice efficiency. The fact that it is always evolving implies that dental treatment will be even more specific and accurate.

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Ansh Mittal: Contributed to the conceptualization, writing of the original draft, and data analysis.

Simran Sapra: Led the study design and methodology. Supervised the overall research process and critically reviewed the manuscript.

Savita Bansal: Contributed to data collection, analysis, and interpretation. She also provided substantial revisions to the manuscript.

Bitasta Roy: Assisted in writing and reviewing the manuscript, providing insights into the interpretation of the findings.

Ansh Midha: Contributed to the writing and reviewing process. Provided critical revisions and helped in the final drafting of the manuscript.

ABBREVIATIONS USED IN THE STUDY:

- a) 3D: Three-dimensional
- b) CAD: Computer-Aided Design

- c) CAM: Computer-Aided Manufacturing
- d) SLA: Stereolithography
- e) SLS: Selective Laser Sintering
- f) FDM: Fused Deposition Modeling
- g) DLP: Digital Light Processing
- h) CBCT: Cone Beam Computed Tomography
- i) AI: Artificial Intelligence

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