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Review Article

Digital dentistry: Evolution, current applications, and future directions

Erika De Vries[1], Shilpi Deshpande[2*], Sruthi Kalalota[3], Salina Manandhar[4], Ridhi Bhola[5], Sandeep Singh[5]

[1]Wroclaw Medical University, Poland
[2]Government Dental College, Aurangabad, Maharashtra, India
[3]Drs Sudha and Nageswara Rao Siddhartha Institute of Dental Sciences, Gannavaram Mandal, Andhra Pradesh, India
[4]Rangpur Dental College, Rangpur, Bangladesh
[5]Postgraduate Institute of Dental Sciences, Rohtak, Haryana, India

Abstract

The advent of digital dentistry has significantly transformed how dental practitioners deliver care. Digital dentistry involves the integration of modern digital technologies across various dental practices, including diagnosis, imaging, treatment planning, and patient rehabilitation. This approach incorporates tools such as CAD/CAM systems, 3D printing, artificial intelligence, augmented reality, and teledentistry. As a dynamic and fast-growing field, digital dentistry is reshaping clinical workflows. Dental professionals are increasingly incorporating advanced solutions into daily practice to enhance productivity, reduce time and costs, and improve patient experiences. This article provides a concise overview of the evolution of digital dental technologies, explores their current applications in clinical settings, and offers insights into future advancements. To enhance understanding, real-life examples of how digital dentistry is being used in modern dental practices are also provided to the reader.

Keywords: Artificial intelligence, Augmented reality, CAD/CAM, Chatgpt, Digital dentistry, 3D printing, Extraoral scanning, Intraoral scanning, Teledentistry.

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1. Introduction

Digitalization has significantly influenced every facet of dentistry, reshaping conventional workflows and redefining the communication among dentists, surgeons, and laboratory professionals. Integrating digital technologies has streamlined communication and collaboration, resulting in more efficient and predictable treatment outcomes. In recent years, digital dentistry has emerged as a prominent and indispensable branch of the profession, with many practitioners embracing its versatile advantages.[1]

Digital dentistry can be broadly described as the application of dental technologies or devices that utilize digital or computer-based systems instead of relying solely on mechanical or electrical methods. Beyond improving diagnostic accuracy, treatment planning, and execution, digital workflows are gradually replacing conventional methods and setting new standards for clinical practice. Furthermore, the advent of artificial intelligence and robot-assisted procedures is expanding the horizons of what is possible in dentistry, with future advancements likely to exceed our current expectations.[2]

2. History of Digital Dentistry

The history of digital dentistry is marked by continuous research and innovation, with developments that have transformed conventional dental practices. One of the most groundbreaking discoveries was 3D printing, credited to Charles Hull from the University of Colorado, USA. In the early 1980s, Hull began experimenting with ultraviolet radiation to develop a technique to convert virtual 3D models into physical objects. This technology, known as additive

*Corresponding author: Shilpi Deshpande
Email: shilpi.deshpande@gmail.com

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manufacturing, builds objects layer by layer and has become a cornerstone in modern dental fabrication.[3]

Another significant advancement that helped shape current digital workflows was cone-beam computed tomography (CBCT), a technology primarily developed in Europe. The use of CBCT in dentistry was first documented by Mozzo et al. in 1998, marking a significant advancement in diagnostic imaging by providing detailed 3D visualization of oral anatomy while minimizing radiation exposure relative to traditional CT scans.[4]

The 1990s also saw the introduction of the first 3D printer specifically designed for dental applications. [5] Since then, the technology has rapidly progressed and is now widely employed in clinical dentistry for designing and producing crowns, bridges, surgical guides, and orthodontic models. During the same period, the CEREC system (Chairside Economical Restoration of Esthetic Ceramics), developed by the German company Sirona, became one of the early pioneers of digital dentistry.[6] Utilizing digital imaging and CAD/CAM technology, CEREC enabled dentists to fabricate custom restorations such as crowns and bridges in a single appointment, significantly reducing treatment time and procedural complexity. Its efficiency and convenience quickly made it a popular tool among dental professionals.[7]

In addition to clinical settings, digital transformation has also begun influencing dental laboratories. A major milestone was achieved in the 1980s with Dr. Matts Andersson's development of the Procera system—an innovative CAD/CAM application designed for producing alumina crown copings. This innovation within the laboratory setting served as a foundation for incorporating digital workflows into both clinical practice and dental laboratory procedures.[8]

3. Present scenario of Digital Dentistry

Digital dentistry is now an integral part of modern dentistry. CAD/CAM systems are used for the design and fabrication of dental restorations, while 3D printing technology is used for the fabrication of surgical guides, models, and prosthodontic appliances.[9-11] Augmented Reality (AR) is enhancing patient education and aiding in treatment planning, whereas teledentistry is expanding access to dental services for individuals in remote or underserved regions. Artificial Intelligence (AI) and Machine Learning (ML) algorithms are increasingly being utilized to operate robotic dental systems. For instance, robotic arms can be programmed to carry out specific dental procedures such as the placement of dental implants with enhanced precision and accuracy, significantly minimizing the chances of human error.[12]

4. Real-world Applications of Emerging Digital Dentistry Technologies

4.1. Digital radiography

The advent of CBCT and 3D imaging marked a significant breakthrough in diagnostic accuracy and treatment planning. Digital Images can be enhanced or modified post-acquisition, eliminating the need for repeat exposures and thereby reducing patient radiation dose. Additionally, digital files can be easily stored, are immune to physical deterioration over time and are less likely to be misplaced. Furthermore, digital formats enable fast, electronic sharing across networks, facilitating remote consultations and interdisciplinary collaboration.[13]

4.2. 3D printing technology

3D printing has revolutionized the dentistry. Nowadays 3D printing technologies are being extensively used in almost every field of dentistry. The uses of 3D printing can help provide patients with lower-cost, more customized services and ease the complicated workflow associated with the manufacturing of all dental equipment due to its quick production, high precision, and personal customization.[1] (**Figure 1**)

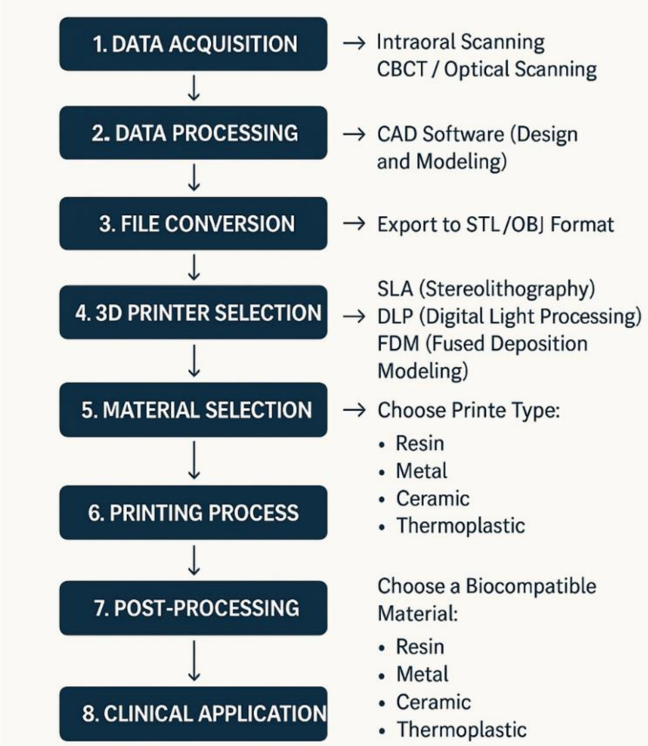

Figure 1: 3D printing in dentistry

4.3. Intraoral scanning technology

Intraoral scanning offers multiple advantages over conventional impressions, primarily by reducing patient discomfort and anxiety, especially beneficial for those with a strong gag reflex. It eliminates the requirement of impression trays and materials, making procedures more comfortable and efficient. IOS is particularly helpful in complex cases, such as those involving undercuts or multiple implants, by simplifying the clinical workflow. Additionally, it removes the need for plaster models, saving both time and storage space, and enhances communication with dental technicians. Intraoral scanners also serve as an effective patient communication and marketing tool, reflecting a modern, patient-friendly approach to care. For single restorations or short-span bridges, IOS provides accuracy comparable to traditional impressions. [14]

4.4. Extraoral scanning technology

Extraoral scanners are helpful tools that allow clinicians to capture the shape and details of a patient’s face without causing any pain and discomfort. They are fast, accurate, and comfortable for patients, making the scanning process easy and stress-free. In the clinic, they are used to record the 3D shape of the face, while in the lab, they can scan impressions or casts to create digital models. These digital models help in designing and making dental prostheses using CAD/CAM technology. Extraoral scanning also helps dentists explain treatment plans better to patients and create more personalized and precise treatments. [15]

4.5. Implant placement

Digital technology has greatly improved dental implant procedures by making them more accurate and efficient. It helps in detailed diagnosis and treatment planning through 3D visualization of the patient’s jaw, teeth, and future prosthesis using data from scans and software. This allows for precise planning of implant positions before surgery. During surgery, digital tools like surgical guides, navigation systems, and even robotic assistance help transfer the virtual plan to the real procedure accurately, improving outcomes. In the final steps, digital methods are used to take impressions, match shades, and design prostheses, making the whole process faster and more accurate.[16] (**Figure 2**,**Figure 3**)

Figure 2: Surgical guide for mandibular all-on-4

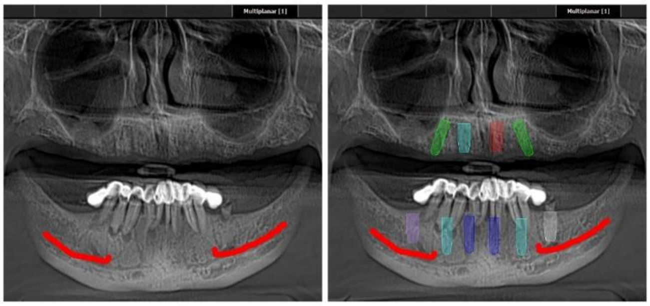

Figure 3: Digital implant planning

4.6. Maxillofacial rehabilitation

Recent advancements like rapid prototyping are widely used in managing maxillofacial defects due to their ability to create complex shapes. In maxillofacial prosthodontics, 3D printing is helpful for creating facial prostheses (ocular, auricular, nasal, etc.), making obturators after maxillectomy or tumor resection, producing radiation shields to protect healthy tissues, fabricating burn stents without painful impressions, designing surgical stents for lesion excision, making 3D models for mock surgeries, and visualizing facial structures with accurate models.[1,17,18] (**Figure 4**)

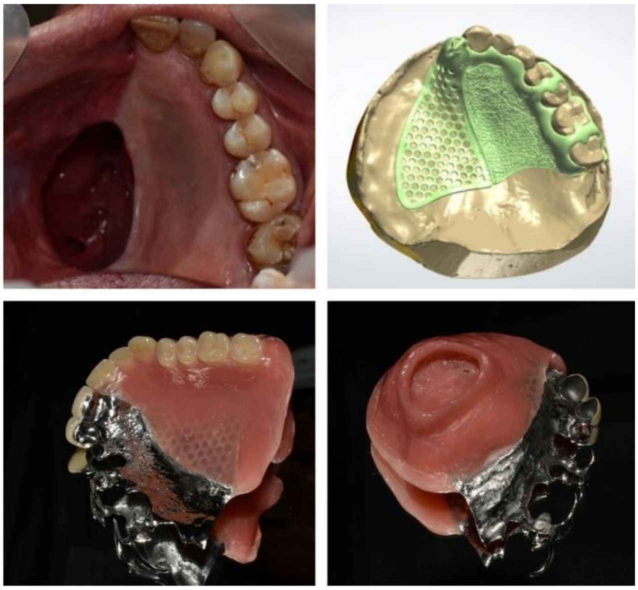

Figure 4: Maxillary obturator fabricated using 3D printing

4.7. Digital occlusal analysis

Digital occlusal analysis offers a highly accurate, objective, and patient-friendly approach to evaluating occlusion, significantly improving upon traditional methods. It provides quantifiable data that enhances diagnostic precision and allows for targeted occlusal adjustments, reducing the chances of prosthetic remakes and material failures. The process is non-invasive, more comfortable for patients, and improves communication between clinicians and dental labs through easy data sharing. Additionally, systems like T-Scan offer detailed insights into occlusal force and timing, aiding in better treatment planning. By enhancing patient education and streamlining clinical workflows, digital occlusal analysis leads to more predictable, cost-effective, and successful treatment outcome. [19,20]

4.8. Digital smile designing

Digital smile designing (DSD) offers numerous advantages by enhancing the predictability, accuracy, and patient satisfaction of aesthetic dental treatments. It allows patients to visualize their final smile before the procedure begins, increasing motivation, understanding, and trust in the treatment plan. DSD facilitates customized smile design through the patient's active participation, enabling them to approve or suggest changes beforehand, which minimizes post-treatment regret and boosts satisfaction. Clinically, it improves diagnosis and treatment planning by analyzing facial, gingival, and dental parameters in a standardized, objective way. It also strengthens communication not only between the dentist and patient but also across interdisciplinary teams, including lab technicians, through shared digital data, feedback loops, and real-time collaboration. This ensures a more refined, aesthetically pleasing, and emotionally rewarding outcome. [21]

4.9. AI in dentistry

Artificial Intelligence (AI) is revolutionizing the field of dentistry by improving diagnostic precision, treatment planning, and overall patient care. Technologies such as machine learning, deep learning, and neural networks have shown remarkable accuracy in interpreting radiographs, identifying oral diseases, designing prostheses, and planning orthodontic treatments. Beyond clinical applications, AI is also making significant contributions to areas like forensic dentistry and dental education. Its integration into academic settings is expected to greatly enhance the quality of both undergraduate and postgraduate dental training in the coming years. [22]

4.10. Teledentistry

The concept of Teledentistry was introduced in 1997, when Cook described it as the use of video conferencing tools to facilitate remote diagnosis and treatment consultation.[23] Teledentistry has the ability to improve access to oral healthcare, improve the delivery of oral healthcare, and lower its costs. It also holds promise in bridging the gap in oral healthcare access between rural and urban populations.[24] Today, teledentistry is a rapidly growing area of digital dentistry, particularly in the wake of the COVID-19 pandemic, improving access to care, treatment outcomes and reducing the risk of disease transmission via enabling the early detection and treatment of oral and dental problems.[25]

5. Integrating Digital Dentistry into Undergraduate Education

Digital technologies such as CAD/CAM, 3D printing, and digital imaging are rapidly transforming the field of dentistry. To keep pace with these advancements, it is essential to introduce digital dentistry into undergraduate dental education. Early exposure to these tools not only builds clinical competence but also prepares students for modern dental practice. Digital platforms offer students a chance to learn through virtual simulations and interactive models, helping them practice key skills in a safe environment. This enhances both their confidence and their ability to handle complex procedures in real-world settings.[26]

Equally important is training faculty to effectively teach digital techniques. With proper support and resources, educators can better guide students in using digital tools. Collaboration with technology developers can also help design up-to-date modules that reflect current trends in dental care. By embracing digital dentistry at the undergraduate level, we can ensure that future dentists are well-prepared to deliver efficient, accurate, and patient-centred care.[27]

5.1. Pros of digital dentistry

1. Improved accuracy and precision: Digital impressions, CAD/CAM restorations, and guided surgeries enhance treatment outcomes by reducing human error.
2. Time efficiency: Faster turnaround times for prostheses and restorations due to chairside milling and intraoral scanning, reducing multiple appointments.
3. Enhanced patient comfort: Intraoral scanners eliminate the need for conventional impressions, increasing patient acceptance and comfort.
4. Predictable treatment outcomes**:** Digital planning software (for implants, orthodontics, etc.) allows simulation and visualization of final outcomes, enhancing treatment predictability.
5. Better communication: Visual treatment plans and digital records facilitate improved interdisciplinary collaboration and patient education.
6. Digital storage and retrieval: Easier maintenance and sharing of patient records, radiographs, and 3d models allows integration with electronic health records.
7. Customization and personalization: Enables fabrication of patient-specific prostheses (e.g., surgical guides, facial prosthetics) with better anatomical adaptation.
8. Reduced material waste: Additive manufacturing (3D printing) and subtractive techniques (CAD/CAM milling) optimize material usage and reduce waste.
9. Remote consultations and teledentistry: Expands access to expert care and enables virtual treatment planning and monitoring.

5.2. Cons of digital dentistry

1. High initial investment: Equipment such as intraoral scanners, 3D printers, and CAD/CAM systems entails significant upfront and maintenance costs.
2. Steep learning curve: Requires comprehensive training for dentists, technicians, and staff to use hardware and software efficiently.

3. Technology dependence and downtime: Equipment failures, software bugs, or power outages can interrupt clinical workflows.
4. Limited material options: Not all restorative materials are compatible with digital systems, potentially limiting clinical choices.
5. Obsolescence and upgrades: Rapid technological advancement may lead to frequent upgrades, making existing systems outdated quickly.
6. Accuracy issues in complex cases: Intraoral scanning may be less reliable in deep subgingival margins, edentulous arches, or highly mobile soft tissue areas.
7. Cybersecurity and data privacy: Increased risk of data breaches and patient confidentiality concerns due to cloud-based and networked systems.
8. Limited haptic feedback: In digital design environments, especially in virtual articulators, the tactile perception may be reduced compared to analog methods.
9. Interoperability challenges: Compatibility issues may arise between different digital systems or proprietary software platforms.

6. Discussion

The future of digital dentistry looks very promising and is set to transform the way dental care is provided. In the coming years, traditional methods will be largely replaced by advanced digital technologies, making treatments faster, more accurate, and more comfortable for both dentists and patients. One exciting area is the combination of digital technology with nanotechnology. This can help in designing special materials and tools at the microscopic level, such as coatings on dental implants to prevent bacterial growth or nano-sized imaging agents that improve disease detection. Nanoparticle imaging, for example, can offer clearer digital radiographs for better diagnosis and treatment planning.[28]

Digital tools also save valuable time and allow for more personalized care. Technologies like CBCT-based 4D jaw motion tracking can help dentists tailor treatments for each patient, especially in conditions like temporomandibular disorders (TMD). New imaging methods like optical coherence tomography (OCT), ultrasound, and MRI may soon offer 3D views of the teeth and gums without harmful radiation. Additionally, artificial intelligence (AI) is already being used to detect and predict dental diseases using smart software that learns and improves over time.[29,30]

In short, the next 10–20 years will bring major changes to dentistry. Digital advancements will affect how we diagnose, plan, and deliver care, run dental clinics, communicate with labs and colleagues, and monitor patients' oral health. The goal is clear: more accurate, less invasive, and patient-centred care through the power of digital technology.

7. Conclusion

The advent of digital dentistry marks a paradigm shift in the diagnosis, treatment planning, and delivery of dental care. Integration of technologies such as 3D imaging, dynamic jaw tracking, artificial intelligence, and nanotechnology has significantly improved clinical precision, efficiency, and patient satisfaction. These innovations not only enable better visualisation and customization but also foster seamless communication among dental professionals. As digital tools continue to evolve, they are poised to replace conventional workflows, making dental procedures more predictable, minimally invasive, and outcome-driven. Embracing this digital transformation will be essential for advancing oral healthcare in the coming decades.

8. Source of Funding

None.

9. Conflict of Interest

None.

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