Check for updates

REVIEW

The evolution of digital technologies in dentistry: Latest updates, challenges and barriers

[version 1; peer review: awaiting peer review]

Ana González[1], Mario Monzón[1], Rubén Paz[1], Luis Suárez[1], Joshua García[1], Pablo Bordón[1], Zaida Ortega[2]

[1]Department of Mechanical Engineering, Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Canary Islands, 35017, Spain
[2]Department of Process Engineering, Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Canary Islands, 35017, Spain

v1 **First published:** 10 Sep 2025, **5**:276
https://doi.org/10.12688/openreseurope.21242.1
Latest published: 10 Sep 2025, **5**:276
https://doi.org/10.12688/openreseurope.21242.1

Abstract

Digital technology has brought about an important evolution in the dental field, especially in diagnostic, treatment/surgery planning and design/manufacturing processes. From early developments in computer-aided design and computer-aided manufacturing (CAD/CAM) systems to the integration of Artificial Intelligence (AI) and Additive Manufacturing (AM), this review aims to provide an overview of major advancements which have formed digital dentistry. This review synthesizes historical and recent literature on digital technologies used in dentistry, categorizing them into six key domains: diagnostic tools, scanning systems, design and manufacturing technologies, treatment planning and simulation, patient management, and artificial intelligence/machine learning applications. The study highlights the applications, benefits, and current limitations of each category. Digital technologies have significantly improved patient comfort, clinical efficiency andtreatment accuracy.Tools such as cone-beam computed tomography (CBCT), intraoral scanners, CAD/CAM systems, and digital workflow software allow for more predictable and personalized care. AI-driven diagnostics and treatment planning, combined with additive manufacturing, further optimize outcomes. Despite these advances, challenges such as high initial costs, technical barriers, and training needs still block full acceptance in some practices. Digital dentistry has revolutionized dental care delivery and continues to advance rapidly. Its integration offers numerous clinical and operational advantages, yet further innovation and strategic implementation are required to ensure equitable access and sustainable assumption

Open Peer Review

Approval Status *AWAITING PEER REVIEW*

Any reports and responses or comments on the article can be found at the end of the article.

across the dental field.

Plain language summary
Digital technology has brought about an important evolution in the dental field, especially in diagnostic, treatment/surgery planning and design/manufacturing processes. From early developments in computer-aided design and computer-aided manufacturing systems to the integration of Artificial Intelligence and 3d printing, this review aims to provide an overview of major advancements which have formed digital dentistry. The study highlights the applications, benefits, and current limitations in diagnostic tools, scanning systems, design and manufacturing technologies, treatment planning and simulation, patient management, and artificial intelligence. Digital technologies have significantly enhanced clinical efficiency, treatment accuracy, and patient comfort. Despite these advances, challenges such as high initial costs, technical barriers, and training needs still block full acceptance in some practices. Digital dentistry has revolutionized dental care delivery and continues to advance rapidly. Its integration offers numerous clinical and operational advantages, yet further innovation and strategic implementation are required to ensure equitable access and sustainable assumption across the dental field.

Keywords
Digital dentistry, CAD-CAM, intraoral scanning, Artificial Intelligence, additive manufacturing

This article is included in the Erasmus+ gateway.

Corresponding authors: Mario Monzón (mario.monzon@ulpgc.es), Zaida Ortega (zaida.ortega@ulpgc.es)

Author roles: González A: Investigation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Monzón M**: Funding Acquisition, Investigation, Methodology, Project Administration, Resources, Supervision, Writing – Review & Editing; **Paz R**: Investigation, Writing – Review & Editing; **Suárez L**: Investigation, Writing – Review & Editing; **García J**: Investigation, Writing – Review & Editing; **Bordón P**: Investigation, Writing – Review & Editing; **Ortega Z**: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This project has received funding from NTA project: "New technological approaches in dental technique" (NTA, 2023-1-RO01-KA220-VET-000157812), funded by the Erasmus + program of European Union.
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Copyright: © 2025 González A *et al*. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: González A, Monzón M, Paz R *et al.* **The evolution of digital technologies in dentistry: Latest updates, challenges and barriers [version 1; peer review: awaiting peer review]** Open Research Europe 2025, **5**:276 https://doi.org/10.12688/openreseurope.21242.1

First published: 10 Sep 2025, **5**:276 https://doi.org/10.12688/openreseurope.21242.1

Introduction

Digital dentistry constitutes a key technological advancement in dental clinic, integrating various digital and information technologies that support the diagnosis, treatment, and management of the dental practice. This evolution is the result of decades of innovation and research, which started with the integration of early digital technologies into medical and dental practices.

Digital dentistry originated at the beginning of the 1960s, coinciding with the introduction of Computer Numerical Control (CNC) technologies. The Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) systems were initially developed for industrial applications, such as the aerospace and automotive industries, but soon found their way into the dental field. The pioneering work of Dr. François Duret in the 1970s marked a significant milestone, and is usually considered as the developer of the first dental CAM devoted system. This pioneer device allowed to produce dental prosthetics by digital impressions and computer-controlled milling machines[1–3].

From those early CAD/CAM systems, a next generation of specialized tools were developed in order to overcome the limitations of the primitive systems, mainly their cost and limited capabilities. The importance of such initial developments highlighted the potential of CAD/CAM for precision and efficient obtaining of parts, which was a fundamental issue in dental prosthetics[2]. During 1980s Dr. Werner Moörmann and Dr. Marco Brandestini developed the Chairside Economical Restoration of Esthetic Ceramics (CEREC) on the basis of Dr. Duret developments (Figure 1); CEREC was the first company in commercializing dental CAD/CAM technology, thus leading the change from manual to automatized processes[2,4–6]. This was a revolutionary system that allowed dentists to design, mill and conduct ceramic restorations in a single visit[5,7,8].

Another pivotal development in digital dentistry was the appearance of digital imaging technologies. Traditional dental radiography, which relied on film-based X-rays, began to be supplemented and eventually replaced by digital radiography in the late 20th century. Digital radiography offered several advantages over traditional methods, including reduced radiation exposure, immediate image viewing, and the ability to enhance images for better diagnostic accuracy[9–11]. An important step forward was given in the 90s with the introduction of cone-beam computed tomography (CBCT), which further expanded the capabilities and scope of dental imaging. CBCT provided 3D imaging with a more detailed visualization of dental structures, which was particularly relevant for implant planning, orthodontics, and complex surgical procedures[9–11]. This technology marked a significant milestone: the shift from 2D to 3D imaging, enabling more accurate diagnoses and allowing for a better planning of treatments.

As digital technologies evolved, the integration of various digital tools into a cohesive workflow became a focal point. The development of intraoral scanners in the early 21st century was a critical element. Intraoral scanners are able to capture detailed digital impressions of teeth, gums and any element present in the patient's anatomy, without needing the use of traditional impression materials and trays, improving patient comfort and the accuracy of dental restorations[12–14].

The digital workflow was further enhanced by advancements in software that allowed for seamless integration between different stages of dental treatment. Digital treatment planning software enabled practitioners to visualize and simulate various treatment options, improving precision and predictability.

The rise of Additive Manufacturing technologies (AM, commonly known as 3D printing) in the dental field constitutes another transformative development. By the early 2010s, AM began to be used for the fabrication of dental models, surgical guides, dentures, and even crowns and bridges[12,15,16]. These technologies offer a range of advantages in terms of customization, speed, and cost-efficiency. The ability to produce highly precise dental prosthetics and appliances directly from digital designs has streamlined the manufacturing process and reduced the time required for treatment completion[15–17]. For example, in orthodontics, digital technologies such as aligners (such as Invisalign or Sparks) leveraged 3D modeling and printing to create customized clear aligners, transforming orthodontic care by offering a more aesthetically pleasing and comfortable alternative to traditional braces[16,18–20].

Finally, the most recent innovations in digital dentistry are related to the integration of artificial intelligence (AI) and machine learning (Figure 2), being this a transversal discipline to the different techniques in digital dentistry. These are being applied to various aspects of dental practice, from diagnostic imaging to treatment planning and patient and data management. AI algorithms can analyze large datasets of dental images to identify patterns and assist in diagnosing conditions such as cavities, periodontal disease, and oral cancers with a high degree of accuracy[6,16,18].

The development of digital dentistry is a testament to the profound impact of technological innovation on healthcare. From the early days of CAD/CAM technology in the 60s to the latest advancements in AI and AM happening nowadays, digital dentistry has evolved continuously to enhance the precision, efficiency, and overall quality of dental care. These advancements have not only improved the patient experience but also expanded the capabilities of dental practitioners, enabling them to deliver more effective and accurate treatments. As technology continues to evolve, the future of digital dentistry promises relevant innovations capable of transforming the dental field and optimizing oral health worldwide. Figure 3 summarizes the concepts of higher relevance from the literature survey conducted.

The present review aims to provide a historical overview of the development of digital dentistry, emphasizing key milestones and technological advancements that have allowed for achieving its current level of development. It also seek to

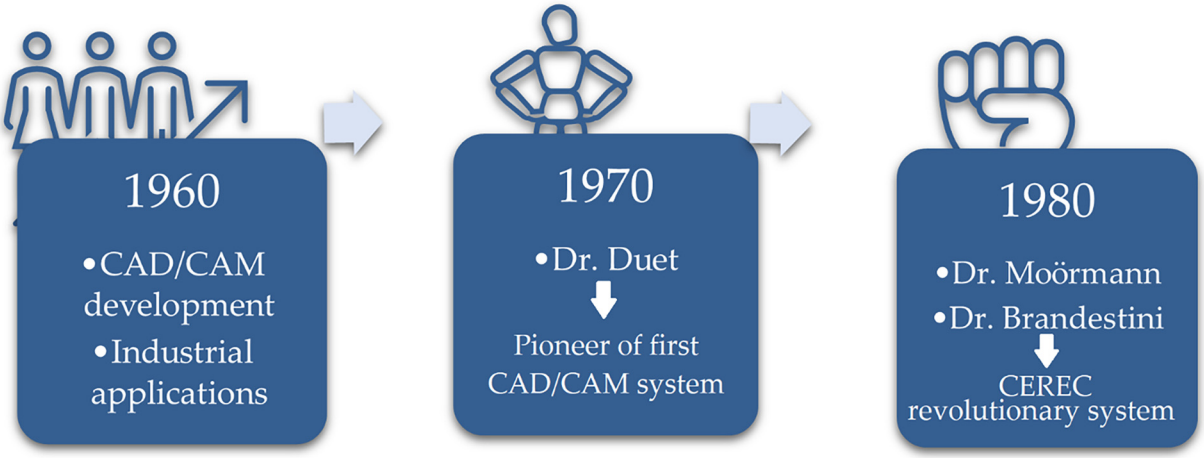

Figure 1. **Summary of historical context of CAD/CAM.**



Figure 2. **Summary of historical context of imaging, design and manufacturing.**

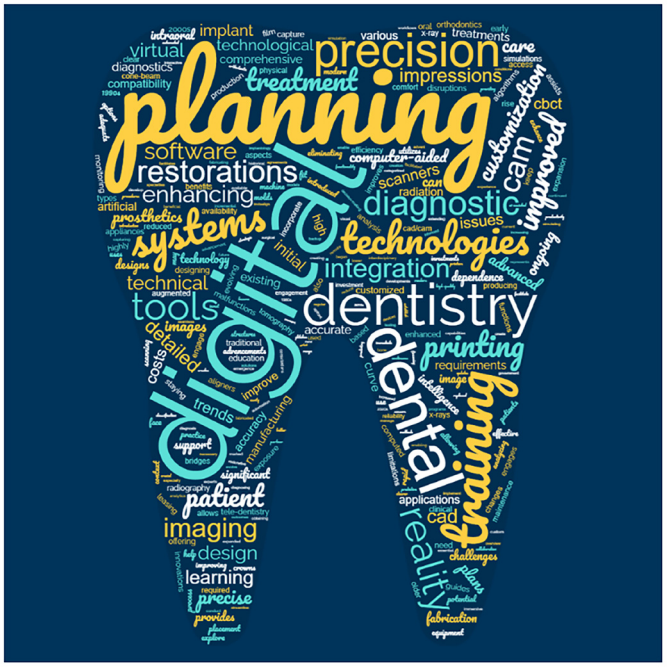

Figure 3. **Most relevant terms for digital dentistry, obtained using wordclouds.com, from the literature review.**

offer guidance for future advancements, being specially devoted for professionals, students and practitioners with a more technological profile, such as biomedical engineers, mechanical engineers, technicians, etc.

Types of digital technologies in dentistry

It is well-accepted that digital dentistry has revolutionized dental practice, integrating various advanced technologies that enhance the precision, efficiency, and overall quality of dental care. These technologies encompass a broad spectrum of tools and systems, contributing to different aspects of dental practice: diagnosis, treatment, and management. Technologies applied in digital dentistry can be classified into five main groups: diagnostic imaging, design and manufacturing, treatment/surgery planning and simulation, data and patients' management, and AI.

Diagnosis and scanning tools

Diagnostic tools are critical in enhancing precision, improving patient experience, and streamlining dental workflows, marking a significant advancement in dental technology. Figure 4 summarizes in a schematic way the most relevant scanning tools used nowadays.

The conventional film X-rays have been gradually replaced by digital sensors in the tasks of dental imaging and radiography. This transition has improved image quality, reduced patient radiation exposure, and streamlined processing. Thanks to digital imaging, clinicians can more clearly visualize oral anatomy, facilitating diagnosis and treatment procedures. Digital imaging encompasses a range of technologies, including digital radiography, CBCT, and intraoral cameras (Table 1). Digital radiography, which uses digital sensors instead of traditional film, offers several advantages such as reduced radiation exposure, immediate image availability, and enhanced image quality through digital processing[21–23]. More recently, CBCT has become an indispensable tool, providing three-dimensional imaging that allows for detailed visualization of dental and maxillofacial structures. This technology is particularly useful in implantology, orthodontics, and complex surgical procedures. Its ability to produce high-resolution images with relatively low radiation doses has been well-documented[10].

Intraoral cameras and scanners also play a crucial role in diagnostics and patient communication. These small, handheld devices capture detailed images of the inside of the mouth, helping in the detection of dental issues and enhancing patient education by allowing patients to see the conditions that need treatment[24–26]. Regarding scanners, these can be intraoral or extraoral, and they allow to capture direct optical impressions of the oral cavity. Various imaging technologies can be found to create detailed 3D digital models of both teeth and soft tissues, including structured light, laser, or photogrammetry. These techniques provide high accuracy and precision, allow for the immediate visualization of scans and reduce the errors from impression procedures and the need for retakes, with the added benefit of enhanced patient comfort compared to traditional impression materials.

Intraoral scanners have transformed the process of producing dental impressions. These manual digital scanners are based on optical technology to generate 3D models of a patient's teeth and oral cavity. By replacing traditional putty impressions,

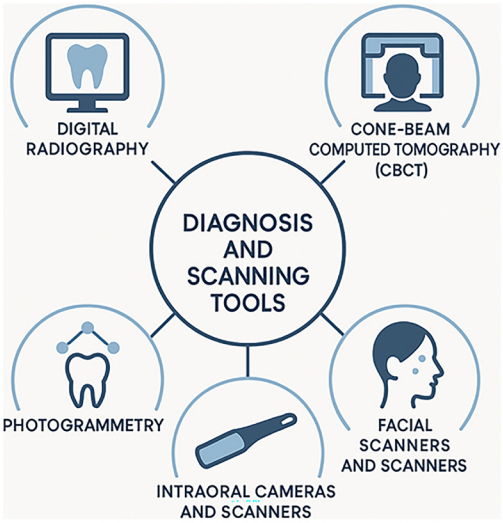

Figure 4. Summary diagnosis and scanning tools.

Table 1. Summary of different tools used in diagnosis.

Method	Description	Benefits	Examples	References
Digital radiography	Uses digital sensors to capture images of teeth and surrounding structures.	Reduced radiation exposure, immediate image availability, enhanced image quality.	Digital X-ray systems Photostimulable phosphor (PSP) plates.	21–23
Cone-Beam Computed Tomography (CBCT)	Provides 3D imaging of dental and maxillofacial structures.	Detailed visualization for implant planning, orthodontics, and complex surgeries.	Planmeca ProMax 3D Carestream CS 9300.	10
Intraoral Cameras	Small, handheld devices that capture detailed images inside the mouth.	Enhance diagnostics and patient communication by visualizing hard-to-see areas.	DEXIS DEXcam 4 HD MouthWatch Intraoral Camera.	24–27

intraoral scanners increase the usability and provide precise 3D models that facilitate diagnosis and treatment planning., such as designing restorations, planning orthodontic appliances, or to be used as surgical guides. Intraoral scanners are able to capture digital impressions of teeth and gums using scanning technology[28–30] with high accuracy. Some examples of this technology are iTero Element and 3Shape TRIOS. On the other hand, extraoral scanners are sued to scan dental models or impressions outside the patient's mouth, generally to produce digital replicas of existing physical models. Some of the most used ones are 3Shape D2000 and Dental Wings 7Series[13,14,25].

At this point, it is interesting to make a special emphasis on photogrammetry as a promising technique within the field of digital dentistry, demonstrating significant potential as an alternative to traditional methods of capturing dental models. As already mentioned, traditional dental impression techniques have been widely criticized for their limitations in accuracy and comfort, prompting the exploration of digital methods that promise enhanced precision and efficiency[31,32]. Photogrammetry, particularly utilizing structure-from-motion (SfM) techniques, allows for the generation of high-fidelity 3D models using standard photographic equipment, which can be more accessible and cost-effective compared to established digital scanning technologies[32,33]. Research indicates that photogrammetry can achieve a level of accuracy comparable to that of high-resolution digital scanners, effectively preserving the geometry of dental structures while also offering practitioners a lower-cost solution[33,34]. The accuracy of models produced through photogrammetry has been shown to be robust, with studies demonstrating that measurements derived from photogrammetric models are consistent with values obtained from traditional 3D scanning methods[34,35]. Furthermore, mobile photogrammetry techniques have facilitated the emergence of a simpler workflow that can be particularly beneficial in environments with limited access to advanced scanning technologies. For instance, studies showed that mobile approaches provide practical solutions for generating facial and dental models, which are essential for diagnostics and treatment planning[34–36].

One pivotal advantage of photogrammetry is its non-invasive nature and the ability to quickly generate digital models that can facilitate immediate communication between dental professionals and laboratories. Unlike conventional impression materials, which may cause discomfort to patients, digital impressions made via photogrammetry can be obtained with minimal patient interaction and discomfort, thereby increasing patient satisfaction[33,37,38]. Moreover, the utility of photogrammetry in producing full-color, 3D dental images has enabled more comprehensive visual assessments and applications across various dental disciplines, from orthodontics to restorative dentistry. The integration of photogrammetry with 3D printing technology is another dimension that enhances its applicability, allowing for the rapid and cost-effective prototyping of dental devices or prosthetics based on accurate data captured from patients[39–41].

Similarly, it is of particular relevance to consider the use of facial scanners within this field, playing a significant role particularly in aesthetics dentistry. Facial scanners have become increasingly significant in digital dentistry due to their ability to provide precise assessments of soft tissue, which are integral for treatment planning and aesthetic evaluations. The integration of three-dimensional (3D) facial scanning technology allows dental professionals to capture intricate details of a patient's facial morphology and its relationship to dental structures. This capability is crucial in ensuring that cosmetic and orthodontic treatments are both functionally effective and aesthetically pleasing[42]. In this sense, some works have assessed the accuracy of mobile device-compatible 3D scanners for facial digitization, revealing their ability to extract facial landmarks and perform advanced dimensional analyses, including surface-to-surface distance measurements and volume misfit evaluations[43,44]. Advancements in scanning technology can positively impact clinical outcomes by facilitating a more accurate representation of a patient's soft-tissue profile, which is pivotal for various dental procedures, including orthodontics and prosthodontics[42,45].

They are being increasingly used to customize dental appliances following a holistic view of the specific morphology of each patient, therefore improving clinical accuracy but also enhancing patient engagement and satisfaction through more visual assessments and the planning of realistic results of the chosen treatment[45–47]. Furthermore, comparing 3D facial scans before and after orthodontic treatment can help clinicians evaluate changes in soft tissue contours, leading to improved patient satisfaction and psychosocial well-being[48,49].

Design and Manufacturing Tools

CAD CAM technology has become an essential procedure for today's digital dentistry. It allows dentists to design highly accurate digital models of dental restorations, such as bridges, crowns, orveneers. These models are then uploaded to milling machines or 3D printers, enabling the fast manufacturing of customized restorations. Ceramic or composite materials are mostly used for manufacturing such final parts. The efficiency of these systems significantly reduces the time required for producing dental restorations, often allowing for same-day procedures.

A prominent example is the CEREC system[5,7], already mentioned in the introduction of this review, which has continued to evolve since its introduction. Recent studies highlight its effectiveness and accuracy in creating dental restorations[50,51]. This system enabled clinicians to take digital impressions, design restorations chairside, and mill them within a single visit, improving patient convenience and reducing the need for temporary restorations. Figure 5 outlines design and manufacturing tools used in digital dentistry, summarizing the main benefits of main two options, namely CAD/CAM and Additive Manufacturing (AM), also mentioning the most relevant manufacturing systems for each of them.

AM has become increasingly integral to dental practices. This technology allows custom fit dental components, such as crowns, bridges, dentures, and orthodontic aligners, to be manufactured directly from 3D models. AM offers significant

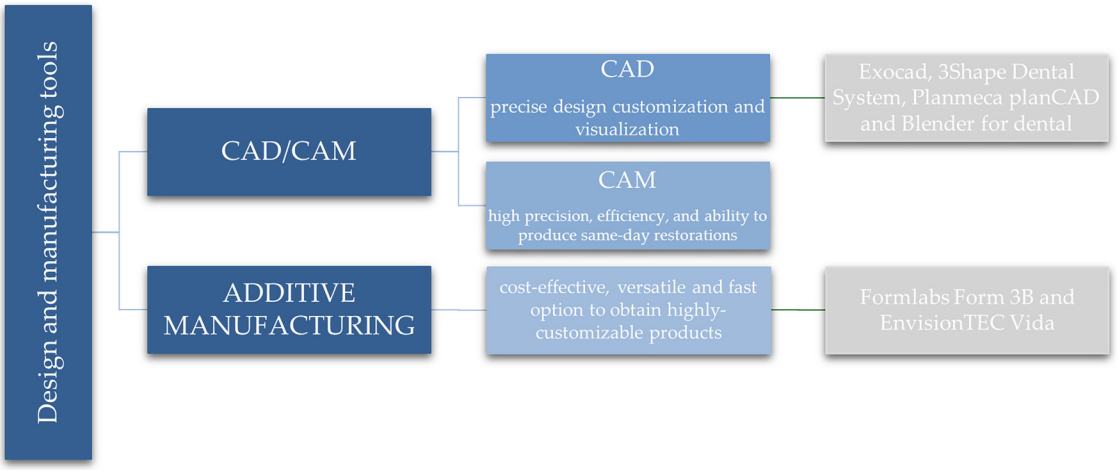

Figure 5. Summary of design and manufacturing tools.

benefits in terms of speed, precision, accuracy and cost-effectiveness. Surgical guides and complex prosthesis can also be produced by these technologies. One of the most important benefits of AM is the capability of producing completely tailored items according to each patient specific needs. Recent research highlights the expanding applications of AM in dentistry, from creating biocompatible materials to developing innovative surgical guides[52]. The continuous evolution of these digital technologies promises further advancements in material properties and printing techniques, enhancing its role in dental care.

Computer-Aided Design (CAD) Software is used to design dental restorations, appliances, and implants/prosthetics[53], allowing for precise design customization and visualization. Some of the most common software used in dentistry applications are Exocad, 3Shape Dental System, Planmeca planCAD[54–57] and Blender for dental[58]. 3Shape Dental System is software for designing various dental restorations, while Exocad is a very well-known option due to its flexibility and extensive range of dental applications. Planmeca PlanCAD allows for a seamless integration with Planmeca's imaging and milling units. Finally, Blender for dental is a free source software to design specific dental labor, such as crown, bridge or surgical guides, etc.

Computer-Aided Manufacturing (CAM) relates to equipment used for the manufacturing of dental items from digital designs using milling or grinding[50,51]. These systems provide high precision, efficiency, and ability to produce same-day restorations.

Finally, AM systems allow for the creation of dental models, surgical guides, and appliances[52]. These methods are highly-customizable and are a cost-effective, versatile and fast option to obtain such type of products. Some examples of AM equipment adapted to dentistry are Formlabs Form 3B and EnvisionTEC Vida[6,16,17,52].

Treatment planning and simulation tools

The integration of these advanced tools in digital dentistry enhances the precision, efficiency, and predictability of dental treatments, significantly improving both clinical outcomes and patient experiences.

Virtual reality (VR) and augmented reality (AR) technologies have become a powerful tool in dental education and training. These immersive tools allows students and professionals to improve practical skills, on different clinical procedures, under realistic environments. This virtual and safe environment enhances the training process without the need of practizing, from the beginning, on real patients, therefore reducing the risk of failures. Virtual Treatment Planning Software are tools used for planning complex treatments such as orthodontic interventions, implant placements, and full-mouth reconstructions using 3D models derived from scans and CBCT images. Some examples are NobelClinician, Dolphin Imaging or BlueSkyPlan. They allow to plan the treatment for implants and orthondontics[59]. Related to these tools, one can also find Digital Smile Design (DSD) Software, specifically devoted to the planning of aesthetic treatments by simulating potential outcomes and ensuring the final results meet patient expectations. Some of such tools are 3Shape Smile Design, which can be integrated with other 3Shape tools for a cohesive workflow, DSDApp or Smile Designer Pro, which allow for the integration of detailed aesthetic and clinical planning as well as patient engagement, contributing to a higher satisfaction of patients[60–63]. In the same line, there are some specific software to plan orthodontic treatments, including both transparent aligners and traditional bracers; some examples are Invisalign ClinCheck, SureSmile, OrthoCAD or OrthoAnalyzer by 3Shape[64–68].

Finally, some developments are focused on the design of software to serve as surgical guide; these are used to create custom surgical guides that ensure precise placement of dental

implants based on virtual treatment plans. coDiagnostiX provides advanced implant planning and surgical guide design capabilities, SIMPLANT brings extensive features for implant treatment planning and guide creation, while Dentiq Guide provides detailed surgical planning and custom guide fabrication[69–73].

Figure 6 provides a visual summary of the virtual tools for planning available nowadays, including the most relevant commercial systems for each of them.

Patient management and communication tools

Dental digital technologies are also assuming integrated practice management software and electronic health record (EHR) systems to optimize operational efficiency, associated with streamlined administration and the automation of billing, such as scheduling and treatment plans[74] (Figure 7).

Electronic health record (EHR) systems are the first step to digitalized dental world. These databases collect patient data to encourage the saving data in a standard format and the safety sharing of information between dental professionals[75].

Thanks to EHR systems, by securely storing and accessing patient medical histories, diagnosis and insurance details, dental professionals can focus on patient care rather than time-consuming paperwork.

These digital platforms also facilitate a long-term care[76] and patient communication and education[74], with websites or social media[77], (i.e. WhatsApp, Instagram, YouTube, etc.) for appointments or, such as tools to educate patient about dental health.

Artifical Intelligence (AI)

AI algorithms can analyze large datasets of dental images and patient records to assist in diagnosis, treatment planning, and predictive analytics. These technologies can identify patterns and anomalies that may be difficult for human practitioners to detect, thus improving diagnostic accuracy and treatment outcomes. For example, AI-driven diagnostic tools are being developed to detect caries, periodontal disease, and oral cancers with high precision[18]. Machine learning models are also being used to predict patient responses to treatments and optimize personalized treatment plans. The integration of AI in digital dentistry is still in its early stages, but its potential to enhance clinical decision-making and patient care is immense.

The integration of digital technologies into a seamless workflow is essential for maximizing their mutual benefits. Digital workflows in dentistry encompass everything from initial patient consultations and diagnostics to treatment planning and execution. Software platforms that integrate various digital tools enable practitioners to create comprehensive and precise treatment plans. Digital workflow systems often include features such as electronic health records (EHR), treatment simulation, and patient communication tools. These systems streamline administrative tasks, improve clinical efficiency, and enhance the patient experience by providing transparent and interactive treatment processes[69,70].

There are currently some examples on AI-driven systems for diagnosis, such as VideaHealth AI or Overjet, which allows for analyzing dental images and identifying particular conditions[18], supporting the practitioners in decision-making. Some steps have also been given in the programming of predictive analytical tools, that is, in machine learning models that predict patient outcomes and optimize treatment plans; some examples are Pearl's Second Opinion or Denti.AI[18,60,78].

Applications of digital dentistry

Digital dentistry can be applied to several aspects of dentistry such as optimization of diagnostic accuracy, treatment and surgical planning, and clinical outcomes. The integration of advanced technologies has revolutionized the field, making dental procedures more efficient, precise, and patient-friendly. From diagnostics and treatment planning to manufacturing and patient communication, digital tools have enhanced precision, efficiency, and quality of care (Table 2).

Benefits of digital dentistry

Digital dentistry integrates advanced technologies into various aspects of dental care, offering numerous advantages while also presenting certain challenges, as already mentioned. Digital dentistry offers multiple advantages for dentists and patients. For practitioners, it improves treatment accuracy, optimizes workflows, and increases overall efficiency. Digital tools enable accurate measurements, virtual treatment planning,

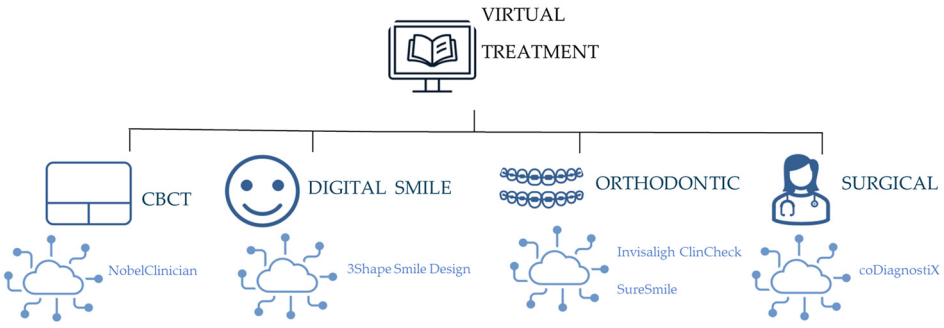

Figure 6. Summary of virtual treatment planning software.



Figure 7. Summary of Electronic Health Records (HER) benefits.

and more predictable results. Patients, in turn, benefit from reduced chair time, greater comfort, and a more satisfying treatment experience. Furthermore, digital dentistry facilitates communication between dentists and patients, allowing them to make informed decisions about their dental care. In summary, some of the main benefits of digital dentistry are[6,22,25,53]:

- Enhanced Diagnostic Accuracy[18,21,23,28,52,79]
- Improved treatment planning[18,21,23,28–30,50–52,79]
- Increased Efficiency and Productivity[18,52,79]
- Enhanced Patient Experience[18,23,28–30,51,52,79]
- Customization and Precision[21,23,28,29,51,52,79]

On the other hand, digital dentistry still has some limitations and barriers that need to be solved for a wider adoption of these technologies; in summary, the main drawbacks of digital dentistry are[18,77,80,81]:

- High initial costs: digital technologies require of a substantial initial investment, particularly considering

Table 2. Main applications of digital dentistry.

Method	Application	Description	Benefits	References
Digital diagnostics	Caries detection	Use of digital imaging and AI to detect dental caries.	Early detection, improved accuracy, reduced patient discomfort.	18,21–23
	Periodontal disease assessment	Digital radiography and AI for evaluating periodontal health.	Precise measurement of bone loss and detection of periodontal pockets.	82,83
	Oral cancer screening	Digital tools for early detection and diagnosis of oral cancers.	Enhanced visualization, early intervention, and improved patient outcomes.	18
Digital impressions and models	Intraoral scanning	Capture digital impressions for restorative and orthodontic purposes.	High accuracy, improved patient comfort, and immediate digital models.	13,14,29,30
	Digital orthodontic models	Creation of digital models for orthodontic diagnosis and treatment planning.	Enhanced precision, ease of storage, and better visualization for treatment planning.	68
Restorative dentistry	CAD/CAM restorations	Designing and manufacturing dental restorations using CAD/CAM technology.	High precision, reduced chair time, and improved aesthetics.	50,51,53
	3D Printing of prosthetics	Use of 3D printing technology to produce dental prosthetics.	Customization, speed, and cost-effectiveness.	52
Implant dentistry	Digital implant planning	Use of CBCT and planning software for precise implant placement.	Enhanced accuracy, reduced surgical risks, and improved outcomes.	28,82
	Guided implant surgery	Utilization of digital guides for implant surgery.	Minimally invasive procedures, reduced chair time, and higher precision.	30,71
Orthodontics	Clear aligners	Digital design and fabrication of clear aligners for orthodontic treatment.	Improved aesthetics, patient comfort, and treatment precision.	66,68,70
	Orthodontic simulation	Software to simulate orthodontic treatments and outcomes.	Enhanced treatment planning, patient communication, and predictable results.	79

Method	Application	Description	Benefits	References
Surgical applications	Surgical guides	Digital planning and 3D printing of surgical guides for precise surgical interventions.	Increased accuracy, reduced operative time, and better patient outcomes.	84–86
	Virtual surgical planning	Use of digital tools for planning complex maxillofacial surgeries.	Enhanced precision, improved surgical outcomes, and patient-specific customization.	28,72,87
Digital smile design (DSD)	Aesthetic treatments	Creates a virtual 3D model of oral cavity with digital imaging software.	Make part patient of the treatment choice.	88
Patient management and communication	Electronic Health Records (EHR)	Digital management of patient records and clinical data.	Streamlined data management, improved accessibility, and interoperability.	74
	Patient education tools	Digital tools for educating patients about their dental health and treatment plans.	Enhanced patient understanding and engagement, improved communication.	77,89
Tele-dentistry	Remote consultations	Use of digital communication tools for remote dental consultations.	Increased accessibility, convenience, and ability to provide care to underserved areas.	90–93
	Remote monitoring	Digital tools for remotely monitoring patient progress in orthodontic and other treatments.	Improved treatment adherence, timely interventions, and enhanced patient outcomes.	94–96
Dental education	Clinical and theoretical dental education	Provide students with real-time feedback on their performance with, for example, 3D models of denture to train.	Eliminate the need for constant direct supervision.	97
Digital marketing in dentistry	Web and social media	Dental practices cultivate an online identity.	Attract new patients, retain existing ones, and provide valuable educational content.	98

equipment and software, although without disregarding training. These costs can be a significant barrier for smaller clinics or practitioners with lower resources[89].

- Learning curve and training requirements: continuous education is necessary to stay updated with technological advancements and maximize the effectiveness of these tools, as the use of digital tools involves a significant learning curve and extensive training for dental professionals[99,100].

- Technical issues and reliability: digital systems tend to having some technical issues, including software glitches and hardware malfunctions. Ensuring the reliability and security of digital systems is crucial for maintaining clinical efficiency and patient trust[89].

- Integration with existing systems: Integrating new digital technologies with existing practice management systems can be challenging. Compatibility issues and the need for seamless data transfer require careful planning and execution[89].

- Dependence on technological advancements: the rapid evolution of technology means that digital tools can quickly become outdated. Dental practices must keep continually investing in updates and new technologies to stay up to date and keep high standards.

Strategies for overcoming the digital divide in dental care

Once defined the main advances in digital dentistry and summarized their benefits and limitations as well as their main application fields, it is worthy to bring them all together and outline the approaches proposed in the literature to overcome their limitations and maximize their benefits. This analysis is summarized in Table 3.

Future trends and innovations in digital dentistry

- Digital dentistry continues to develop, with significant innovations anticipated in the future. Emerging trends include: Artificial intelligence (AI) algorithms to produce optimal and efficient diagnosis and treatment planning. AI and machine learning are expected to play increasingly significant roles in digital dentistry, enhancing diagnostic accuracy, treatment planning, and personalized patient care. These technologies can analyze large datasets to predict outcomes and optimize treatment strategies[18].

- Combining digital dentistry with other areas of dental health, such as orthodontics and maxillofacial surgery. Future trends in digital dentistry will likely involve greater integration with other medical and dental disciplines. This interdisciplinary approach will improve comprehensive patient care and streamline treatment workflows[101,102].

Table 3. Main strategies to overcome limitations for a wider adoption of digital dentistry.

Method	Description	Benefits	References
High initial costs	The adoption of digital technologies in dentistry requires a substantial investment in equipment, software, and training. These initial costs can be prohibitive, especially for smaller practices.	-Incremental Investment: Practitioners can adopt digital technologies incrementally, starting with less expensive or more versatile tools. This approach allows for gradual integration and financial planning. -Financing Options: Exploring leasing or financing options can help spread the cost of equipment over time, making it more manageable for practices. -Government and Industry Support: Taking advantage of subsidies, grants, or industry support programs can offset some of the initial costs. Engaging with dental technology manufacturers who offer training and support can also be beneficial.	77,89
Learning Curve and Training Requirements	Digital tools come with a steep learning curve and require extensive training for dental professionals. This can impact productivity and increase the time required for practice staff to become proficient.	-Comprehensive Training Programs: Investing in comprehensive training programs, including hands-on workshops and online courses, can help staff become proficient more quickly. -Continuous Education: Implementing ongoing education and refresher courses can ensure that dental professionals stay current with new technologies and techniques. -Vendor Support: Leveraging support from technology vendors for training and troubleshooting can help ease the transition and address technical challenges.	74,103,104
Technical issues and reliability	Digital systems are prone to technical issues, including software glitches and hardware malfunctions, which can disrupt clinical workflows and affect patient care.	-Regular Maintenance: Implementing regular maintenance and updates for both hardware and software can help prevent technical issues and improve system reliability. -Technical Support: Establishing a reliable technical support system, including on-call IT support and user manuals, can assist in resolving issues promptly. -Backup Systems: Utilizing backup systems and protocols can ensure data integrity and minimize disruptions in case of technical failures.	74,104,105
Integration with existing systems	Integrating new digital tools with existing dental practice management systems can be complex, leading to compatibility issues and data transfer challenges.	-Compatibility Testing: Conducting thorough compatibility testing before implementing new systems can help identify potential issues and ensure smooth integration. -Consulting IT Experts: Engaging with IT consultants or experts in dental technology can provide guidance on best practices for integration and data management. -Phased Implementation: Implementing digital tools in phases can help manage integration challenges and minimize disruption to existing workflows.	77,94,99,106
Dependence on Technological Advancements	The rapid pace of technological advancements means that digital tools can quickly become outdated, requiring ongoing investment in upgrades and new technologies.	-Strategic Planning: Developing a long-term technology adoption and upgrade plan can help practices manage technological changes and budget for future investments. -Staying Informed: Keeping up-to-date with industry trends and advancements can help practices make informed decisions about when and what technologies to adopt. -Vendor Relationships: Building strong relationships with technology vendors can provide access to the latest updates and support for maintaining current systems.	18,107

- Further advancements in AM technology, allowing for more complex and biocompatible dental prosthetics. Advances in 3D printing will make it possible to manufacture dental restorations, implants, and orthodontic appliances more quickly and accurately. . Enhanced biocompatible and durable materials and techniques will allow for more complex and customized solutions[52].

- Growth of teledentistry, using digital tools to treat patients virtually. The expansion of tele-dentistry will facilitate remote consultations, follow-up appointments, and patient monitoring. This trend is expected to increase access to care and streamline patient management, especially in rural or isolated areas[91,96,99].

- Improved patient engagement through Smartphones/ wearable devices. VR and AR technologies are anticipated to enhance both clinical training and patient education. These immersive technologies will provide interactive simulations for dental procedures and treatment planning[108–111].

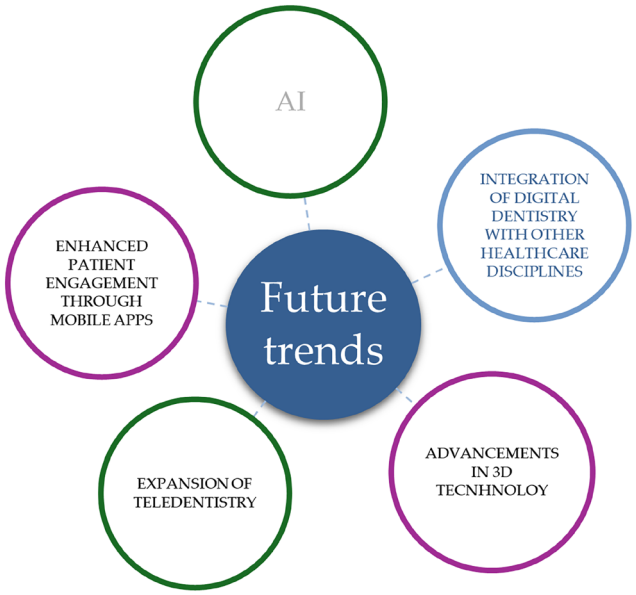

Figure 8. Future trends and innovations in dentistry.

While digital dentistry presents several challenges, including high initial costs, training requirements, and technical issues, there are viable solutions to address these obstacles. Looking ahead, digital dentistry is poised to evolve with advancements in AI, AM, VR/AR, tele-dentistry, and interdisciplinary integration. These trends (Figure 8) promise to enhance diagnostic accuracy, treatment efficacy, and patient care, shaping the future of dental practice.

Conclusions

Digital technologies have transformed the landscape of modern dentistry, providing enhanced diagnostic capabilities, more efficient workflows, and improved patient experiences. This review has detailed the major categories of digital tools currently used in clinical practice, including diagnostic imaging, CAD/CAM systems, AM technologies, treatment planning software, and AI-based solutions. These advancements have enabled greater precision, customization, and interdisciplinary integration.

However, despite the evident advantages, digital dentistry still faces significant barriers such as high initial costs, learning curves, and technological limitations. Strategies to overcome these barriers—such as phased implementation, comprehensive training, and support services—are crucial to facilitate broader adoption.

As digital technologies continue to evolve, they will increasingly define the best practices in dental care. The integration of artificial intelligence, tele-dentistry, and advanced manufacturing methods is poised to push the boundaries even further. In conclusion, while challenges remain, the future of dentistry is unequivocally digital, with a huge potential to enhance patient outcomes and redefine clinical standards.

Ethics and consent

Ethical approval and consent were not required

Data and software availability

No data are associated with this article

References

1. Duret F, Blouin JL, Duret B: **CAD-CAM in dentistry.** *J Am Dent Assoc.* 1988; **117**(6): 715–720.
PubMed Abstract | Publisher Full Text

2. Rekow D: **Computer-aided design and manufacturing in dentistry: a review of the state of the art.** *J Prosthet Dent.* 1987; **58**(4): 512–516.
PubMed Abstract | Publisher Full Text

3. Duret F, Termoz C: **Method of and apparatus for making a prosthesis, especially a dental prosthesis**. 1984.
Reference Source

4. Stappert CFJ, Goldstein RE, Tjiptowidjojo FA, *et al.*: **Ceramic veneers and partial-coverage restorations**. In: Ronald E. *Goldstein's Esthetics in Dentistry.* Wiley, 2018; 432–497.
Publisher Full Text

5. Moörmann WH: **The evolution of the CEREC system.** *J Am Dent Assoc.* 2006; **137**(Suppl): 7S–13S.
PubMed Abstract | Publisher Full Text

6. da Silva RLB, Kim JH, Markarian RA, *et al.*: **Introduction to digital dentistry**. In: *Digital Dentistry.* Wiley, 2022; 1–17.
Publisher Full Text

7. Nejatidanesh F, Amjadi M, Akouchekian M, *et al.*: **Clinical performance of**

CEREC AC Bluecam conservative ceramic restorations after five years—A retrospective study. *J Dent.* 2015; **43**(9): 1076–1082.
PubMed Abstract | Publisher Full Text

8. Davidowitz G, Kotick PG: **The use of CAD/CAM in dentistry.** *Dent Clin North Am.* 2011; **55**(3): 559–570.
PubMed Abstract | Publisher Full Text

9. White SC, Scarfe WC, Schulze RKW, *et al.*: **The image gently in dentistry campaign: promotion of responsible use of maxillofacial radiology in dentistry for children.** *Oral Surg Oral Med Oral Pathol Oral Radiol.* 2014; **118**(3): 257–261.
PubMed Abstract | Publisher Full Text

10. Scarfe WC, Farman AG: **What is cone-beam CT and how does it work?** *Dent Clin North Am.* 2008; **52**(4): 707–730.
PubMed Abstract | Publisher Full Text

11. Carter L, Farman AG, Geist J, *et al.*: **American Academy of Oral and Maxillofacial Radiology executive opinion statement on performing and interpreting diagnostic cone beam computed tomography.** *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2008; **106**(4): 561–562.
PubMed Abstract | Publisher Full Text

12. Sadid-Zadeh R: **Clinical applications of digital technology in fixed prosthodontics**. In: *Clinical Applications of Digital Dental Technology.* Wiley, 2023; 122–153.
Publisher Full Text

13. Logozzo S, Kilpelä A, Mäkynen A, *et al.*: **Recent advances in dental optics – Part II: experimental tests for a new intraoral scanner.** *Opt Lasers Eng.* 2014; **54**: 187–196.
Publisher Full Text

14. Logozzo S, Zanetti EM, Franceschini G, *et al.*: **Recent advances in dental optics – Part I: 3D intraoral scanners for restorative dentistry.** *Opt Lasers Eng.* 2014; **54**: 203–221.
Publisher Full Text

15. van Noort R: **The future of dental devices is digital.** *Dent Mater.* 2012; **28**(1): 3–12.
PubMed Abstract | Publisher Full Text

16. Elshazly TM, Keilig L, Alkabani Y, *et al.*: **Potential application of 4D technology in fabrication of orthodontic aligners.** *Front Mater.* 2022; **8**: 794536.
Publisher Full Text

17. Bodaghi M, Damanpack AR, Liao WH: **Adaptive metamaterials by functionally graded 4D printing.** *Mater Des.* 2017; **135**: 26–36.
Publisher Full Text

18. Schwendicke F, Samek W, Krois J: **Artificial intelligence in dentistry: chances and challenges.** *J Dent Res.* 2020; **99**(7): 769–774.
PubMed Abstract | Publisher Full Text | Free Full Text

19. Wong BH: **Invisalign A to Z.** *Am J Orthod Dentofac Orthop.* 2002; **121**(5): 540–541.
PubMed Abstract | Publisher Full Text

20. Gandedkar NH, Allareddy V, Vaiid N: **Decoding the nuances of scholarly output and publication metrics in orthodontics.** *Semin Orthod.* 2024; **30**(4): 456–462.
Publisher Full Text

21. El-Sharkawy YH, Elbasuney S: **Design and implementation of novel hyperspectral imaging for dental carious early detection using laser induced fluorescence.** *Photodiagnosis Photodyn Ther.* 2018; **24**: 166–178.
PubMed Abstract | Publisher Full Text

22. Wenzel A: **Digital imaging for dental caries.** *Dent Clin North Am.* 2000; **44**(2): 319–338.
PubMed Abstract | Publisher Full Text

23. Wenzel A: **Digital radiography and caries diagnosis.** *Dentomaxillofac Radiol.* 1998; **27**(1): 3–11.
PubMed Abstract | Publisher Full Text

24. Angelone F, Ponsiglione AM, Ricciardi C, *et al.*: **Diagnostic applications of intraoral scanners: a systematic review.** *J Imaging.* 2023; **9**(7): 134.
PubMed Abstract | Publisher Full Text | Free Full Text

25. Mangano F, Gandolfi A, Luongo G, *et al.*: **Intraoral scanners in dentistry: a review of the current literature.** *BMC Oral Health.* 2017; **17**(1): 149.
PubMed Abstract | Publisher Full Text | Free Full Text

26. Aragón MLC, Pontes LF, Bichara LM, *et al.*: **Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: a systematic review.** *Eur J Orthod.* 2016; **38**(4): 429–434.
PubMed Abstract | Publisher Full Text

27. Al-Hassiny A, Végh D, Bányai D, *et al.*: **User experience of intraoral scanners in dentistry: transnational questionnaire study.** *Int Dent J.* 2023; **73**(5): 754–759.
PubMed Abstract | Publisher Full Text | Free Full Text

28. Gianfreda F, Pesce P, Marcano E, *et al.*: **Clinical outcome of fully digital workflow for single-implant-supported crowns: a retrospective clinical study.** *Dent J (Basel).* 2022; **10**(8): 139.
PubMed Abstract | Publisher Full Text | Free Full Text

29. Mangano F, Mangano C, Margiani B, *et al.*: **Combining intraoral and face scans for the design and fabrication of Computer-Assisted Design/Computer-Assisted Manufacturing (CAD/CAM) Polyether-Ether-Ketone (PEEK) implant-supported bars for maxillary overdentures.** *Scanning.* 2019; **2019**: 4274715.
PubMed Abstract | Publisher Full Text | Free Full Text

30. Mangano F, Hauschild U, Admakin O: **Full in-office guided surgery with open selective tooth-supported templates: a prospective clinical study on 20 patients.** *Int J Environ Res Public Health.* 2018; **15**(11): 2361.
PubMed Abstract | Publisher Full Text | Free Full Text

31. Sanda M, Miyoshi K, Baba K: **Trueness and precision of digital implant impressions by intraoral scanners: a literature review.** *Int J Implant Dent.* 2021; **7**(1): 97.
PubMed Abstract | Publisher Full Text | Free Full Text

32. Silvester CM, Hillson S: **A critical assessment of the potential for Structure-from-Motion photogrammetry to produce high fidelity 3D dental models.** *Am J Phys Anthropol.* 2020; **173**(2): 381–392.
PubMed Abstract | Publisher Full Text

33. Chaudhary S, Kumar S, Aggarwal R, *et al.*: **Evaluation of the accuracy of Digital Models generated using photogrammetry.** *Cureus.* 2024; **16**(12): e75448.
PubMed Abstract | Publisher Full Text | Free Full Text

34. Zotti F, Rosolin L, Bersani M, *et al.*: **Digital dental models: is photogrammetry an alternative to dental extraoral and intraoral scanners?** *Dent J (Basel).* 2022; **10**(2): 24.
PubMed Abstract | Publisher Full Text | Free Full Text

35. Soliman I, Ashry A, Kheneifar K, *et al.*: **A comparative evaluation of mobile photogrammetry for facial scanning... face banking.** *Alexandria Dent J.* 2023; **48**(2): 110–114.
Publisher Full Text

36. Abhijeet K, Mody E, Jei J, *et al.*: **Mobile phone assisted 3D extra oral scanner for acquiring dental digital models - an innovative approach.** *J Evol Med Dent Sci.* 2021; **10**(23): 1815–1818.
Publisher Full Text

37. Patel C, Barot GN, Patel MC, *et al.*: **Accuracy and comfort in digital and conventional impression in pediatric dental patients: a randomized comparative study.** *Cureus.* 2025; **17**(1): e76882.
PubMed Abstract | Publisher Full Text | Free Full Text

38. Guiraldo RD, Hiruo EY, Gregorio D, *et al.*: **Development of computational thinking for dental students in the use of the intraoral impressions' technique.** *Contrib A LAS CIENCIAS Soc.* 2023; **16**: 23379–23389.
Publisher Full Text

39. Yang B, Schinke J, Rastegar A, *et al.*: **Cost-effective full-color 3D dental imaging based on close-range photogrammetry.** *Bioengineering (Basel).* 2023; **10**(11): 1268.
PubMed Abstract | Publisher Full Text | Free Full Text

40. Ismail R, Taqriban RB, Ariyanto M, *et al.*: **Affordable and faster transradial prosthetic socket production using photogrammetry and 3D printing.** *Electronics.* 2020; **9**(9): 1456.
Publisher Full Text

41. Fu X, Peng C, Li Z, *et al.*: **The application of multi-baseline digital close-range photogrammetry in three-dimensional imaging and measurement of dental casts.** *PLoS One.* 2017; **12**(16): e0178858.
PubMed Abstract | Publisher Full Text | Free Full Text

42. Tsuchida Y, Shiozawa M, Handa K, *et al.*: **Comparison of the accuracy of different handheld-type scanners in three-dimensional facial image recognition.** *J Prosthodont Res.* 2023; **67**(2): 222–230.
PubMed Abstract | Publisher Full Text

43. Mai HN, Lee DH: **Accuracy of mobile device-compatible 3D scanners for facial digitization: systematic review and meta-analysis.** *J Med Internet Res.* 2020; **22**(10): e22228.
PubMed Abstract | Publisher Full Text | Free Full Text

44. Hou X, Xu X, Zhao M, *et al.*: **An overview of three-dimensional imaging devices in dentistry.** *J Esthet Restor Dent.* 2022; **34**(8): 1179–1196.
PubMed Abstract | Publisher Full Text

45. Gao J, Wang X, Qin Z, *et al.*: **Profiles of facial soft tissue changes during and after orthodontic treatment in female adults.** *BMC Oral Health.* 2022; **22**(1): 257.
PubMed Abstract | Publisher Full Text | Free Full Text

46. Wu Z, Gao X, Long H, *et al.*: **Quantitative analysis of facial symmetry by using three-dimensional technology.** *BMC Oral Health.* 2022; **22**(1): 277.
PubMed Abstract | Publisher Full Text | Free Full Text

47. Suese K: **Progress in digital dentistry: the practical use of Intraoral Scanners.** *Dent Mater J.* 2020; **39**(1): 52–56.
PubMed Abstract | Publisher Full Text

48. AlQhtani FABA: **Evaluating the impact of myofunctional therapy on orthodontic treatment outcomes.** *J Pharm Bioallied Sci.* 2024; **16**(Suppl 3): S2667–S2669.
PubMed Abstract | Publisher Full Text | Free Full Text

49. Fatima N, Singh G, Gupta N, *et al.*: **Prospective comparison of facial soft tissue changes using 2D photographs and 3D scanning after en masse dentoalveolar maxillary distalization using tads.** *Orthod J Nepal.* 2022; **12**(Suppl 3): 28–36.
Publisher Full Text

50. Andrade J, Stona D, Bittencourt H, *et al.*: **Effect of different Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) materials and**

thicknesses on the fracture resistance of occlusal veneers. *Oper Dent.* 2018; **43**(5): 539–548.
PubMed Abstract | Publisher Full Text

51. Wahied DM: **Effect of thickness and CAD/CAM materials on the fracture resistance of biomimetic occlusal veneers.** *MSA Dent J.* 2024; **3**(2): 11–20.
Publisher Full Text

52. Javaid M, Haleem A: **Current status and applications of additive manufacturing in dentistry: a literature-based review.** *J Oral Biol Craniofac Res.* 2019; **9**(3): 179–185.
PubMed Abstract | Publisher Full Text | Free Full Text

53. Joda T, Brägger U: **Digital vs. conventional implant prosthetic workflows: a cost/time analysis.** *Clin Oral Implants Res.* 2015; **26**(12): 1430–1435.
PubMed Abstract | Publisher Full Text

54. Choi J, Ahn J, Park JM: **Deep learning-based automated detection of the dental crown finish line: an accuracy study.** *J Prosthet Dent.* 2024; **132**(6): 1286.e1–1286.e9.
PubMed Abstract | Publisher Full Text

55. Rençber Kizilkaya A, Kara A: **Impact of different CAD software programs on marginal and internal fit of provisional crowns: an in vitro study.** *Heliyon.* 2024; **10**(2): e24205.
PubMed Abstract | Publisher Full Text | Free Full Text

56. Sarhan MM, Khamis MM, Abdelhamid AM, *et al.*: **Evaluation of the virtual cement gap parameter of different CAD software programs in designing a single crown restoration: an in vitro study.** *J Prosthet Dent.* 2023; **129**(5): 777.e1–777.e7.
PubMed Abstract | Publisher Full Text

57. Miyazaki T, Hotta Y, Kunii J, *et al.*: **A review of dental CAD/CAM: current status and future perspectives from 20 years of experience.** *Dent Mater J.* 2009; **28**(1): 44–56.
PubMed Abstract | Publisher Full Text

58. Abad-Coronel C, Pazán, DP, Hidalgo L, *et al.*: **Comparative analysis between 3D-printed models designed with generic and dental-specific software.** *Dent J (Basel).* 2023; **11**(9): 216.
PubMed Abstract | Publisher Full Text | Free Full Text

59. Patzelt SBM, Emmanouilidi A, Stampf S, *et al.*: **Accuracy of full-arch scans using intraoral scanners.** *Clin Oral Investig.* 2014; **18**(6): 1687–1694.
PubMed Abstract | Publisher Full Text

60. Ceylan G, Özel GS, Memisoglu G, *et al.*: **Evaluating the facial esthetic outcomes of Digital Smile Designs generated by artificial intelligence and dental professionals.** *Appl Sci.* 2023; **13**(15): 9001.
Publisher Full Text

61. Coachman C, Calamita MA, Coachman FG, *et al.*: **Facially generated and cephalometric guided 3D digital design for complete mouth implant rehabilitation: a clinical report.** *J Prosthet Dent.* 2017; **117**(5): 577–586.
PubMed Abstract | Publisher Full Text

62. Finelle G: **Digital Smile Design in interdisciplinary and orthodontic dental treatment planning.** *J Dentofac Anomalies Orthod.* 2017; **20**(3): 303.
Publisher Full Text

63. Coachman C, Calamita MA, Sesma N: **Dynamic documentation of the smile and the 2D/3D Digital Smile Design process.** *Int J Periodontics Restorative Dent.* 2017; **37**(2): 183–193.
PubMed Abstract | Publisher Full Text

64. Papadimitriou A, Mousoulea S, Gkantidis N, *et al.*: **Clinical effectiveness of invisalign® orthodontic treatment: a systematic review.** *Prog Orthod.* 2018; **19**(1): 37.
PubMed Abstract | Publisher Full Text | Free Full Text

65. Galan-Lopez L, Barcia-Gonzalez J, Plasencia E: **A systematic review of the accuracy and efficiency of dental movements with Invisalign®.** *Korean J Orthod.* 2019; **49**(3): 140–149.
PubMed Abstract | Publisher Full Text | Free Full Text

66. Al-Nadawi M, Kravitz ND, Hansa I, *et al.*: **Effect of clear aligner wear protocol on the efficacy of tooth movement.** *Angle Orthod.* 2021; **91**(2): 157–163.
PubMed Abstract | Publisher Full Text | Free Full Text

67. Kravitz ND, Kusnoto B, Agran B, *et al.*: **Influence of attachments and interproximal reduction on the accuracy of canine rotation with Invisalign. A prospective clinical study.** *Angle Orthod.* 2008; **78**(4): 682–7.
PubMed Abstract | Publisher Full Text

68. Rossini G, Parrini S, Castroflorio T, *et al.*: **Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review.** *Angle Orthod.* 2015; **85**(5): 881–889.
PubMed Abstract | Publisher Full Text | Free Full Text

69. Christensen LR: **Digital workflows in contemporary orthodontics.** *APOS Trends Orthod.* 2017; **7**(1): 12–18.
Publisher Full Text

70. Cunha TMAD, da Silva Barbosa I, Palma KK: **Orthodontic digital workflow: devices and clinical applications.** *Dental Press J Orthod.* 2021; **26**(6): e21spe6.
PubMed Abstract | Publisher Full Text | Free Full Text

71. Al Yafi F, Camenisch B, Al-Sabbagh M: **Is digital guided implant surgery accurate and reliable?** *Dent Clin North Am.* 2019; **63**(3): 381–397.
PubMed Abstract | Publisher Full Text

72. Whitley D, Eidson RS, Rudek I, *et al.*: **In-office fabrication of dental implant surgical guides using desktop stereolithographic printing and implant treatment planning software: a clinical report.** *J Prosthet Dent.* 2017; **118**(3): 256–263.
PubMed Abstract | Publisher Full Text

73. Arisan V, Karabuda ZC, Özdemir T: **Accuracy of two stereolithographic guide systems for computer-aided implant placement: a computed tomography-based clinical comparative study.** *J Periodontol.* 2010; **81**(1): 43–51.
PubMed Abstract | Publisher Full Text

74. Schleyer TKL, Thyvalikakath TP, Spallek H, *et al.*: **Clinical computing in general dentistry.** *J Am Med Inform Assoc.* 2006; **13**(3): 344–352.
PubMed Abstract | Publisher Full Text | Free Full Text

75. Joda T, Waltimo T, Probst-Hensch N, *et al.*: **Health data in dentistry: an attempt to master the digital challenge.** *Public Health Genomics.* 2019; **22**(1–2): 1–7.
PubMed Abstract | Publisher Full Text

76. Gomez GGF, Wang M, Siddiqui ZA, *et al.*: **Longevity of dental restorations in Sjogren's disease patients using electronic dental and health record data.** *BMC Oral Health.* 2024; **24**(1): 203.
PubMed Abstract | Publisher Full Text | Free Full Text

77. Neville P, van der Zande MM: **Dentistry, e-health and digitalisation: a critical narrative review of the dental literature on digital technologies with insights from health and technology studies.** *Community Dent Health.* 2020; **37**(1): 51–58.
PubMed Abstract | Publisher Full Text

78. Hung M, Voss MW, Rosales MN, *et al.*: **Application of machine learning for diagnostic prediction of root caries.** *Gerodontology.* 2019; **36**(4): 395–404.
PubMed Abstract | Publisher Full Text | Free Full Text

79. Brown MW, Koroluk L, Ko CC, *et al.*: **Effectiveness and efficiency of a CAD/CAM orthodontic bracket system.** *Am J Orthod Dentofacial Orthop.* 2015; **148**(6): 1067–1074.
PubMed Abstract | Publisher Full Text

80. Alotaibi KF, Kassim AM: **Factors that influence the adoption of digital dental technologies and dental informatics in dental practice.** *Int J Online Biomed Eng.* 2023; **19**(15): 103–126.
Publisher Full Text

81. Khurshid Z: **Digital dentistry: transformation of oral health and dental education with technology.** *Eur J Dent.* 2023; **17**(4): 943–944.
PubMed Abstract | Publisher Full Text | Free Full Text

82. Jacobs R, Fontenele RC, Lahoud P, *et al.*: **Radiographic diagnosis of periodontal diseases – current evidence versus innovations.** *Periodontol.* 2000; **95**(1): 51–69.
PubMed Abstract | Publisher Full Text

83. Rodriguez Betancourt A, Samal A, Chan HL, *et al.*: **Overview of ultrasound in dentistry for advancing research methodology and patient care quality with emphasis on periodontal/peri-implant applications.** *Z Med Phys.* 2023; **33**(3): 336–386.
PubMed Abstract | Publisher Full Text | Free Full Text

84. Block MS, Emery RW, Cullum DR, *et al.*: **Implant placement is more accurate using dynamic navigation.** *J Oral Maxillofac Surg.* 2017; **75**(7): 1377–1386.
PubMed Abstract | Publisher Full Text

85. Khaohoen A, Powcharoen W, Sornsuwan T, *et al.*: **Accuracy of implant placement with computer-aided static, dynamic, and robot-assisted surgery: a systematic review and meta-analysis of clinical trials.** *BMC Oral Health.* 2024; **24**(1): 359.
PubMed Abstract | Publisher Full Text | Free Full Text

86. Schnutenhaus S, Edelmann C, Knipper A, *et al.*: **Accuracy of dynamic computer-assisted implant placement: a systematic review and meta-analysis of clinical and in vitro studies.** *J Clin Med.* 2021; **10**(4): 704.
PubMed Abstract | Publisher Full Text | Free Full Text

87. Steinbacher DM: **Three-dimensional analysis and surgical planning in craniomaxillofacial surgery.** *J Oral Maxillofac Surg.* 2015; **73**(12 Suppl): S40–S56.
PubMed Abstract | Publisher Full Text

88. Poojar B, Ommurugan B, Adiga S, *et al.*: **Methodology used in the study.** *Asian J Pharm Clin Res.* 2017; **7**: 1–5.

89. van der Zande MM, Gorter RC, Wismeijer D: **Dental practitioners and a digital future: an initial exploration of barriers and incentives to adopting digital technologies.** *Br Dent J.* 2013; **215**(11): E21.
PubMed Abstract | Publisher Full Text

90. Chen JW, Hobdell MH, Dunn K, *et al.*: **Teledentistry and its use in dental education.** *J Am Dent Assoc.* 2003; **134**(3): 342–346.
PubMed Abstract | Publisher Full Text

91. Islam MRR, Islam R, Ferdous S, *et al.*: **Teledentistry as an effective tool for the communication improvement between dentists and patients: an overview.** *Healthcare (Basel).* 2022; **10**(8): 1586.
PubMed Abstract | Publisher Full Text | Free Full Text

92. Estai M, Kanagasingam Y, Tennant M, *et al.*: **A systematic review of the research evidence for the benefits of teledentistry.** *J Telemed Telecare.* 2018; **24**(3): 147–156.
PubMed Abstract | Publisher Full Text

93. Ghai S: **Teledentistry during COVID-19 pandemic.** *Diabetes Metab Syndr.* 2020; **14**(5): 933–935.
PubMed Abstract | Publisher Full Text | Free Full Text

94. Ashish P, Anurag T: **The impact of teledentistry on modern dental practice.**

IgMin Res. 2024; **2**(6): 457–459.
Publisher Full Text

95. Sabourin C, Giraudeau N, Baccino E, *et al.*: **Teledentistry and forensic odontology: qualitative study on the capacity of implementation.** *Int J Environ Res Public Health.* 2023; **20**(19): 6807.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

96. Giraudeau N, Bauer M, Tramini P, *et al.*: **A national teledentistry study on the knowledge, attitudes, training and practices of private dentists.** *Digit Health.* 2022; **8**: 205520762210850.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

97. Yazdanpanahi F, Shahi M, Davaridolatabadi N: **Investigating the application of new technologies in dental education: a systematic review.** *Acta Med Iran.* 2022; **60**(8): 465–472.
Publisher Full Text

98. Haidar ZS: **Digital dentistry: past, present, and future**. 2023; 1–16.
Reference Source

99. Shaik N, Sriharsha P, Sundararajan P, *et al.*: **Digital revolution: a new era in dentistry .** *Int J Health Sci (Qassim).* 2022; **6**(S2): 12332–12348.
Publisher Full Text

100. Róth I, Czigola A, Joós-Kovács GL, *et al.*: **Learning curve of digital intraoral scanning – an *in vivo* study.** *BMC Oral Health.* 2020; **20**(1): 287.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

101. Zapata O, Barbosa D, Carvajal A, *et al.*: **Finishing Analysis of Dental Outcome (FADO) as a new guide in orthodontic treatment.** *Cureus.* 2023; **15**(2): e34808.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

102. Yassmin F, Blatz MB: **The impact of digital dentistry in interdisciplinary esthetic treatment.** *Compend Contin Educ Dent.* 2022; **43**(9): 571–576; quiz 577.
PubMed Abstract

103. Favaretto M, Shaw D, De Clercq E, *et al.*: **Big data and digitalization in dentistry: a systematic review of the ethical issues.** *Int J Environ Res Public Health.* 2020; **17**(7): 2495.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

104. Schleyer T, Song M, Gilbert GH, *et al.*: **Electronic dental record use and clinical information management patterns among practitioner-investigators in The Dental Practice-Based Research Network.** *J Am Dent Assoc.* 2013; **144**(1): 49–58.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

105. Lelyana N: **Strategic analysis in the application of digital technology in dental practice.** *J Soc Interact Humanit.* 2023; **2**(3): 253–274.
Publisher Full Text

106. Addy L: **Summary of: dental practitioners and a digital future: an initial exploration of barriers and incentives to adopting digital technologies.** *Br Dent J.* 2013; **215**(11): 562–563.
PubMed Abstract | **Publisher Full Text**

107. Gracco A, De Stefani A, Bruno G: **Influence of new technology in dental care: a public health perspective.** *Int J Environ Res Public Health.* 2023; **20**(7): 5364.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

108. Wiederhold MD, Gao K, Wiederhold BK: **Clinical use of virtual reality distraction system to reduce anxiety and pain in dental procedures.** *Cyberpsychol Behav Soc Netw.* 2014; **17**(6): 359–365.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

109. Taysi AE, Taysi NM, Sismanoglu S: **Evaluation of the efficacy of a simulation model used in oral and maxillofacial surgery education.** *BMC Med Educ.* 2024; **24**(1): 310.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

110. Dzyuba N, Jandu J, Yates J, *et al.*: **Virtual and augmented reality in dental education: the good, the bad and the better.** *Eur J Dent Educ.* 2025; **29**(3): 497–515.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

111. Santos BSR, Trevisan D: **Overview and tendencies of augmented reality applications in medicine.** In: *Proceedings of the Symposium on Virtual and Augmented Reality.* ACM: New York, NY, USA, 2023; 26–37.
Reference Source