ARTIFICIAL INTELLIGENCE IN ORTHODONTIC DIAGNOSIS:

HISTORY, CHATBOT TECHNOLOGY, DIAGNOSTIC FOUNDATIONS, AND ETHICAL CONSIDERATIONS

Author:
Elif SAĞIR

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www.bidgeyayinlari.com.tr - bidgeyayinlari@gmail.com
Krc Bilişim Ticaret ve Organizasyon Ltd. Şti.
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PREFACE

Artificial intelligence (AI) has moved, over the course of little more than seventy years, from a theoretical question posed by a single mathematician to a technology embedded in everyday clinical practice, including dentistry and orthodontics. Understanding how AI-based tools, and in particular chatbot systems, are used in contemporary clinical and educational settings requires several interlocking foundations: a clear grasp of what artificial intelligence is, how it learns, and how the field arrived at its present state; a specific understanding of chatbot technology, its industry applications, and its expanding role in dentistry and orthodontics; familiarity with the broader evolution of medical and dental image analysis and the conventional clinical and radiographic foundations of orthodontic diagnosis against which any AI-assisted approach must be evaluated; a balanced, evidence-based appreciation of what these systems do well and where they continue to fall short; and, finally, an awareness of the ethical and regulatory considerations that must accompany their clinical adoption.

This book addresses these needs in five parts. The first part reviews the definition and types of artificial intelligence and machine learning and traces the field's historical development from Alan Turing's foundational 1950 proposal to the emergence of contemporary large language models. The second part turns to chatbot technology specifically, examining its definition, its applications across industries, the current landscape of large language model-based systems such as ChatGPT, Gemini, and

Claude, and its expanding uses within dentistry and orthodontics. The third part reviews the broader evolution of medical and dental image analysis and the conventional clinical examination, study model, and radiographic foundations of orthodontic diagnosis. The fourth part offers a focused, evidence-based appraisal of the advantages and disadvantages of chatbot technology. The fifth and final part considers the ethical and regulatory principles that must guide the responsible use of artificial intelligence in dental and orthodontic practice.

Taken together, these five parts move from the historical and conceptual foundations of artificial intelligence, through the specific technology and clinical applications of chatbots and the diagnostic methods they are increasingly applied to, to a critical appraisal of their genuine strengths and limitations and the ethical framework within which they must be used. It is our hope that this progression offers the reader a coherent and clinically grounded introduction to artificial intelligence and chatbot technology, of particular relevance to dentistry, orthodontics, and the broader study of AI-assisted clinical practice.

Elif SAĞIR[1]

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[1] Uzm.Arş.Görevlisi]. Gaziantep Üniversitesi, Diş Hekimliği Fakültesi, Ortodonti Anabilim Dalı. ORCID: [0009-0002-6491-1973]

ARTIFICIAL INTELLIGENCE: DEFINITION, TYPES, AND HISTORICAL DEVELOPMENT

Artificial intelligence (AI) has developed, over little more than seventy years, from a theoretical question posed by a single mathematician into a technology embedded throughout contemporary science, industry, and clinical medicine. A clear understanding of what artificial intelligence is, how it is organized into distinct learning paradigms, and how the field reached its present state provides the necessary foundation for examining any of its more specific applications, including chatbot technology and its uses in dentistry and orthodontics, examined in the parts that follow. This part reviews the definition and principal types of artificial intelligence and machine learning, and traces the field's historical development from its mid-twentieth-century origins to the emergence of contemporary large language models.

The Definition of Artificial Intelligence

Artificial intelligence is a broad branch of computer science concerned with developing intelligent systems capable of performing tasks that would normally require human intelligence, by programming computers, robots, or other devices to reason in human-like ways (Rajaram, 1990). Its central aim is to study the cognitive processes underlying human thinking, learning, decision-making, and problem-solving, and to reproduce these mechanisms within computational systems, so that abilities such as learning, problem-solving, and reasoning, ordinarily understood as expressions of human logic, can be conferred upon computer systems (Shinners et al., 2020).

Types of Machine Learning and Deep Learning

Machine learning, the branch of artificial intelligence most directly responsible for its recent clinical applications, is generally organized into three principal learning paradigms. In supervised learning, an algorithm is trained on labeled data, meaning that each input is paired with a known correct output, allowing the system to learn a mapping between the two that it can later apply to new, unlabeled cases; classification and regression tasks, such as distinguishing a carious from a non-carious tooth surface or predicting a continuous measurement, are the two principal forms this paradigm takes. In unsupervised learning, by contrast, the algorithm is given data without labeled outcomes and must instead identify structure or patterns within the data on its own, most commonly through clustering or dimensionality reduction. Reinforcement learning differs from both in that the system learns not from labeled examples or unlabeled structure but through trial-and-error interaction with an environment, receiving evaluative feedback in the form of rewards or penalties that gradually shape its behavior toward a desired outcome.

Deep learning represents a particular and increasingly dominant approach within machine learning, built on artificial neural networks composed of multiple layers of interconnected processing units, loosely modeled on the structure of biological neurons. Rather than requiring a human engineer to manually specify which features of the input data are relevant, deep learning architectures learn these representations directly from raw data across successive layers, with earlier layers typically capturing simple patterns and later layers combining these into progressively more abstract and complex representations (LeCun et al., 2015). This capacity to learn hierarchical representations directly from data, without extensive manual feature engineering, is a principal reason why deep learning methods, and convolutional neural networks in particular, have become the dominant approach for image-based diagnostic tasks in medicine and dentistry, a theme examined in greater detail in the third part of this book (LeCun et al., 2015).

The Historical Development of Artificial Intelligence

The field entered scientific discourse in 1950, when the British mathematician Alan Turing published his paper "Computing Machinery and Intelligence," posing the question of whether machines can think and proposing what became known as the Turing test, in which an evaluator attempts to distinguish human from machine responses to identical questions; a computer is considered to have "passed" the test if the evaluator cannot reliably identify which response originated from the machine (Turing, 2021).

In 1955, John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon launched a project at Dartmouth College aimed at developing software capable of imitating human intelligence, and the 1956 Dartmouth Conference that followed introduced the term "artificial intelligence" into the scientific literature. Arthur Samuel subsequently coined the term "machine learning" in the 1960s in the course of his own work on programs that learned to play checkers, helping to set the direction the field would take in the following decades (Samuel, 1959).

Joseph Weizenbaum's ELIZA, developed at MIT in 1964, became one of the earliest natural language processing programs capable of imitating human-machine dialogue and laid the conceptual groundwork for the conversational systems that followed it (Weizenbaum, 1966). Between 1966 and 1972, the Shakey mobile robot, developed at the Stanford Research Institute, marked a milestone in robotics through its ability to perceive complex instructions and translate them into appropriate actions; insufficient computing infrastructure and high costs nonetheless slowed research during two subsequent periods, in 1976 and again between 1980 and 1990, commonly referred to in the literature as "AI winters" (Kaul et al., 2020).

The field regained momentum when IBM's Deep Blue, capable of evaluating 200 million chess moves per second, defeated world chess champion Garry Kasparov in 1997, offering a striking demonstration of the technology's capabilities (Schaeffer & Plaat, 1997). In 2011, IBM's Watson outperformed the two highest-scoring human contestants on the quiz show Jeopardy! (Ferrucci et al., 2013), and the same decade saw the widespread adoption of virtual assistants, including Apple's Siri (2011), Amazon's Alexa (2014), and Microsoft's Cortana and Google Assistant (2015), bringing AI into daily consumer use (Haenlein & Kaplan, 2019). Google's AlphaGo program, also developed in 2015, attracted considerable scientific attention after defeating Go champion Lee Sedol in 2017, while the humanoid robot Sophia, developed by Hong Kong-based Hanson Robotics from 2015 onward, drew notice for modeling aspects of human thought, decision-making, and learning (Goertzel et al., 2017).

Among the most recent and widely discussed developments in the field is ChatGPT, released by OpenAI in 2022. Built on natural language processing techniques, ChatGPT distinguished itself not only by answering user questions but by analyzing the assumptions embedded within them and evaluating their accuracy, a capability that has been described as revolutionizing conversational, AI-assisted approaches to working with data and information more broadly (Hassani & Silva, 2023).

From Artificial Intelligence to Chatbot Technology

The historical trajectory outlined above, culminating in the emergence of large language models such as ChatGPT, illustrates why chatbots, the conversational subset of artificial intelligence, warrant dedicated attention as a distinct technology in their own right. A conversational agent capable of answering questions, drafting text, and evaluating user assumptions is no longer a peripheral curiosity but a technology already embedded in industries ranging from banking to education to healthcare, and increasingly in dentistry and orthodontics specifically. The following part turns to this technology directly, examining its definition, its applications, and its expanding clinical uses.

CHATBOT TECHNOLOGY: DEFINITION, APPLİCATİONS, AND ITS USES IN DENTISTRY AND ORTHODONTICS

Chatbots represent the conversational subset of artificial intelligence that has become most visible to clinicians and patients alike, through systems such as ChatGPT, Google Gemini, and Claude. This part reviews the definition of chatbot technology, the range of industries and settings in which it is applied, the current landscape of large language model-based chatbots, and the expanding range of applications this technology has found across dentistry in general and orthodontics in particular.

Chatbot Technology: Definition

The term "chatterbot" was introduced by Michael Loren Mauldin in 1994 to describe conversational software systems, a term later shortened to "chatbot," combining "chat" and "robot" (Mauldin, 1994). Chatbots have been defined in various ways: Deshpande and colleagues emphasized their capacity to communicate through spoken or written natural language (Deshpande et al., 2017), while Bala and colleagues described a chatbot as a tool that interprets user input, draws on a knowledge base to generate a meaningful response, and presents that response through a graphical user interface (Bala et al., 2017). At their simplest, chatbots are computer programs that imitate human conversation using natural language processing techniques to analyze user queries and generate appropriate responses, thereby providing rapid and efficient access to information.

Applications of Chatbot Technology Across Industries

Chatbot applications have expanded across numerous industries. In banking, systems such as Bank of America's Erica and Bank of Australia's Ceba support balance inquiries, bill payments, and card activation; in food service, chatbots manage order taking, delivery updates, and customer feedback; in education, they provide interactive, personalized learning support, answer questions, and track student progress; and in healthcare, chatbots such as One Remission, Youper, and Florence provide informational and supportive services related to cancer information, emotional health, and medication reminders, respectively (Adamopoulou & Moussiades, 2020).

Current Large Language Model Chatbots

Among currently available large language model chatbots, ChatGPT reached over one million users within a week of its public release in November 2022 and is capable of tasks ranging from creative writing to code generation and debugging. Google's competing system, initially released as Bard in 2023 and rebranded as Gemini in 2024, is noted for its capacity to analyze complex graphics and images, including medical images, while Claude, developed by Anthropic and released in 2023, processes text, audio, and visual input and can summarize documents and generate long-form content, diagrams, and program code (Adamopoulou & Moussiades, 2020).

Artificial Intelligence and Chatbots in Dentistry

Artificial intelligence has introduced a new perspective into dentistry, supporting patient education, counseling, and diagnostic decision support in ways that can improve the effectiveness and safety of care while reducing cost (Schwendicke et al., 2020). Beyond direct patient interaction, AI-based systems have been used to assess disease risk and outcomes, accelerate drug discovery, and prepare discharge summaries, thereby reducing the documentation burden on healthcare staff and improving workflow efficiency (Bush, 2018; Xue et al., 2023). In dentistry specifically, the integration of AI has been associated with improved diagnostic accuracy, fewer errors, and reduced staffing demands, with applications spanning appointment scheduling, diagnostic support, and treatment planning, and extending to the automatic classification of dental restorations and detection of periodontal disease, root caries, bone lesions, and craniofacial anomalies on panoramic radiographs (Ahmed et al., 2021).

In endodontics, AI applications include the detection of periapical lesions and root fractures, mapping of the root canal system, prediction of pulp stem cell viability, working length measurement, and prediction of retreatment success (Aminoshariae et al., 2021). Surgical applications include tracking of the mandibular alveolar canal, detection of impacted or supernumerary teeth, maxillary sinus analysis, oral cancer screening, orthognathic surgical planning, and prediction of post-extraction complications, while periodontal applications include quantitative assessment of bone loss and prediction of implant success. Large language models in particular have been noted to offer meaningful, if complementary, benefits to dentists, dental assistants, and dental hygienists, provided their current limitations and risks are appropriately managed (Eggmann et al., 2023).

Artificial Intelligence and Chatbot Applications in Orthodontics

Artificial intelligence now supports numerous clinical tasks within orthodontics, contributing meaningfully to both diagnosis and treatment planning. Automated detection and analysis of cephalometric landmarks, assessment of orthodontic extraction need, evaluation of maxillary constriction, and detection of impacted canines have each been demonstrated with high accuracy using AI-based approaches, while AI-based decision-support tools have also been applied to determining orthodontic treatment need, predicting treatment outcomes, and selecting an appropriate appliance for a given patient, including the assessment of growth and development stage (Chen et al., 2020; Lux et al., 1998).

Strunga and colleagues, reviewing advanced AI software specifically within orthodontics, concluded that such tools can meaningfully improve patient care at several stages, including cone-beam computed tomography (CBCT)-based diagnostic assessment, monitoring of treatment progress, and maintenance of post-treatment stability (Strunga et al., 2023). Although limitations remain, including variable accuracy, the need for specialized expertise, ethical concerns, cost, and regulatory constraints, AI-assisted systems already exert a tangible influence on contemporary orthodontic practice; AI algorithms trained to analyze CBCT images can additionally determine tooth alignment and position and assess bone quality relevant to implant placement, thereby improving the efficiency of image processing and analysis workflows (Urban et al., 2023).

Chatbot systems based on large language models have found a specific niche in orthodontic patient education, answering questions about clear aligner therapy, interceptive approaches, and bracket options, and helping to manage patient expectations by explaining the stages of orthodontic procedures. For dental students, such systems provide accessible, interactive support for literature review and research, while in clinical settings they offer orthodontists a supplementary decision-support resource; the accuracy and reliability of large language model outputs specific to orthodontic content nonetheless remains variable, and human oversight of chatbot-generated information continues to be necessary (Kurt Demirsoy et al., 2024).

From Chatbot Applications to Diagnostic Foundations

The orthodontic applications of artificial intelligence reviewed above, from cephalometric landmark detection to CBCT-based treatment planning, depend fundamentally on the interpretation of radiographic and photographic images. Understanding how these AI-assisted diagnostic tools have come to be developed and evaluated therefore requires, in turn, an understanding of the broader evolution of medical and dental image analysis, and of the conventional clinical and radiographic foundations of orthodontic diagnosis against which any AI-assisted approach must ultimately be measured. The following part turns to this foundation.

MEDICAL AND DENTAL IMAGE PROCESSING AND THE FUNDAMENTALS OF ORTHODONTIC DıAGNOSIS

Orthodontic diagnosis depends heavily on the interpretation of radiographic and photographic images, which makes the broader evolution of medical and dental image analysis directly relevant to understanding how artificial intelligence-assisted diagnostic tools have come to be developed and evaluated. This part first reviews the evolution of medical image analysis and its image-based artificial intelligence applications within dentistry, before turning to the conventional clinical and radiographic foundations of orthodontic diagnosis, namely clinical examination, study model analysis, and two- and three-dimensional imaging methods, against which any AI-assisted diagnostic approach must ultimately be evaluated.

The Evolution of Medical Image Analysis

Medical imaging has served as a diagnostic aid for more than a century, and computer-assisted diagnostic techniques have substantially improved the efficiency of radiological workflows built on this foundation (Holmes et al., 2004). Machine learning methods, and in particular deep learning neural networks, have outperformed earlier computational approaches and accelerated progress in this area. Feature maps extracted by deep learning networks from medical images acquired through computed tomography, magnetic resonance imaging, positron emission tomography, mammography, ultrasound, and histopathology provide clinically valuable information, and such networks now represent the state of the art for image detection, segmentation, and classification tasks in medical image analysis more broadly (Shapiro, 2003; Schmuelling et al., 2021).

Image-Based Artificial Intelligence Applications in Dentistry

Within dentistry, artificial intelligence is transforming diagnosis, treatment planning, care coordination, and follow-up by enabling more accurate early detection of disease. As in medicine more broadly, dentistry has adopted systems capable of imitating aspects of expert clinical judgment, allowing clinicians to analyze diverse imaging modalities more efficiently, make better patient-specific treatment decisions, and ultimately improve patient care (Khattak et al., 2025).

One of the most extensively developed applications of AI in dentistry is medical image analysis itself. Convolutional neural networks, a specific subtype of AI architecture, have been applied to periapical and panoramic radiographs for the detection of dental caries, apical lesions, and bone loss, evaluating affected teeth independently and distinguishing among the various structures present in the oral cavity in ways that reduce diagnostic error and save clinical time (Ekert et al., 2019; Bouchahma et al., 2019). Beyond diagnosis, AI-enabled robotic systems now fully automate certain dental operative procedures, performing three-dimensional tooth preparation without damaging surrounding tissue, while artificial neural networks in restorative dentistry evaluate material properties to help prevent debonding of composite restorations; orthodontic applications similarly draw on cephalometric analysis and treatment-planning adjustments aimed at harmonizing facial esthetics (Kuwada et al., 2020).

AI-based approaches applied to standardized single-tooth photographs have achieved caries-detection accuracy exceeding 90%, and software capable of analyzing intraoral images and near-infrared transillumination recordings has been shown to identify early carious lesions and shorten diagnostic time considerably (Askar et al., 2021; Casalegno et al., 2019). While artificial intelligence holds substantial potential to improve diagnostic accuracy and treatment planning across dentistry, its benefits, limitations, and associated ethical considerations require careful evaluation before further clinical integration, and future work should prioritize improving model interpretability and addressing cost and data protection challenges so that these tools can be used effectively and safely in routine dental care (Khattak et al., 2025).

Clinical Examination as the Starting Point of Orthodontic Diagnosis

The success of orthodontic treatment depends closely on an accurate and complete diagnostic and treatment-planning process tailored to each patient's individual needs. Clinical examination represents the first and most critical step in this process. This stage is not merely a matter of identifying dental and skeletal problems but also a dialogue through which the patient's chief complaint and treatment expectations are understood, providing the clinical context within which subsequent radiographic and photographic findings must be interpreted (Littlewood & Mitchell, 2019). Analysis of dental study models complements this clinical assessment by providing a three-dimensional record of the occlusion, arch form, and tooth positions that can be examined away from the chairside and compared over the course of treatment; digital study models derived from intraoral or laboratory scanning have been shown to offer accuracy and reproducibility comparable to conventional plaster models, while additionally facilitating storage, measurement, and remote review (Rheude et al., 2005; Wiranto et al., 2013).

Two- and Three-Dimensional Radiographic Methods in Orthodontics

Radiographs are of critical importance in orthodontic diagnosis and treatment planning for evaluating the teeth and the maxillofacial complex. Conventional two-dimensional radiographs, namely cephalometric and panoramic radiographs, have served as standard diagnostic tools for decades: panoramic radiographs provide fundamental information on tooth position, eruption pathology, and root angulation, while cephalometric radiographs are used to assess the craniofacial complex, dentofacial proportions, and growth-related changes. These two-dimensional techniques nonetheless carry recognized limitations, including geometric distortion and the superimposition of overlapping anatomical structures (Pittayapat et al., 2014).

Three-dimensional imaging, particularly cone-beam computed tomography, removes many of the constraints associated with two-dimensional cephalometry by allowing craniofacial structures to be examined volumetrically, enabling more reliable landmark identification and more accurate measurement. Lateral cephalometric images derived from cone-beam computed tomography data have been validated against both direct measurements on dry skulls and conventional cephalograms, and three-dimensional imaging offers particular advantages in the assessment of facial asymmetry, the position of impacted teeth, and complex craniofacial anomalies (Pittayapat et al., 2014). Advancing technology has also enabled automated, model-based analysis of conventional radiographs: systems have been developed that automatically segment tooth contours on panoramic radiographs and evaluate orthodontically relevant parameters, such as axial inclination and crown overlap position, offering clinicians greater consistency and time savings in routine assessment (Wu et al., 2017). Digital model analysis methods have likewise demonstrated methodological accuracy comparable to manual analysis in retrospective clinical comparisons (Lippold et al., 2015).

The Role of Intraoral Photographs and Panoramic and Cephalometric Radiographs

Orthodontic diagnosis and treatment planning require a comprehensive evaluation of skeletal, dental, and soft-tissue relationships, and intraoral photographs together with panoramic and cephalometric radiographs are among the principal diagnostic tools supporting clinical examination in this process; each plays a critical role in classifying malocclusion, detecting dental anomalies, and monitoring treatment progress (Littlewood & Mitchell, 2019). Intraoral photographs allow objective assessment of occlusal relationships, arch form, and soft-tissue health, including determination of the dental relationship according to Angle's classification, measurement of overjet and overbite, and documentation of crossbite, open bite, and dental crowding, as well as periodontal and dental findings such as gingivitis, gingival recession, oral hygiene status, caries, and tooth wear.

Panoramic radiographs present the entirety of the maxilla and mandible on a single image, permitting evaluation of tooth eruption status, missing teeth, retained primary teeth, root resorption, and pathological findings, and are particularly widely used before orthodontic treatment to assess the presence of impacted teeth, anomalies of tooth number, and root morphology. Although their two-dimensional nature limits anatomical accuracy relative to three-dimensional imaging, panoramic radiographs remain a fundamental screening method in routine orthodontic diagnosis owing to their low radiation dose and broad anatomical coverage (Surdu et al., 2024). Cephalometric radiographs, meanwhile, remain one of the gold-standard methods for analyzing the sagittal and vertical relationships of skeletal and dental structures: measurements such as the SNA, SNB, and ANB angles, first formalized within a comprehensive method of cephalometric evaluation, allow determination of an individual's skeletal classification and the position of the maxilla and mandible relative to the cranial base (McNamara, 1984). Cephalometric analysis further contributes to determining the direction of growth and development, guiding treatment strategy, and planning orthopedic or camouflage treatment approaches, and allows objective evaluation and comparison of treatment effects over the course of orthodontic care (Bishara, 2001; Houston et al., 1992).

The Importance of Combining Multiple Imaging Modalities

Although intraoral photographs and panoramic and cephalometric radiographs each provide valuable information individually, the greatest diagnostic accuracy in orthodontics is achieved when these methods are evaluated together. Each imaging modality reveals different anatomical and clinical parameters, and their combined use provides a complementary contribution to the overall diagnostic process; this multimodal approach also constitutes a reliable reference framework for the development and validation of artificial intelligence-assisted diagnostic systems of the kind reviewed earlier in this part, since such systems must ultimately be evaluated against the same combination of clinical and radiographic information that underlies conventional orthodontic diagnosis (Pittayapat et al., 2014).

From Diagnostic Foundations to a Critical Appraisal

Having reviewed the clinical applications of artificial intelligence in dentistry and orthodontics and the diagnostic foundations against which these applications must be evaluated, it is now necessary to turn to a more balanced and critical assessment of chatbot technology specifically. The clinical applications reviewed above are only as trustworthy as the underlying technology permits, and the same systems capable of supporting diagnosis, treatment planning, and patient education also carry recognized limitations that must be understood before their benefits can be safely realized. The following part offers this balanced appraisal, examining the advantages and disadvantages of chatbot technology in turn.

Part Four

Advantages and Disadvantages of Chatbots

Having reviewed the definition, industry applications, and dental and orthodontic uses of chatbot technology, along with the broader diagnostic foundations these applications rest upon, this part turns specifically to a balanced assessment of what chatbots do well and where they continue to fall short. A clear understanding of these strengths and limitations is essential for any clinician or researcher considering the integration of chatbot-based tools into patient care, education, or administrative workflows, since the same underlying technology that enables continuous, personalized interaction also introduces risks that must be actively managed.

Recognized Advantages of Chatbot Technology

Chatbots offer several well-documented advantages. They increase user engagement and satisfaction by providing help, recommendations, and offers on demand, and they can generate increasingly personalized responses by learning from prior interactions (Kucherbaev et al., 2018). Following an initial investment, chatbot systems typically achieve considerable long-term cost savings relative to human staffing, while providing continuous, round-the-clock availability that contributes meaningfully to user satisfaction and, in commercial contexts, to business outcomes more broadly (Kucherbaev et al., 2018).

A large-scale rapid review of 161 primary studies on health care chatbots, published in 2024, offers a more granular, evidence-based picture of these benefits within a clinical context. The review grouped reported benefits into two overarching themes:

improvement of health care quality and efficiency and cost-effectiveness in health care delivery. Within the first theme, the most frequently reported benefit, cited in 60 of 62 relevant studies, was increased accessibility and reach of health care, achieved by helping diverse populations access services for minor concerns that do not require an emergency visit, with the convenience of continuous, 24-hour availability; a further subset of studies reported that chatbots achieved engaged and satisfied users, with acceptance typically measured through positive user feedback and stated willingness to continue using the system (Laymouna et al., 2024). Within the second theme, 75 of 157 studies reporting limitations-related data nonetheless also identified efficiency benefits, most commonly savings in the time and cost associated with health interventions, indicating that chatbots can help relieve administrative and staffing burdens in overstretched care settings (Laymouna et al., 2024).

Recognized Disadvantages and Limitations of Chatbot Technology

Chatbots also carry notable and well-documented limitations. Rule-based systems generally can only respond to relatively simple queries falling within predefined domains, and most chatbots remain limited in their ability to perceive and express emotional nuance, which can make interactions feel mechanical rather than genuinely responsive (Alkaissi & McFarlane, 2023). More advanced, machine-learning-based chatbots require substantial time and resources to develop and maintain, a complexity that can lengthen response times and reduce user satisfaction if not carefully managed. Perhaps most significantly, such systems remain susceptible to a phenomenon known as "hallucination," in which a system produces plausible-sounding but inaccurate or irrelevant information; mitigating this risk requires training and testing on large, balanced datasets, together with human oversight or automated anomaly-detection mechanisms, before such systems can be safely relied upon in clinical contexts (Alkaissi & McFarlane, 2023).

The 2024 rapid review of health care chatbots similarly organized reported limitations into five categories, the most heavily reported of which concerned challenges in user experience and overreliance, cited in 157 of 161 included studies. Within this category, 154 of 157 relevant studies specifically raised concerns about overconfidence and overreliance, describing a tendency for users to overestimate chatbot capabilities or to substitute professional medical advice with chatbot-generated suggestions, while a further 135 of these studies raised usability and accessibility concerns related to interface design and adaptability across users with differing levels of technological familiarity (Laymouna et al., 2024). Additional limitations identified in the review included technical challenges related to the complexity of accurate language processing and the difficulty of establishing empathy and rapport with users; medicolegal and safety concerns regarding regulatory compliance, liability, and the reliability of chatbot-generated medical content; societal and economic challenges, including the risk of exacerbating existing disparities in access to care; and ethical challenges related to patient privacy, confidentiality, and the need for transparency about the non-human nature of the chatbot interaction (Laymouna et al., 2024).

Balancing Advantages and Limitations in Clinical Practice

Taken together, this evidence indicates that the advantages and disadvantages of chatbot technology are not simply opposing considerations to be weighed once at the point of adoption, but interconnected features of the same underlying system that must be actively and continuously managed throughout its clinical use. The scalability, availability, and efficiency gains that make chatbots attractive for patient education, administrative support, and preliminary triage are inseparable from the same automation that limits their capacity for nuanced clinical judgment, and the personalization that increases user engagement depends on data practices that in turn raise legitimate privacy and confidentiality concerns. Effective integration of chatbot technology into dental and orthodontic practice therefore depends less on treating advantages and disadvantages as a simple balance sheet, and more on the deliberate design of oversight mechanisms, appropriate scope limitations, and ongoing evaluation that allow the genuine benefits of this technology to be realized while its recognized risks are actively contained.

From Limitations to Ethical and Regulatory Considerations

The limitations reviewed above, particularly those concerning patient privacy, confidentiality, and the reliability of chatbot-generated clinical content, point directly to a broader set of ethical and regulatory questions that must accompany the clinical adoption of artificial intelligence in dentistry. The final part of this book turns to these questions directly, examining the ethical principles and regulatory frameworks that are increasingly being developed to guide the responsible use of AI in dental and orthodontic practice.

Part Five

Ethical and Regulatory Considerations in the Use of Artificial Intelligence in Dentistry

As artificial intelligence becomes further embedded in dental and orthodontic practice, its clinical benefits cannot be considered in isolation from the ethical and regulatory questions that its use raises. This part reviews the principal ethical challenges associated with AI-based tools in dentistry, together with the regulatory frameworks that have emerged to address them.

Ethical Principles Governing Artificial Intelligence in Dental Practice

The integration of artificial intelligence into dental practice raises ethical challenges that extend well beyond the technical accuracy of a given diagnostic tool. Foremost among these is the protection of patient privacy: because AI systems, including diagnostic image-analysis tools and chatbot-based patient interfaces, typically require large volumes of patient data for training and operation, dental practitioners and technology developers bear a shared responsibility to ensure that patients are informed about how their data are collected, used, and stored, and that appropriate technical and organizational safeguards are in place to protect that data (Duggal & Tripathi, 2024). A further ethical consideration concerns the long-term and not yet fully understood consequences of AI-assisted diagnostic and treatment-planning decisions, which places a responsibility on clinicians to maintain active oversight of AI-generated recommendations rather than deferring to them uncritically (Duggal & Tripathi, 2024).

A recent review of ethical responsibility in dental AI adoption similarly emphasized that the transformative diagnostic and treatment-planning benefits of AI in dentistry cannot be separated from careful attention to privacy, security, and legal considerations, and identified good machine learning practices, transparent model development, and rigorous evaluation of training data quality as essential safeguards for responsible clinical integration (Kaur et al., 2025). The same review highlighted the importance of professional codes of conduct, such as those requiring adherence to the principles of beneficence, non-maleficence, patient autonomy, justice, and veracity, in guiding how dental professionals incorporate AI-based recommendations into patient care without displacing their own clinical judgment (Kaur et al., 2025).

Regulatory Frameworks for Artificial Intelligence in Health Care

Alongside these ethical principles, a growing number of formal regulatory frameworks have been developed to govern the use of AI-based tools in health care, including dentistry. In the United States, the Health Insurance Portability and Accountability Act (HIPAA) establishes requirements for the protection of patient health information that apply directly to AI systems trained on or processing dental patient data, while the Food and Drug Administration has developed a specific regulatory framework for AI- and machine-learning-based medical devices, reflecting the recognition that such systems, unlike traditional medical devices, can continue to learn and change behavior after their initial approval (Kaur et al., 2025). In the European Union, the General Data Protection Regulation (GDPR) governs the collection, processing, and storage of patient data using a risk-based approach, while the more recently introduced European Union Artificial Intelligence Act classifies AI applications, including those used in medical devices, according to their level of risk, with correspondingly stricter transparency, accuracy, and oversight requirements imposed on higher-risk clinical applications (Duggal & Tripathi, 2024).

Taken together, these ethical principles and regulatory frameworks indicate that the responsible clinical use of artificial intelligence in dentistry and orthodontics depends on more than technical accuracy alone. Effective integration requires transparent communication with patients about how their data are used, active clinical oversight of AI-generated recommendations rather than passive acceptance of them, and ongoing attention to an evolving regulatory landscape that continues to adapt as AI technologies, including the chatbot systems reviewed earlier in this book, become further embedded in everyday dental and orthodontic practice.

Conclusion

This book has traced a deliberate progression: from the historical and conceptual foundations of artificial intelligence and its principal learning paradigms, through the specific definition, industry applications, and dental and orthodontic uses of chatbot technology, to the broader evolution of medical and dental image analysis and the conventional diagnostic foundations these applications rest upon, a balanced, evidence-based appraisal of the advantages and disadvantages of chatbot technology, and finally the ethical and regulatory considerations that must accompany its clinical adoption. Read together, these five parts illustrate a broader principle relevant to the clinical adoption of any AI-based tool: that meaningful integration of a new technology requires understanding what it is and how it learns, where it can be applied, the diagnostic foundations it builds upon, a clear-eyed appreciation of its genuine strengths and limitations, and an active commitment to the ethical and regulatory principles that ensure its benefits are realized responsibly. When applied together, the historical, technical, diagnostic, critical, and ethical perspectives offered in this book provide a coherent foundation for the responsible study and clinical use of artificial intelligence and chatbot technology in dentistry and orthodontics.

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