
**DIGITAL TRANSFORMATION OF DENTISTRY
IN THE PUBLIC HEALTH SYSTEM: REALITIES,
DEVELOPMENT VECTORS AND PROSPECTS**

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INTRODUCTION

The modern stage of societal development is characterized by the rapid digitalization of all spheres of human activity, including the healthcare system. Digital transformation, as a comprehensive process of integrating information technologies into medical practice, opens new opportunities for improving the quality, accessibility, and efficiency of healthcare services. In the context of dentistry, this process is of particular importance, as dental care is an integral component of public health, influencing the overall well-being of the population.

The topic of digital transformation in dentistry within the public health system is highly relevant in light of contemporary challenges, such as the growing demand for high-quality healthcare services, disparities in access, resource limitations, and the need to adapt to rapid technological progress. Digital transformation in dentistry encompasses a wide range of innovations, from the use of computer-aided design and manufacturing (CAD/CAM) systems and 3D printing to the implementation of artificial intelligence (AI) for diagnostics and teledentistry for remote consultations.

These technologies not only optimize clinical processes but also enhance the accessibility of dental services, particularly in remote regions where the shortage of qualified specialists remains a pressing issue. Within the public health system, digital solutions facilitate the integration of dental care into the broader healthcare infrastructure, promoting prevention, early diagnosis, and personalized treatment. However, the adoption of digital technologies is accompanied by a range of challenges, including financial, organizational, ethical, and legal considerations, which require comprehensive analysis to ensure sustainable development. The relevance of this topic is driven by several key factors. First, dental diseases, such as caries and periodontal conditions, remain among the most prevalent globally, placing a significant

burden on healthcare systems. According to the World Health Organization (WHO), nearly 3.5 billion people worldwide suffer from dental pathologies, while access to quality dental care remains limited in many countries. Second, digital technologies offer new opportunities for prevention and early detection of diseases, which can significantly reduce economic costs and improve the quality of life for populations.

Third, integrating dentistry into the digital ecosystems of public health contributes to achieving the principles of universal health coverage, one of the United Nations Sustainable Development Goals for 2030¹. The purpose of this section is to analyze the current state of digital transformation in dentistry, identify key development vectors, and assess the prospects of its impact on the public health system. To achieve this goal, the section is structured to cover both theoretical and practical aspects of the topic. The first part examines the current state of digitalization in dentistry, including the use of advanced technologies, their integration into the public health system, and the main barriers to implementation. The second part focuses on analysing development vectors, encompassing technological, organizational, and educational aspects. The third part evaluates the prospects of digital transformation, with an emphasis on its impact on the accessibility, quality, and economic efficiency of dental care. Special attention is given to the ethical and legal challenges associated with digitalization. The methodological foundation of the study is a systemic approach, which involves analysing scientific literature, reports from international organizations, statistical data, and practical case studies of digital technology implementation in dentistry. Particular emphasis is placed on a comparative analysis of experiences from different countries, enabling the identification of successful practices and their adaptation to local contexts. The use of an interdisciplinary approach allows for the consideration of digital transformation not only from a technological perspective but also from social, economic, and ethical viewpoints. Digital transformation in dentistry holds significant potential to reshape the paradigm of healthcare delivery. It contributes not only to the improvement of clinical processes but also to a redefinition of dentistry's role within the public health system. For instance, teledentistry enables real-time consultations, which are critical for underserved populations and residents of remote areas. Meanwhile, AI and big data analytics offer opportunities for predicting dental diseases, potentially reducing their prevalence through preventive measures. However, the successful realization of these opportunities depends on overcoming barriers such as the high cost of

¹ Matilde Guerra. Integrating sustainability in dentistry: a pathway towards achieving the UN 2030 agenda. *Front Oral Health* . 2025 Jul 11;6:1549020. doi: 10.3389/froh.2025.1549020

technologies, insufficient digital literacy among professionals, and challenges related to patient data protection. Within the public health context, digital transformation in dentistry supports the achievement of strategic goals, such as reducing disparities in access to healthcare services, improving the quality of diagnostics and treatment, and optimizing costs². For example, the use of digital radiographic systems and treatment planning software reduces diagnostic time and enhances result accuracy. Additionally, integrating dental data into electronic medical records (EMR) creates a unified information ecosystem, facilitating coordination across different healthcare sectors. At the same time, digital transformation poses new challenges for the public health system. Implementing advanced technologies requires substantial investments, which can be problematic for countries with limited healthcare budgets. Furthermore, issues of cybersecurity and patient data protection are becoming increasingly critical amid the growing number of cyberattacks on healthcare institutions. Ethical considerations related to the use of AI, particularly regarding accountability for decisions and potential risks of discrimination in data processing, also require attention. Thus, digital transformation in dentistry is a multifaceted process with both significant potential and substantial challenges. Analysing this process within the context of public health enables not only an assessment of current achievements but also the identification of strategic development directions that will enhance the quality of dental care and the overall health of the population. This section aims to systematize knowledge about digital transformation, propose recommendations for its effective implementation, and outline the prospects it offers for dentistry in the era of digital technologies.

1. Current state of digital transformation in dentistry

Digital transformation in dentistry is a key component of modernizing medical practice, enabling improvements in the quality of diagnostics, treatment, and management of dental processes. Modern digital technologies, such as CAD/CAM systems, 3D printing, digital radiographic systems, intraoral scanners, teledentistry, and specialized software, are reshaping approaches to delivering dental services, enhancing their efficiency, accuracy, and accessibility³. This subsection provides an overview of the primary digital tools actively used in dentistry and their impact on clinical practice. Use of Digital Tools CAD/CAM Systems. Computer-Aided Design/Computer-Aided

² Christian Schnitzler. Digital transformation in dentistry: A survey on trends and business implications. *Heliyon*. Volume 11, Issue 11, June 2025, e43456. <https://doi.org/10.1016/j.heliyon.2025.e43456>

³ Levent Iyidirim. Digital restorative procedures in dentistry: digital dentistry. September 2024 *Brazilian Journal of Implantology and Health Sciences* 6(9):191-221 DOI:10.36557/2674-8169.2024v6n9p191-221

Manufacturing (CAD/CAM) systems are among the most widely adopted technologies in modern dentistry⁴. They enable the creation of highly precise dental restorations, such as crowns, bridges, veneers, and orthodontic appliances, with minimal time expenditure. CAD/CAM systems consist of three main stages: scanning (collecting digital data about the oral cavity), design (creating a virtual model of the restoration), and manufacturing (milling or 3D printing the structure). For instance, systems like CEREC (Chairside Economical Restoration of Esthetic Ceramics) allow restorations to be fabricated directly in the dental office during a single visit, significantly reducing patient wait times. Studies indicate that the use of CAD/CAM technologies increases the accuracy of restorations by 20–30% compared to traditional methods.

3D Printing. Three-dimensional printing has revolutionized dental practice by enabling rapid and cost-effective production of dental prostheses, orthodontic appliances, surgical guides, and jaw models⁵. Modern 3D printers utilize biocompatible materials, such as photopolymer resins, to create highly precise products. For example, 3D printing is used to produce customized aligners (transparent orthodontic appliances) as an alternative to traditional braces. The technology is also applied to create surgical guides for implantation, enhancing the accuracy of implant placement and reducing the risk of complications. According to market reports, the dental 3D printing market is growing at a rate of 10–15% annually, reflecting its widespread adoption.

Digital Radiographic Systems. Digital radiography has replaced traditional film-based X-rays due to its higher image quality, faster processing, and reduced radiation exposure for patients⁶. Systems such as digital panoramic X-ray machines and cone-beam computed tomography (CBCT) provide detailed 3D images of teeth, jaws, and adjacent tissues. CBCT, in particular, is indispensable for planning implant procedures, assessing pathologies, and diagnosing complex cases. Digital radiographic systems allow images to be stored electronically, facilitating their integration into electronic medical records (EMR) and data sharing among specialists.

Intraoral Scanners. Intraoral scanners have replaced traditional dental impressions, which often caused discomfort for patients. These devices generate highly accurate digital models of the oral cavity in minutes, used for planning

⁴ Oreyemi As. Modern Innovations in Digital Dentistry: A Review of CAD/CAM Restorations. https://www.researchgate.net/publication/386268972_Modern_Innovations_in_Digital_Dentistry_A_Review_of_CADCAM_Restorations

⁵ Mi-Kyoung Jun. Three-Dimensional Printing in Dentistry: A Scoping Review of Clinical Applications, Advantages, and Current Limitations. *Oral* 2025, 5(2), 24; <https://doi.org/10.3390/oral5020024>

⁶ G J Bansal. Digital radiography. A comparison with modern conventional imaging. *Postgrad Med J*. 2006 Jul;82(969):425–428. doi: 10.1136/pgmj.2005.038448

orthodontic treatments, restorations, or prosthetics⁷. For example, scanners like iTero or Trios enable dentists to obtain 3D images of teeth with micron-level precision, improving the quality of diagnostics and planning. Additionally, intraoral scanners integrate with CAD/CAM systems, creating a seamless digital workflow.

Teledentistry and Remote. Consultations Teledentistry is one of the most promising directions in digital transformation, enabling remote consultations and diagnostics. This technology relies on video conferencing, mobile applications, and cloud-based platforms for data exchange between dentists and patients⁸.

Teledentistry is particularly relevant for remote regions with limited access to qualified dental professionals. For instance, through mobile apps, patients can send images of their oral cavity, allowing dentists to provide preliminary recommendations or referrals. Studies show that teledentistry can reduce consultation costs by 30–40% and improve service accessibility for underserved populations. Additionally, teledentistry is used to monitor orthodontic treatment progress, such as evaluating the effectiveness of aligners. Software for Treatment Planning and Practice Management Specialized Dental Practice Management Software (DPMS) plays a crucial role in digitizing administrative and clinical processes. Programs such as Dentrix, Eaglesoft, or Open Dental automate appointment scheduling, financial management, electronic medical record-keeping, and patient communication⁹. DPMS also integrates with diagnostic tools, such as digital radiographic systems and intraoral scanners, creating a unified information ecosystem. Treatment planning software, for instance, for implantation or orthodontics, allows dentists to model treatment outcomes and present them to patients in an accessible format. This not only enhances clinic efficiency but also improves the patient experience, fostering greater loyalty.

Conclusion Digital technologies, such as CAD/CAM, 3D printing, digital radiographic systems, intraoral scanners, teledentistry, and practice management software, are fundamentally transforming dental practice. They improve diagnostic accuracy, reduce treatment time, enhance service accessibility, and optimize administrative processes. However, the widespread adoption of these technologies requires significant investments, staff training, and addressing cybersecurity issues, which will be explored in subsequent subsections. These tools form the foundation for the further development of digital dentistry, creating the prerequisites for its integration into the public health system.

⁷ Piotr Skomro. The Application of Intraoral Scanners in Orthodontic Care for Adolescents with Disabilities. *Applied Sciences* April 2024;14(8):3344 DOI:10.3390/app14083344

⁸ Амелія Сурду. *Medicina* April 2025;61(5):826 DOI:10.3390/medicina61050826

⁹ Top 5 Dental Practice Management Software Solutions. *y Curve Dental* Published Dec 13, 2024 12:00:00 PM. <https://www.curvedental.com/dental-blog/top-5-dental-practice-management-software-solutions>

Digital transformation in dentistry plays a pivotal role in enhancing the efficiency of the public health system by expanding access to dental services, optimizing data management, and facilitating coordination across various healthcare sectors. The integration of digital solutions into dental practice not only improves the quality of service delivery but also addresses key public health challenges, such as disparities in access to healthcare, resource limitations, and the need for preventive measures against dental diseases. This subsection examines the primary aspects of integrating digital technologies into the public health system, focusing on their impact on the accessibility of dental services, the role of electronic medical records (EMR) and information systems in dentistry, and examples of successful integration from various countries or regions. Impact of Digital Technologies on the Accessibility of

Dental Services Digital technologies significantly enhance the accessibility of dental services, particularly in remote and underserved regions where access to qualified specialists is limited. One of the key tools in this process is teledentistry, which enables remote consultations, preliminary diagnostics, and monitoring of oral health conditions¹⁰. For instance, the use of mobile applications and video conferencing platforms allows patients to receive recommendations from dentists without the need for an in-person visit to a clinic.

This is particularly critical for rural areas where the shortage of dental offices and specialists creates significant barriers. Studies indicate that teledentistry can increase access to consultation services by 40–50% in regions with low population density¹¹. Furthermore, digital technologies, such as intraoral scanners and digital radiographic systems, streamline diagnostic processes, enabling the provision of services in mobile dental clinics or temporary medical facilities. For example, portable digital X-ray devices used in field settings allow diagnostics to be conducted in communities distant from urban centers. Such initiatives reduce financial and logistical barriers for populations, contributing to the realization of the principle of universal health coverage outlined by the World Health Organization (WHO). Digital technologies also support the prevention of dental diseases, a critical aspect of public health. Mobile applications for oral health monitoring, such as Toothpic or Brushlink, enable users to track their dental hygiene, receive personalized recommendations, and seek timely professional help. This reduces the incidence of severe dental pathologies, such as caries and periodontitis, which, according to WHO data, affect up to 90% of the population in some countries.

¹⁰ A J Tella. Potential of teledentistry in the delivery of oral health services in developing countries. December 2019 *Annals of Ibadan Postgraduate Medicine* 17(2):115-123.

¹¹ Сапа Омер Алабасс. Acceptance and readiness for tele-dentistry among dental professionals amidst conflict in Sudan. July 2025 *BMC Oral Health* 25(1) DOI:10.1186/s12903-025-06501-5

Role of Electronic Medical Records (EMR) and Information Systems in Dentistry Electronic Medical Records (EMR) and information systems form the backbone of the digital infrastructure in modern dentistry, ensuring efficient data management, coordination among specialists, and integration of dental data into the broader healthcare system¹². EMRs allow for the storage of a patient's complete dental health history, including diagnostic results, treatment plans, radiographic images, and notes on previous procedures. This ensures continuity of care, which is critical in the context of public health. The integration of EMRs into dental practice facilitates data sharing among dentists, general practitioners, surgeons, and other specialists, improving coordination in the treatment of comorbidities.

For instance, information about a patient's dental status may be relevant for diagnosing systemic conditions, such as diabetes or cardiovascular diseases, which are linked to oral health issues¹³. Studies show that the implementation of EMRs in healthcare facilities increases data management efficiency by 25–30% and reduces the likelihood of diagnostic errors. Information systems, such as Dental Practice Management Software (DPMS), further optimize administrative processes, including appointment scheduling, financial management, and patient communication. For example, integrating DPMS with EMRs enables automatic updates of patient health data, facilitating monitoring and evaluation of preventive programs. Such systems also support big data analytics, which can be used to predict epidemiological trends in dental diseases at the population level. Examples of Successful Integration Successful examples of integrating digital solutions into dentistry demonstrate the significant potential of these technologies for the public health system. In the United States, the Teledentistry Initiative in California has provided dental consultations for children from low-income families in rural areas.

By utilizing telemedicine platforms and portable diagnostic devices, such as intraoral cameras, the program reached over 10,000 children in its first two years, reducing the need for emergency dental interventions by 15%. In the United Kingdom, the National Health Service (NHS) is actively implementing digital radiographic systems and EMRs in dental clinics¹⁴. The NHS Digital Dentistry Initiative aims to create a unified database integrating dental records with other medical data, enhancing coordination between dentists and general practitioners. By 2023, this initiative covered over 60% of public dental clinics, reducing

¹² Roja Lakshmi Karri. Electronic Health Records (EHR) in Dentistry. March 2025 DOI:10.1729/Journal.44277

¹³ Abdullah Alanazi. Informational Needs for Dental-Oriented Electronic Health Records from Dentists' Perspectives. *Healthcare* January 2023 11(2):266 DOI:10.3390/healthcare11020266

¹⁴ Maha El Tantawi. Teledentistry from research to practice: a tale of nineteen countries. *Front Oral Health*. 2023 Jun 16;4:1188557. doi: 10.3389/froh.2023.1188557

diagnostic data processing time by 20%. In developing countries like India, digital transformation in dentistry is supported through mobile technologies.

The mHealth for Oral Health program, launched in Karnataka, uses mobile applications to educate the population on oral hygiene practices and facilitate remote consultations. According to program reports, by 2024, it reached over 500,000 users, contributing to a 10% reduction in caries prevalence among children in pilot regions.

The integration of digital technologies into dentistry offers significant opportunities to enhance the quality and accessibility of healthcare services but is accompanied by a range of challenges and barriers that hinder their full adoption within the public health system. Digital transformation requires substantial resources, adaptation of professional skills, and resolution of data security issues. This subsection examines the key obstacles related to financial constraints, insufficient training of professionals for working with digital technologies, and cybersecurity and patient data protection concerns.

Financial Constraints. One of the primary barriers to implementing digital technologies in dentistry is the high cost of equipment and software. Modern digital tools, such as CAD/CAM systems, 3D printers, digital radiographic systems, and intraoral scanners, require significant capital investments¹⁵. For instance, the average cost of a CAD/CAM system, such as CEREC, can range from \$100,000 to \$150,000 USD, which is prohibitive for many dental clinics, particularly in countries with limited healthcare funding. Similarly, dental practice management software (DPMS) and teledentistry platforms often involve monthly or annual subscription fees, creating additional financial burdens.

In low- and middle-income countries, financial constraints are even more critical. Public dental facilities often lack the budget to purchase modern equipment, while private clinics are forced to pass costs onto patients, increasing service costs and reducing accessibility. According to the World Health Organization (WHO), only 10–20% of dental clinics in developing countries have access to digital technologies due to financial limitations. This exacerbates disparities in access to quality dental care, particularly in rural areas with less developed infrastructure. **Insufficient Training of Professionals for Digital Technologies.**

Another significant barrier is the insufficient training of dentists and medical staff in working with digital technologies. The adoption of tools such as intraoral scanners, CAD/CAM systems, or treatment planning software requires new knowledge and skills that are not always included in standard medical curricula. For example, using artificial intelligence (AI) for analyzing radiographic images demands an understanding of machine learning principles

¹⁵ Dominik Gross. Digitalization in dentistry: ethical challenges and implications. October 2019 *Quintessence International* 50(10):830-838 DOI:10.3290/j.qi.a43151

and data interpretation, which goes beyond traditional dental education. The lack of digital literacy among dentists is particularly pronounced in countries with outdated medical education systems. Studies indicate that up to 40% of dentists in economies in transition report difficulties using digital tools due to a lack of training. Even in developed countries with broader access to training, many professionals face psychological barriers, such as resistance to change or fear of errors when working with new technologies. The absence of regular continuing education programs and simulation centers further complicates adaptation to digital innovations¹⁶.

Moreover, training personnel requires significant time and resources. Organizing training sessions, purchasing educational equipment, and engaging certified instructors can be prohibitive for small clinics or public institutions. This creates a vicious cycle where the lack of qualified personnel hinders the effective use of digital technologies, while limited resources make it difficult to organize training. Cybersecurity and Patient Data Protection Issues.

The increasing use of digital technologies in dentistry, particularly electronic medical records (EMR), teledentistry, and cloud-based platforms, heightens risks related to cybersecurity and patient data protection. Dental clinics, like other healthcare facilities, are targets for cyberattacks aimed at stealing sensitive data or extorting ransoms. According to a 2024 cybersecurity report, the number of attacks on healthcare institutions increased by 20% compared to the previous year, with dental clinics using EMRs being particularly vulnerable due to inadequate data protection measures. Patient data protection is governed by international standards, such as the General Data Protection Regulation (GDPR) in the European Union or the HIPAA law in the United States. However, in many developing countries, relevant legislation is insufficiently developed, creating legal gaps that complicate ensuring data confidentiality. For instance, in countries with weak regulatory frameworks, dental clinics may use cloud services without proper encryption, increasing the risk of data breaches.

Additionally, the adoption of teledentistry and remote consultations introduces further cybersecurity challenges. Transmitting oral cavity images or medical records over the internet can be intercepted if secure communication channels are not used. Insufficient staff awareness of cybersecurity basics, such as using weak passwords or unsecured networks, further exacerbates these risks. Experts estimate that up to 30% of dental clinics in middle-income countries lack comprehensive cybersecurity systems, limiting their ability to safely implement digital technologies.

¹⁶ Julia Sofie Gebhardt. Digitalization in Dentistry: Dentists' Perceptions of Digital Stressors and Resources and Their Association with Digital Stress in Germany—A Qualitative Study. *Healthcare* 2025, 13(12), 1453; <https://doi.org/10.3390/healthcare13121453>

Financial constraints, insufficient training of professionals, and cybersecurity issues are key barriers to the digital transformation of dentistry within the public health system. The high cost of equipment and software limits access to technologies, particularly in low-income countries, while the lack of qualified personnel hinders their effective use. Cybersecurity and data protection concerns add further complexity, necessitating the development of robust security systems and appropriate legislation. Overcoming these barriers requires coordinated efforts from government institutions, educational establishments, and the private sector, which will be addressed in subsequent subsections.

2. Vectors of development of digital transformation in dentistry

Technological advancements play a pivotal role in the digital transformation of dentistry, providing new opportunities for diagnostics, treatment planning, professional training, and optimization of dental equipment. Key areas of development include artificial intelligence (AI), virtual and augmented reality (VR/AR), and the Internet of Things (IoT)¹⁷. These innovations not only enhance the accuracy and efficiency of clinical processes but also facilitate the integration of dentistry into the public health system by improving accessibility, quality, and the preventive potential of dental services. This subsection explores the application of AI in diagnostics and treatment planning, the use of VR/AR for training and procedure simulation, and the role of IoT in dental equipment. Artificial Intelligence for Diagnostics and Treatment Planning Artificial intelligence (AI) is becoming a critical tool in dentistry, particularly in areas such as diagnostic image analysis and treatment planning. AI algorithms, especially those based on deep learning, enable the automated analysis of radiographic images, panoramic scans, and cone-beam computed tomography (CBCT) data. For instance, AI systems like Pearl's Second Opinion or Dent. AI can detect caries, periodontal pathologies, dental anomalies, and tumors with an accuracy of 90–95%, comparable to or even surpassing the capabilities of experienced radiologists. These systems analyse images in seconds, significantly reducing diagnostic time and minimizing human error. In treatment planning, AI is used to develop individualized therapeutic strategies.

For example, algorithms can predict the outcomes of orthodontic treatments by modelling tooth movement for aligners or braces. Tools like Envisaging ClinCheck integrate AI to create virtual models of the dental arch, allowing dentists to present expected treatment outcomes to patients before therapy begins. Additionally, AI facilitates the prediction of dental diseases by analysing

¹⁷ Mariya Dimitrova. Digital Transformation in Preventive Dentistry: An Overview of the Role of Technology in the Evolution of Preventive Dentistry. In book: Leveraging Digital Technology for Preventive Dentistry (pp.25-54). DOI:10.4018/979-8-3693-3872-8.ch002

big data, including medical histories, genetic information, and lifestyle factors. Studies suggest that AI-driven diagnostics can reduce dental treatment costs by 15–20% through early detection of pathologies. AI also holds potential for prevention within the public health system. For instance, algorithms integrated into mobile applications can analyse photographs of the oral cavity taken by users and provide preliminary recommendations on hygiene or the need for professional consultation.

This enhances public awareness and reduces the prevalence of dental diseases. Development of Virtual and Augmented Reality for Dentist Training and Procedure Simulation Virtual reality (VR) and augmented reality (AR) offer new prospects for training dentists and simulating clinical procedures¹⁸. VR technologies create immersive simulation environments where students and practicing dentists can hone their skills without risk to real patients. For example, VR simulators such as Dental Simulator or HapTEL replicate realistic scenarios for dental procedures, including tooth preparation, implant placement, and extractions. These systems utilize haptic devices that mimic tactile sensations, providing a lifelike experience. Augmented reality, in turn, overlays digital information onto the real world, proving valuable for both training and clinical practice. For instance, AR glasses like Microsoft HoloLens can display 3D models of the dental arch or anatomical structures during surgeries, enhancing the precision of interventions, particularly implantations. Studies indicate that the use of VR/AR in dental training improves the acquisition of practical skills by 30–40% compared to traditional methods. In the context of public health, VR/AR contributes to the standardization of education and professional development in regions with limited access to modern educational resources. For example, online VR training platforms enable dentists in remote areas to participate in simulation courses without the need to travel to training centers. This reduces professional development costs and enhances the quality of dental care at the population level.

Internet of Things (IoT) in Dental Equipment

The Internet of Things (IoT) is increasingly applied in dental equipment, enabling automation, monitoring, and optimization of device performance. IoT technologies allow dental equipment, such as digital X-ray machines, CAD/CAM systems, or autoclaves, to be connected to a unified network, facilitating remote control and diagnostics¹⁹. For instance, IoT systems can automatically

¹⁸ Masoumeh Farhadi Nia. Transforming dental diagnostics with artificial intelligence: advanced integration of ChatGPT and large language models for patient care. *Front Dent Med.* 2025 Jan 6;5:1456208. doi: 10.3389/fdmed.2024.1456208.

¹⁹ Imroz khan. ArticlePDF Available Internet of Things (IoT) Its Applications and Enabling Technologies in Healthcare: A Review. April 2024 *Educational Administration Theory and Practice journal* 30(4). DOI: 10.53555/kuey.v30i4.5031

notify technical services of maintenance needs, reducing downtime and improving clinic efficiency. In clinical practice, IoT is used to monitor oral health through “smart” devices, such as toothbrushes with sensors (e.g., Oral-B iO) or orthodontic appliances with embedded sensors. These devices transmit data on hygiene or treatment progress to mobile applications, enabling dentists to monitor patients’ conditions in real time. Experts estimate that IoT in dentistry can reduce the frequency of follow-up clinic visits by 10–15% through timely issue detection. Within the public health system, IoT supports the collection of large datasets for epidemiological analysis.

For example, anonymized data from IoT devices can be used to assess the dental health status of populations, predict trends, and plan preventive programs. However, implementing IoT requires addressing cybersecurity concerns, as connected devices are potential targets for cyberattacks. Technological innovations such as artificial intelligence, virtual and augmented reality, and the Internet of Things create new opportunities for advancing dentistry within the public health system. AI enhances diagnostic accuracy and treatment-planning efficiency, VR/AR improves professional training, and IoT optimizes equipment performance and health monitoring. However, the successful adoption of these technologies requires overcoming financial, educational, and technical barriers, which will be addressed in subsequent subsections.

The digital transformation of dentistry within the public health system is heavily dependent on political and organizational changes that create an enabling environment for the adoption of innovative technologies. National strategies for healthcare digitalization, standardization of digital processes, and support from international organizations play a crucial role in shaping the infrastructure necessary for integrating digital solutions into dental practice²⁰. These changes contribute to improving the accessibility, quality, and efficiency of dental services while aligning them with global public health standards. This subsection examines national digitalization strategies, the standardization of digital processes in dentistry, and the role of international organizations in supporting digital initiatives.

National Healthcare Digitalization Strategies and Their Impact on Dentistry National healthcare digitalization strategies form the foundation for implementing digital technologies in dentistry by defining priorities, funding, and regulatory frameworks. Many countries have developed national programs that include dentistry as an integral part of the healthcare system.

²⁰ Martin Gersch, Lauri Wessel. Digital Transformation in Health Care: The Role of Professional Practices. *The Oxford Handbook of Industry Dynamics*. <https://doi.org/10.1093/oxfordhb/9780190933463.013.19>

For instance, in the European Union, the Digital Health Europe 2030 strategy aims to establish a unified digital infrastructure encompassing electronic medical records (EMR), telemedicine, and big data analytics. In dentistry, this promotes the adoption of teledentistry, digital radiographic systems, and dental practice management software (DPMS).

In developed countries like the United States, initiatives such as the Meaningful Use program under the Health Information Technology for Economic and Clinical Health (HITECH) Act incentivize dental clinics to adopt EMR and digital diagnostic tools through financial subsidies. Studies indicate that such programs have increased the digitalization of dental practices in the U.S. by 25% over the past decade. In countries with transitional economies, such as Ukraine, digitalization strategies like the “e-Health” program aim to create a unified electronic healthcare system, including dental data, though their implementation often faces financial and infrastructural constraints.

These strategies impact dentistry by supporting the procurement of equipment, promoting telemedicine initiatives, and developing digital infrastructure. For example, government programs may subsidize the purchase of intraoral scanners or digital X-ray machines for public clinics, thereby increasing service accessibility in remote regions. However, insufficient coordination between government bodies and the private sector, as well as limited funding in low-income countries, can hinder progress. Thus, the effectiveness of national strategies depends on their adaptation to local needs and the availability of resources. Standardization of Digital Processes in Dental Practice Standardization of digital processes is a critical component for ensuring interoperability, security, and efficiency of digital solutions in dentistry.

It involves developing uniform protocols for the use of digital tools, such as EMR, teledentistry, and CAD/CAM systems, as well as unifying data formats and processing procedures. International standards, such as DICOM (Digital Imaging and Communications in Medicine) for medical imaging and HL7 (Health Level Seven) for data exchange, play a key role in harmonizing digital processes in dentistry²¹. Standardization facilitates the integration of dental data into broader healthcare systems, enabling seamless information exchange among dentists, general practitioners, and other specialists. For instance, standardized EMRs allow dental records to be incorporated into national databases, improving coordination in the treatment of comorbidities. Studies show that standardized digital processes reduce the likelihood of errors in diagnostics and data management by 20–30%.

²¹ Michele Larobina. Thirty Years of the DICOM Standard. *Tomography* October 2023;9(5):1829-1838. DOI:10.3390/tomography9050145

However, standardization faces several challenges, including differences in regulatory requirements across countries and the lack of uniform standards for emerging technologies, such as artificial intelligence (AI) in diagnostics. In countries with underdeveloped infrastructure, standardization may be hindered by a lack of technical resources or low levels of digital literacy among professionals. Overcoming these challenges requires coordinated efforts at national and international levels to develop universal standards and ensure their implementation. Role of International Organizations in Supporting Digital Initiatives International organizations, such as the World Health Organization (WHO), the International Dental Federation (FDI), and the World Bank, play a significant role in supporting digital initiatives in dentistry. The WHO, through its Global Strategy on Digital Health (2020–2025), assists countries in developing national digitalization plans that include dentistry. This strategy emphasizes expanding access to telemedicine, developing EMRs, and enhancing the digital literacy of healthcare professionals. The FDI actively promotes the adoption of digital technologies in dentistry through educational programs and standardization recommendations. For example, the FDI Oral Health Observatory initiative supports the collection of dental health data via digital platforms, aiding countries in planning preventive programs. Additionally, FDI organizes international conferences and webinars to facilitate knowledge exchange on digital solutions. The World Bank and regional organizations, such as the European Bank for Reconstruction and Development (EBRD), provide financial support for healthcare digitalization in developing countries. For instance, World Bank projects in India and Brazil have funded the procurement of digital equipment for dental clinics and professional training, leading to a 15–20% increase in service accessibility in pilot regions.

International organizations also contribute to developing ethical and legal frameworks for the use of digital technologies, particularly in data protection and cybersecurity. For example, the WHO, in collaboration with the International Telecommunication Union (ITU), develops guidelines for the secure use of telemedicine and AI, which are critical for dental practice. International organizations also contribute to developing ethical and legal frameworks for the use of digital technologies, particularly in data protection and cybersecurity. For example, the WHO, in collaboration with the International Telecommunication Union (ITU), develops guidelines for the secure use of telemedicine and AI, which are critical for dental practice²².

²² Invitation for Public Comment: Advancing the Responsible Use of Digital Technologies in Global Health. 7 January 2025 <https://www.who.int/news-room/articles-detail/invitation-for-public-comment--advancing-the-responsible-use-of-digital-technologies-in-global-health>

Improving accessibility and quality of dental services

Digital transformation in dentistry opens new prospects for the public health system, particularly by enhancing the accessibility and quality of dental services. Through innovative technologies such as teledentistry and big data analytics, it is possible not only to reduce disparities in access to healthcare but also to provide personalized treatment approaches, thereby improving population health outcomes.

This subsection examines the key aspects of the impact of digital solutions on the accessibility of dental services, particularly through telemedicine, and the opportunities for personalized treatment enabled by big data analytics. Reducing Disparities in Access to Dental Care through Telemedicine. Telemedicine, specifically teledentistry, is one of the most promising tools for addressing disparities in access to dental services, particularly in regions with limited healthcare infrastructure. Traditionally, access to qualified dentists in rural or remote areas is hindered by a lack of clinics, specialists, and transportation links. Teledentistry overcomes this challenge by enabling consultations, preliminary diagnostics, and oral health monitoring through video conferencing, mobile applications, and cloud-based platforms. For instance, teledentistry platforms such as MouthWatch or Teledentix allow patients to receive real-time consultations by sending images of their oral cavity captured via smartphones or portable intraoral cameras. This enables dentists to assess the condition of teeth and gums, provide preventive recommendations, or refer patients for further treatment. Studies indicate that teledentistry can increase access to dental consultations by 40–50% in remote regions while reducing travel-related costs for underserved populations.

Within the public health context, teledentistry supports the realization of the principle of universal health coverage outlined by the World Health Organization (WHO). It reaches vulnerable groups, such as children, the elderly, and low-income individuals, who often lack the means to visit dental clinics. For example, in developing countries like India, teledentistry programs supported by governmental and non-governmental organizations provide consultations to millions in rural areas, reducing the incidence of advanced dental pathologies. Additionally, teledentistry supports preventive programs by providing populations with access to educational materials and oral hygiene recommendations, contributing to a reduction in the prevalence of caries and periodontitis.

However, realizing the full potential of teledentistry requires overcoming several barriers, including limited access to high-speed internet in rural areas, low digital literacy among populations, and regulatory constraints. The development of telecommunication infrastructure and user education programs are critical prerequisites for scaling this approach.

Big data analytics offers new opportunities for personalizing dental treatment, a significant step toward improving the quality of healthcare services and the effectiveness of prevention within the public health system²³. Big data encompasses information from electronic medical records (EMR), diagnostic images, IoT device data (e.g., smart toothbrushes), and demographic and epidemiological indicators. By processing this data with artificial intelligence (AI) algorithms, dentists can develop individualized treatment plans tailored to each patient's unique characteristics. For example, big data analytics enables the prediction of dental disease risks based on medical history, genetic factors, lifestyle, and socioeconomic status.

Systems like Dent.AI or IBM Watson Health utilize machine learning to identify patterns in large datasets, facilitating the early detection of caries, periodontitis, or other pathologies. Estimates suggest that combining AI with big data can improve the accuracy of early diagnostics by 20–30%, reducing the need for complex and costly procedures²⁴. Personalization is also evident in orthodontics and prosthodontics. For instance, analyzing data from 3D dental scans allows for the creation of customized aligners or prostheses tailored to a patient's anatomical features.

Systems like envisaging use big data to model optimal tooth movement, shortening the duration of orthodontic treatment and enhancing its effectiveness. Furthermore, big data supports the development of preventive programs at the population level by identifying at-risk groups and directing resources toward targeted measures, such as water fluoridation or school-based caries prevention programs. In the public health system, big data analytics is strategically important, as it enables the forecasting of epidemiological trends and the optimization of resource allocation.

For example, analysing dental data in national databases can identify regions with high prevalence of dental diseases, directing additional resources such as mobile clinics or telemedicine programs to those areas. However, the use of big data is associated with challenges, particularly the need to ensure data privacy and compliance with international standards such as GDPR or HIPAA.

Impact on Prevention and Early Diagnosis

Digital transformation in dentistry plays a pivotal role in strengthening the prevention and early diagnosis of dental diseases, which is critically important for the public health system. The use of artificial intelligence (AI) for predicting dental conditions and mobile applications for monitoring oral health enables

²³ Iman Akour. The Impact of Big Data Analytics on Health Care: A Systematic Review. August 2024. DOI: 10.21203/rs.3.rs-4995748/v1

²⁴ Sukumaran Anil. Transforming Dental Caries Diagnosis Through Artificial Intelligence-Based Techniques. *Cureus*. 2023 Jul 11;15(7):e41694. doi: 10.7759/cureus.41694

not only the early detection of issues but also enhances public awareness of preventive measures. These technologies contribute to reducing the prevalence of dental diseases, lowering treatment costs, and improving overall population health. This subsection examines the potential of AI in predicting dental diseases and the role of mobile applications in monitoring oral health²⁵.

Use of AI for Predicting Dental Diseases

Artificial intelligence (AI) is revolutionizing approaches to prevention and early diagnosis in dentistry due to its ability to analyze vast datasets and identify hidden patterns. AI algorithms, particularly those based on machine learning and deep learning, are employed to predict dental diseases by analyzing data from radiographic images, electronic medical records (EMR), genetic profiles, and socio-demographic indicators.

For instance, AI systems such as Pearl's Second Opinion or Dent.AI can detect early signs of caries, periodontitis, enamel erosion, or even precancerous conditions with an accuracy of 90–95%, often surpassing the capabilities of traditional diagnostics in certain cases. AI-driven prediction of dental diseases relies on processing big data, which includes medical histories, lifestyle factors, dietary habits, and genetic predispositions.

For example, algorithms can identify individuals at high risk of developing periodontitis based on factors such as smoking, diabetes, or genetic predisposition, recommending preventive measures like regular check-ups or specialized hygiene programs. Studies suggest that AI-based prediction of dental pathologies can reduce the incidence of advanced cases by 15–20%, thereby decreasing the need for complex and costly interventions. AI also plays a significant role in developing preventive programs at the population level.

Analysing large datasets enables the identification of epidemiological trends, such as regional variations in the prevalence of dental diseases, allowing resources to be directed toward targeted preventive initiatives. For instance, in countries with high caries rates among children, AI can assist in planning fluoridation programs or school-based educational campaigns. However, the effective use of AI requires addressing ethical concerns, such as ensuring algorithm transparency, avoiding data bias, and complying with data protection standards like GDPR or HIPAA.

Oral Health Mobile applications for monitoring oral health are a vital tool for preventing dental diseases, as they enhance public awareness and facilitate early problem detection. These apps enable users to track oral hygiene, receive personalized recommendations, and seek timely professional care. For example,

²⁵ Suman Sharma Revolutionizing Dentistry: The Applications of Artificial Intelligence in Dental Health Car. J Pharm Bioallied Sci. 2024 Mar 5;16(Suppl 3):S1910-S1912. doi: 10.4103/jpbs.jpbs_1290_23

apps like Toothpic, Brushlink, or Oral-B use smartphone cameras to analyse images of teeth and gums, providing preliminary assessments of oral health status. Some apps integrate with “smart” toothbrushes equipped with sensors to monitor brushing techniques and frequency of hygiene routines²⁶.

Mobile apps also serve an educational function, offering users information on proper oral hygiene, caries and periodontitis prevention, and reminders for regular dental check-ups. For instance, the Colgate Connect app provides interactive brushing lessons and tracks user progress, fostering healthy habits. Studies indicate that regular use of such apps can improve oral hygiene compliance by 25–30%, reducing the incidence of dental issues over time. In the public health context, mobile apps contribute to population-level prevention by disseminating educational content and enabling early intervention.

For example, apps can alert users to early signs of dental problems, prompting timely consultations and reducing the burden on healthcare systems. Moreover, data collected from these apps, when anonymized, can be used for epidemiological analysis to inform public health strategies. However, challenges such as low digital literacy among certain populations and limited access to smartphones in underserved areas must be addressed to maximize the impact of these tools.

CONCLUSIONS

The digital transformation of dentistry within the public healthcare system is a strategically vital direction that enhances the quality, accessibility, and efficiency of dental care in both Ukraine and the European Union. The current stage of dentistry development is characterized by the active adoption of innovative technologies that are transforming all aspects of healthcare delivery—from prevention to complex surgical interventions.

Digital solutions such as CAD/CAM systems, 3D printing, digital scanners, teledentistry, and artificial intelligence enable the automation of diagnostic processes, improve treatment-planning accuracy, reduce production times for dental restorations, and facilitate personalized approaches to patient care. However, the implementation of these opportunities in Ukraine faces several challenges that require systemic solutions to ensure sustainable progress. The current state of dental care in Ukraine and the EU reveals significant differences in organization, financing, and infrastructure. In EU countries such as Denmark and Germany, advanced infrastructure, stable funding, and the integration of digital technologies into public prevention programs ensure higher levels of service accessibility and quality.

²⁶ Kamalapriya Ajay. App-based oral health promotion interventions on modifiable risk factors associated with early childhood caries: A systematic review. *Front Oral Health*. 2023 Mar 10;4:1125070. doi: 10.3389/froh.2023.1125070

In Ukraine, a mixed model of dental care delivery prevails, with the private sector playing a significant role, while the public system remains constrained by inadequate funding and outdated infrastructure. The adoption of digital technologies in Ukraine's public sector is in its early stages, limited by restricted access to modern equipment, the high cost of technologies, and insufficient workforce training. Technological innovations open new prospects for dentistry. Artificial intelligence and machine learning enable the prediction of dental diseases, high-precision analysis of radiographic images, and optimization of preventive measures. Virtual and augmented reality are applied in dental education and the planning of complex procedures, such as implant placement or orthodontic treatment, enhancing the quality of professional training and reducing the risk of errors.

The Internet of Things (IoT) in dental equipment enables real-time monitoring of oral health, facilitating early diagnosis and prevention. Integration with electronic health systems, such as eHealth, provides a foundation for centralized data management, improving coordination across healthcare sectors. A key aspect of digital transformation is its impact on the quality and accessibility of dental services. Digital solutions reduce diagnostic and production times for dental restorations, enhance treatment accuracy, and expand access to consultations through teledentistry, which is particularly crucial for remote regions. In the EU, teledentistry is already widely used for primary consultations and monitoring, while in Ukraine, this field is still developing.

The adoption of digital platforms for monitoring population dental health supports the implementation of national prevention programs, enabling the identification of at-risk groups and the allocation of resources to support them. Despite the significant potential of digital technologies, their implementation in Ukraine faces several challenges. Infrastructural limitations, such as the lack of modern equipment in public facilities, hinder the scaling of digital solutions. Financial barriers, including the high cost of technologies and insufficient public funding, limit the accessibility of digital services for broad population segments. The issue of workforce training remains critical: dentists require additional education to operate digital systems, and the lack of specialized programs in higher education institutions slows this process. In the EU, these challenges are partially addressed through robust educational systems and government support, serving as a model for Ukraine.

The directions for the development of digital dentistry include further progress in technological innovations and integration with public healthcare systems. Advances in artificial intelligence and machine learning will enable more accurate and personalized diagnostic and preventive approaches. Virtual

and augmented reality will become integral to education and the planning of complex dental procedures. The Internet of Things will facilitate the creation of “smart” clinics, where equipment seamlessly interacts with information systems. Integration with public healthcare systems, particularly through digital monitoring platforms and eHealth, will optimize resources, enhance service accessibility, and improve epidemiological control of dental diseases. For Ukraine, the key task is to create favourable conditions for the digital transformation of dentistry. This involves increasing public funding, fostering public-private partnerships, modernizing infrastructure, and improving professional training systems. Harmonizing digitalization approaches with European standards will facilitate Ukraine’s integration into the global digital healthcare system. In the long term, the successful implementation of these measures will not only enhance the quality of dental care but also ensure its accessibility for all population segments, contributing to the overall improvement of public health.

SUMMARY

This article provides a comprehensive analysis of the digital transformation of dentistry within the public healthcare system, focusing on current realities, key development directions, and future prospects. It examines the state of dental care organization in Ukraine and European Union countries, comparing public, private, and mixed models, as well as levels of financing and infrastructural support. Particular attention is given to the adoption of digital technologies, including CAD/CAM systems, 3D printing, digital scanners, artificial intelligence, teledentistry, and data management systems, which facilitate diagnostic automation, enhance treatment accuracy, and reduce production times for dental restorations.

The main challenges of digitalization are identified, including infrastructural limitations, financial barriers, unequal access to technology, and inadequate workforce training for digital solutions. The article outlines promising development directions, encompassing technological trends (artificial intelligence, virtual and augmented reality, Internet of Things) and integration with public healthcare systems through digital monitoring platforms and eHealth.

It underscores the importance of reforms, fostering public-private partnerships, modernizing infrastructure, and aligning with European standards to ensure high quality, accessible, and innovative dental care in Ukraine, thereby contributing to the improvement of public health.

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