Artificial Intelligence in Industry 4.0: The future that comes true: AI

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Artificial Intelligence and its Application in Dentistry

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Abstract: *Artificial intelligence (AI) has today become an important factor in the social, scientific and economic development of human society. It has wide application possibilities in the economy and public services, which also applies to dentistry. Its history is about eight decades long, and a special area of its research and development is machine learning models, which today constitute the basic model of AI application. The aim of this paper is to analyze the state of development and application of AI in dentistry, with a proposal for the possibility of its application in the future. Based on that, the paper is structured in such a way as to provide answers to the following questions: what is AI and how was it developed, how were AI models in dentistry created and developed, what are the prospects for the application of AI in dentistry, and possible directions for future research in this area.*

Keywords: *Artificial intelligence, Machine learning, Dentistry*

1. Introduction

Artificial intelligence is a branch of intelligence science, which includes: natural and artificial intelligence. Natural intelligence is the science of models of intelligent behavior of living beings, while artificial intelligence, or AI, is also the science of developing intelligent software and machines. They are connected and have contributed to each other's development in the past eight decades, when AI appeared. Advances in natural intelligence have set new paradigms for AI research, such as neural networks (ANN), genetic algorithms (GA), ant colony optimization (ACO), etc., while advanced AI tools have helped accelerate new discoveries in natural intelligence [1,2]. That's why we can say that the eight-decade long history of AI is promising today, more than ever, which also applies to dentistry.

This review paper aims to provide readers with basic facts and knowledge about the development and application of AI in dentistry to date. It is intended for scientists, researchers and students, who want to get concise information about the beginning of the development of a new scientific branch in dentistry, intelligent dentistry, based on AI.

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The paper itself has several parts: (i) how AI was created and developed, (ii) an overview of the development and application of AI for dentistry, to date, (iii) challenges and future development of AI for dentistry, (iv) conclusions and future research.

2. A Brief History of AI

Before detailing intelligent dentistry (dentistry supported by AI techniques, especially deep machine learning (Deep ML), it is important to briefly analyze the history of AI, which is shown in Table 1 [1,2,21]. It covers an interval of eight decade (1940 - 2020), and has four stages of development, as indicated in the table below.

Table 1. Overview of the development of artificial intelligence (AI) (adapted from [1,2,21])

Year of appearance	The period of AI development	The name of the event	Characteristic
1943	The Dark Age of AI	Binary ANN model (W. McCullouch, W. Pitts)	A two-state neuron
1950		Turing test - can machines think? (A. Turing)	Communication: examiner - examinee - computer
1951		The first neural computer (M. Minsky, D. Edmonds)	A network of forty neurons
1956	The rise of AI	First AI Workshop (J. McCarthy)	Artificial Intelligence (AI) Defined
1958		LISP - The First AI Language (J. McCarthy)	Still in use today - Functional language
1961		General Problem Solver (GPS)(A. Newell, H. Simon)	Uses formal logic to find solutions (does not solve complex cases)
1965		Fazzy sets (L. Zadeh)	A continuous transition from not belonging to complete belonging
1969		Dendral **(** E. Feigenbaum, B. Buchanan , J. Lederberg , C. Derassi)	The first expert system - Spectrogram identification of chemical compounds
1970	AI "Winter"	ANN Learning (A. Bryson and Y. Ho)	Backpropagation model
1975		GA (J. Holland)	The first genetic algorithm
1976		Mysin (E. Shortliffe)	The first expert system for diagnosis
1982		Hopfield networks (J. Hopfield)	Memory systems with binary boundary nodes, a model for understanding human memory
1986		Backpropagation (BP) (D. Rumelhart, J. McClelland) and DAI (Distributed AI) *(* A. Bond *, L. Gasser)*	Computation of neural error (BP) and distributed solutions for AI

1992	AI is becoming a science	Genetic programming (GP) (J. Koza)	LISP symbolic code
1995		Intelligent agents (M. Wooldridge , R. Jennings)	They act on the environment in an intelligent way
2002		ACO, PSO, AIO, DNA computing	AI tools
2006		Honda ASIMO robot	Moving and climbing stairs
2016		AlphaGo DeepMind	Man computer games
2017		IBM Watson	Man computer games
2022	Chat GTP	Open AI	AI for different fields

It can be said that the history of AI starts from the early 40s of the 20th century. It started with the binary ANN model [3], defined by W. McCulloch and W. Pitts of the University of Illinois in 1943. Although their model only considered a binary state (ie on/off for each neuron), this model was used as a starting point for ANN research later in the 1980s. The next important year is 1950, when A. Turing proposed the famous test, named after him, by means of which it is determined whether machines can think [4] ? The Turing test is performed through computer communication, which includes an examiner, a person (subject), a participant in the experiment, and a computer, which are separated from each other, but communicatively connected. The examiner can ask any questions. If the examiner cannot distinguish a machine from a human based on their answers, the computer has passed the test. Then, in 1951, M. Minsky and D. Edmonds [5], researchers from Princeton University, created the first neural computer that simulates the operation of a network of 40 neurons.

We can say that the turning point in the development of AI occurred when the first AI workshop was organized in 1956 at Dartmouth College under the leadership of J. McCarthy [6]. He marked the end of the "dark age of AI" and the beginning of the "rise of AI" as the next stage in the development of AI. The term "artificial intelligence" was then proposed by J. McCarthy, and it is still in use today. J. McCarthy later moved to the Massachusetts Institute of Technology (MIT), where in 1958 he defined the first AI language, LISP, which is still used today. One of the most ambitious projects of those years in this area was the General Problem Solver (GPS), which was defined in 1961 by A. Newell and H. Simon from Carnegie Mellon University [7]. GPS is based on formal logic and can generate an infinite number of operators trying to find a solution, however, it is not effective in solving complicated problems. In 1965, L. Zadeh from the University of California, Berkeley published the famous paper "Fuzzy sets", which became the basis of the theory of fuzzy sets [8], or uncertain decision making.

The first expert system, Dendral [9], was developed at Stanford University in 1969, in a project funded by the National Aeronautics and Space Administration (NASA) led by J. Lederberg, winner of the Nobel Prize for genetics. However, at the time, most AI projects could only solve gaming problems, rather than real-

world ones, so many projects in the United States, Great Britain, and several other countries failed, or were useless. Thus, AI research has entered the "AI winter".

Despite reduced funding, AI research continued, and in 1970, A. Bryson and Y. Ho [10] proposed a back propagation model for neural network learning. Moreover, the first genetic algorithm (GA) model was proposed in 1975 by J. Holland from the University of Munich, who performed selection, crossover and mutation, using genetic operators for optimization [11] and thus developed the GA model. The same team that developed ES Dendral [12], at Stanford University, developed ES Mycin in 1976, which is based on IF-THEN rules, as an expert system for the diagnosis of blood diseases using 600 rules, if (IF)-then (THEN). Research has shown that he works better than a junior doctor [13].

It was only after 30 years that researchers started researching neural networks again, as an important area of AI. A new era has begun — in which AI has become a science. It was in 1982, when J. Hopfield published his Hopfield networks, which are still popular today [14]. In 1986, back propagation became the first implemented learning algorithm in ANN, 16 years after the publication of this model [15]. Also, this year is the beginning of the application of distributed AI (DAI) through parallel distributed knowledge processing. 22 years later, the theory of fuzzy sets was successfully incorporated into the management of dishwashers and laundry machines, in 1987, by Japanese companies that produced these household appliances. In 1992, J. Koza proposed genetic programming for the manipulation of symbolic code, which was generated in the LISP language [16]. Starting from the idea of DAI and artificial life, intelligent agents were defined in the mid-1990s. At the end of the last century, hybrid systems of fuzzy logic, ANN and GA became popular tools for solving complex problems. Since then, various new AI approaches have emerged, including ACO, particle lake optimization (PSO), artificial immunity optimization (AIO), and DNA computing, as well as intelligent agents [17]. The potential of AI in the future – such as dentistry – remains large and unpredictable.

AI-based chess software was the first program, called Deep Blue, developed by IBM [18]. It was in 1997, and then Garry Kasparov, the then world chess champion, was playing an exhibition match, when he lost 2.5 to 3.5 against the computer. The next example is the Honda ASIMO robot in 2005, which moved up stairs. In this case, the robot moves in an unstructured environment and is controlled by a human. This example required natural language processing, the use of computer vision, object recognition, machine learning and motion control during operation. After this, in 2016, AlphaGo DeepMind software defeated world champion L. Sedol in four out of five games, using cloud computing, machine learning and Monte Carlo algorithm, to search with the support of a deep neural network for decision making [19]. Its latest version, AlphaGo Zero

[20,21], surpassed the ability of AlphaGo in just three days, through self-learning from scratch. A new breakthrough in this area was IBM Watson, an intelligent platform.
A recent breakthrough in AI was in Natural Language Processing (NLP) and in generative AI that allowed for the development of chatbots, virtual assistants, and intelligent tools and platforms such as IBM Watson, and ChatGTP.
The more famous, ChatGTP, is able to create human-like conversational dialogue, ie, to respond to questions and compose written content. Moreover, ChatGPT involves a generative AI that lets users enter prompts to receive required images, text, or videos. Therefore, it can be used in different areas including dentistry.
Today, AI techniques and systems can be used in a variety of fields, from playing chess to production management, patient diagnosis, aircraft control, smart design and planning, and intelligent dentistry. The AI techniques reviewed in Table 2, especially supported by machine learning models, hold much promise for the development of intelligent dentistry. To illustrate all this, Table 2 provides an overview of machine learning models, on different bases.

Table 2. Overview of learning models (applied in dentistry) [1,21]

A machine learning model	Supervised / semi-supervised / unsupervised	Discriminative / generative	Learning / deep learning
K-means	Unsupervised	Generative	Learning
K-nearest neighbor	Supervised	Discriminative	Deep learning
Method of support vectors			
Hidden Markov model			
A random forest model			
Extreme Gradient Boosting (XGBoost)			
Ensemble method			
Convolutional neural networks			
Recurrent neural network			
Long short term neural network			
Naive Bayes classifiers			Learning
Gaussian mixture model		Generative	
A generative adversarial network	Semi-supervised	Discriminative	Deep learning

Machine learning (ML) models, which are most widely used in dentistry, are marked with red text. In the next chapter, through examples, the application of ML in dentistry, in different areas, will be given.

3. Artificial Intelligence and Dentistry

This system analysis was performed according to the PRISMA methodology [1,21], and our question was "Which AI techniques are applied in dentistry and how does AI improve dental diagnosis, clinical decision-making and the outcome of dental treatment?". For him, the following were defined: period, type of study, AI dental models, search methodology and study quality assessment. The sample consisted of 364 papers, and 41 papers met the set criteria.
Broadly speaking, a systemic analysis of the application of AI in dentistry is performed here with four aspects: (i) general overviews of application in dentistry, (ii) application in a selected area of dentistry, (iii) case studies for solving specific problems, and (iv) application of ChatGPT in dentistry. The following analysis refers to all the mentioned areas.

3.1. Overview of the Application of AI in Dentistry

General analyzes appeared in the last decade, which is understandable, because it was only from those years that the application of AI in dentistry took off. Thus, the first paper [22] in this field gave general aspects of the application of AI in dentistry, citing several application examples (virtual assistants, diagnosis of oral and maxillofacial diseases and therapy planning (ANN)), concluding that AI has a high potential in dentistry, table 3.

Table 3. General overview of the application of AI in dentistry

Purpose	Ref. / yr.	Method	The goal	Use
High potentials of AI in dentistry	[22] 2017	Virtual assistants, diagnosis of oral and maxillofacial diseases and therapy planning (ANN)	Increasing the accuracy of diagnosis and the success of treatment	Diagnosis and treatment planning with AI
Application of AI in dentistry	[23] 2018	ANN and AVR (Augmented Virtual Reality)	Improving the success of diagnosis and treatment	Patient management and decision-making system, oral and maxillofacial surgery, prosthetics and orthodontics
AI as the technology of the future for dentistry	[24] 2018	ANN/CNN	Improve clinical practice	Aid to the dentist, not his replacement

Comparison of current and future applications of AI in dentistry	[25] 2020	CNN/Deep NN	Unstructured data processing (BDA)	Prediction of treatment results
AI platforms	[26] 2020	AI software for dentistry	Specialized platforms for facilitating the application of AI in dentistry	Applying deep learning models for diagnosis and treatment planning
AI in dentistry	[27] 2020	deep learning (CNN)	Increasing the level of reliability of recommendations	Dental radiology
Future applications of AI in dentistry	[28] 2020	CNN / GA (Genetic Algorithm) / Fuzzy logic	Learning from unstructured databases	Dental radiology, diagnosis, patient management and orthodontics
Development and application of AI in dentistry	[29] 2020	ANN/CNN	Analysis of 43 studies	Diagnoses, clinical decision-making and treatment prognosis predictions
AI as support for standard procedures	[30] 2021	AI tools and techniques	Integrated patient information and improvement of professional interactions	Clinical intuition, ineffable perception, and empathy.
AI to support the dentist	[31] 2021	AI tools and techniques	Analysis of 32 studies	Prediction of failure in clinical treatment scenarios, with the proposal of reliable solutions for it
AI as innovation	[32] 2021	Deep learning	Help the dentist to rule out human error	All areas of dentistry
Application of AI/ML	[33] 2021	CNN	Tooth color research for dental interventions	Aesthetic dentistry
Application of AI techniques	[34] 2021	ML in Image Processing (CNN), ANN, GA, FL	Improving decisions of dentists	Analysis of application in different fields
Caries detection	[35] 2021	CNN	High accuracy and precision of diagnosis	Caries diagnosis
The tool of the future for dentistry	[36] 2022	Deep learning	Correct diagnosis for multiple symptoms	Oral dentistry and dental diseases
Negative aspects of AI	[37] 2022	Reduction of narrative contact with the patient	Cyber security	Determining the balance
Application of AI	[38] 2022	AI	Analysis of 28 studies on the applicability and effectiveness of AI models in different areas of dentistry	Optimal clinical treatment of patients

Application of AI in endodontics	[39] 2022	CNN	Improvement of dental practice	Future applications of AI are drug interactions, prognostic diagnosis and robotic endodontic surgery
Application in dentistry	[40] 2022	ANN/CNN	Faster and more successful treatment	Efficiency, accuracy and time savings during diagnosis and treatment planning
Application in dentistry	[41] 2022	ANN/CNN	Analysis of 33 studies	Data collection and analysis techniques
Development and challenges of AI in dentistry	[42] 2023	AI tools	As much confirmation of clinical results as possible	Diagnostics of a wide range of conditions
AI as a transformative technology in dentistry	[43] 2023	AI algorithms and tools (ML)	Automated detection and diagnosis of dental conditions and improving treatment outcomes	It revolutionizes clinical practice, improves patient outcomes and improve the overall efficiency of dental care
Periodontics and caries research	[44] 2023	ANN/CNN	Fast and accurate analysis of recordings, for early disease detection	Improvement of clinical practice
Application in dentistry	[45] 2024	AI tools	Better treatment outcomes	Improvement of clinical practice in different areas of dentistry
Augmented Intelligence (AuI) in Dentistry	[46] 2024	AI/AuI	ADA White Book	ChatGPT is ready to revolutionize dentistry by providing efficient, accurate and up-to-date information dentists
Application of generative AI techniques	[47] 2024	AI tools	SD (Synthetic Datasets)	Various medical databases

The paper [23] discusses the potential of the integration of clinical practice in dentistry and AI techniques, especially for patient data management (ANN), implantology and oral surgery. It is considered that AI is the future of dentistry [24], because its advantages are: accuracy of diagnosis, standardization of procedures and reduction of treatment time, and disadvantages: system complexity and application costs. Today's model of AI in dentistry will be significantly changed and improved in the future [25]. This means, among other things, that today's samples for analysis of recordings from 2-3 thousand units

(individual patients) will be increased to several million units (population), which will also carry out genetic analysis of the phenomenon in the population. Also, as far as data sources are concerned, with today's data from patients and clinics (structured data), they will move from unstructured data from different institutions (sources), etc. New approaches in this area are AI platforms for dentistry [26], as ready-made software products for specified use. This is certainly one of the main approaches in the future, which will appear more and more. One of the most important features of today's approaches to the application of AI in dentistry is deep learning [27], which enables higher quality inference compared to other learning models. This means that diagnoses, treatment plans and other advisory recommendations to the dentist are more reliable. One of the future directions of AI in dentistry is the greater application of unstructured data in deep learning models, such as CNN, GA and FL [28]. The analysis of 43 studies shows that AI-based systems can perform exceptionally well in various dental applications, including: (i) determining and diagnosing dental caries, vertical root fractures, apical lesions, salivary gland diseases, maxillary sinusitis, maxillofacial cysts, metastases in cervical lymph nodes, osteoporosis, cancerous lesions, alveolar bone loss, and predicting orthodontic extractions, (ii) predicting the need for orthodontic treatments and cephalometric analysis, and (iii) determining age and gender. The studies demonstrate that AI-based systems can match or even surpass the performance and accuracy of trained specialists.

Today, it is considered that AI is an excellent aid for dentists, whose customization for the user as well as clinical validation should be worked on even more intensively [29]. Cognition (reasoning and inference) is that aspect of AI that helps the dentist the most in diagnosis, treatment planning or prediction of its progress [30]. AI should be seen as a complementary tool to help dentists, rather than a replacement. By augmenting their skills and abilities, AI can free up dentists to focus on the aspects of their work that require human intuition, empathy, and professionalism.By leveraging AI as a tool to augment their skills, dentists can focus on the aspects of their work that require human expertise and judgment, while also benefiting from the efficiency and accuracy that AI can provide.A systematic analysis of 32 studies [31] showed that AI can be used to manage patient data, support dental diagnosis, as well as treatment planning. In this way, AI helps dentists to provide quality patient treatment, better oral health care outcomes, and achieve high diagnostic accuracy. Also, AI helps predict failure in different treatment scenarios by suggesting reliable solutions for it, or the best case scenario. AI, as a magical innovation today, will never be able to completely replace the dentist [32] , but it will help him work at a higher and more comfortable level, making his profession much easier and without the appearance of human error. An important aspect of using AI in dentistry is the determination of tooth color for prosthetic restorations, so the paper [33]

presents an AI-based system for color recognition and determination. This approach is significantly more accurate than the usual approach - visual color recognition. An analysis of the use of different AI techniques in dentistry is presented in [34]. All of them are used for different learning models, so each one is suitable for a certain area in its own way, for example CNN (deep learning) for image analysis (radiographic image) and diagnosis. AI is being researched in dentistry for various purposes, especially the identification and diagnosis of normal and abnormal tissue structures (diseases), as well as the prediction of treatment results [35]. CNNs have the ability to detect and recognize anatomical structures, especially to recognize and mark diseased teeth on radiographs, with an accuracy of 95.7–99.44%, which is almost competitive with the work of clinical dentists, whose accuracy rate was 99.97 % [36]. The situation is similar with the detection of carious lesions, where the accuracy is 75.4–93.4% and the sensitivity is 74.3–97.2%. AI is no longer a myth but the future in dentistry, so it is safe to say that it will be the most promising tool in the future for dental diagnostics and treatment. It will be an irreplaceable tool in diagnosis, when several symptoms are correlated. However, there are studies that also talk about the negative aspects of the application of AI, which should be taken into account [37]. These are particularly reflected in the following: data accuracy and security (cyber security), lack of narrative communication with the patient, and patient privacy and medical ethics. A total of 28 studies [38] were analyzed , mostly from periodontology (six), so it was concluded that AI is a good way to analyze clinical dental data. Also, analyzes of randomized clinical trials are performed to confirm the accuracy of this concept in dental practice , with the aim of providing dental care based on data. AI models, such as CNN, can have different applications in endodontics [39] : investigation of root canal anatomy, determination of the viability of dental pulp stem cells, measurement of working canal lengths, precise determination of root fractures and periapical lesions, and determination of the success of their retreatment procedures. Because of all of the above, AI is becoming increasingly important in dentistry these days. Neural networks are part of AI and are similar to the human brain in their work, so they can solve given problems and make quick decisions, so they will become an increasingly common tool in modern dentistry in the near future [40]. With AI expanding in dentistry, its models are used to diagnose almost all dental conditions, ranging from routine dental caries to more complex diseases such as: oral cancer, maxillofacial cysts, alveolar bone loss, determining the urgency of orthodontic extractions. The paper [41] shows the different techniques used for data collection and the application of those techniques to problems in dentistry, with an analysis of challenges and limitations, related to the wider use of AI to improve the quality of diagnosis and treatment of patients. AI models are already used today for [42]: diagnosis of various dental conditions, such as: dental caries, apical lesions, vertical root fracture, salivary gland diseases, maxillofacial

cysts, maxillary sinusitis, cancerous lesions, metastases in cervical lymph nodes, osteoporosis , loss of alveolar bone, need for orthodontic extractions, cephalometric analysis, determination of age and sex, etc. It can be said that the use of AI in dentistry refers to several key areas: patient management, image analysis for diagnostics, treatment planning and personalized care [43]. Due to all of the above, joint efforts are needed: dental experts, AI experts and policy makers (primarily health-related), for the development of solid frameworks that will ensure the responsible and ethical application of AI in dentistry. In [44], a detailed analysis of the application of AI in periodontology and caries detection is given , including classification of different types of periodontal disease, identification of areas of bone loss, determination of disease severity, analysis of dental images and detection of early signs of disease. The same is done for caries. The review paper [45] outlined possible areas of application of AI in oral medicine and radiology, maxillofacial surgery, oral pathology, prosthetics, orthodontics, endodontics and pediatric dentistry. The Augmented Artificial Intelligence (AeI) model is an AI model supported by ChatGTP, and represents the ADA (American Dental Association) view in this area [46], given as a white paper. The main obstacle to the progress of AI is access to different data sets (structured and unstructured), which are used to train deep learning models, ensuring optimal performance of AI models, which will be able to help experts in the field [47]. Generative AI (GenAI) also represents a new type of AI application, which is used to generate more synthetic data sets (SDS), which can overcome the problems arising from the use of traditional data sets.

Summarizing the performed analyses, we can conclude the following: (i) AI is increasingly becoming a clinical tool to assist in the diagnosis and treatment of patients in the field of dentistry, and (ii) digitization of dental services is an imperative of the moment, and AI is an integral part of this process, which is especially stimulated by the development of the Dentistry 4.0 concept.

3.2. Some typical examples of the development of AI tools in dentistry

This part of the analysis refers to the development and application of specific AI techniques in dentistry, namely neural networks (ANN and CNN). The application of AI in dentistry is based on learning, using ANN, or advanced learning models, such as Deep ML (machine learning) algorithms and models, which are collectively known as CNN. Thus, there are 10 ANN models and 23 CNN models.The analysis of the application of neural networks shows that ANN models are used for data analysis (data based) and CNN for image processing and analysis (image based), which is used for diagnosing conditions, table 4 [48].

Table 4. Overview of the application of AI tools in dentistry

AI technique	Ref. / yr.	Method	The goal	Use
Application of ANN/CNN	[48] 2018	Data and image processing and analysis	Improving the accuracy of diagnosis and the success of treatment	Diagnosis and treatment planning with AI
Application of CNN	[49] 2019	Fast image processing	Correct diagnosis	Clinical practice - define rules (eg ADA)
CNN	[50] 2019	Analysis of CT images	Determination of the size, shape and curvature of the root canal	Training on 5680 shots
CNN	[51,52] 2020	Analysis of 2D and 3D images	Diagnosis of the condition	Maxillofacial radiology
CDSS and GA	[53] 2020	Multiparameter pattern recognition method (diseases)	Accurate treatment plan	Use of Clinical Decision Support Systems (CDSS)
(CNN, DNN, RNN)	[54] 2020	Deep learning	Diagnosis and treatment plan	Maxillofacial surgery
CNN	[55] 2020	Analysis of CT scans	Diagnosis of lesions	Periodontology
AI and robotics	[56] 2020	Robot path planning	Diagnosis and intervention	Maxillofacial surgery
Digital transformation in dentistry	[57] 2020	From RP to telehealth (five areas)	Improvement of dental services	In all areas of dentistry (augmented intelligence – AeI)
AI	[58] 2021	Segmentation of CBCT images	Application in clinical practice	Oral dentistry
CNN (three models)	[59] 2022	Decision tree	Choosing the best deep learning model	Treatment planning
AI (RCNN)	[60] 2023	IoT (Dental Internet of Things)	On-line monitoring of dental parameters	Personal intelligent dentistry
CNN	[61] 2024	Analysis of recordings	Diagnosis of oral condition	Dental clinical conditions
CNN	[62] 2024	Deep learning	A meta-analysis of 9 studies	Clinical dentistry

CNN, according to [49], can help in the diagnosis in dentistry, as an advisor, by offering the dentist a more comprehensive, systematic and faster evaluation and a more documented picture of the patient's oral health. Therefore, CNN models are increasingly becoming applicable in routine care, but before that, dental authorities (such as the ADA [46]), should evaluate them against evidence-based clinical practice rules. The analysis of the CT image of the teeth for the purposes of diagnosis is shown in the work [50], using the CNN model while maintaining

the optimal resolution of the image, depending on the subject of the image. Image segmentation was also performed, depending on the type of condition of the tooth that was the object of the recording. In [51], a deep model of maxillofacial radiology supported by CNN (DMFR) was proposed, for more effective diagnosis, classification and prediction of the development of oral diseases, treatment planning, as well as assessment and prediction of treatment outcome, minimizing the possibility of dentist error. Training was performed on 6115 recordings, and good results were obtained in clinical practice. A similar analysis was performed in [52]. It is important to point out that for all areas of dentistry, such as: orthodontics, maxillofacial surgery, periodontology, prosthetics, and others, only an accurate diagnosis ensures the correct treatment plan, which is the most correct way to restore the patient's health. The diagnosis and treatment plan is based on the specialist's knowledge, but is subject to a high risk of error due to a large number of factors [53]. Therefore, the application of multiparametric methods of recognizing patterns of the occurrence of conditions (statistics, machine learning and artificial intelligence (AI)), is a great hope, both for doctors and patients. This article provides an analysis of the application of deep learning techniques (CNN, DNN, RNN) in the field of dentistry, for diagnosis and treatment planning for: dental caries, dental pulp diseases, periodontitis, oral cancer, periapical lesions, oral implants and orthodontics [54]. Clinical validation of all mentioned examples is the main measure of the success of these models. In [55], the use of CNN techniques for the analysis of dental radiographs was analyzed. It was shown that one diagnostic limitation of CNN was the size and characteristics of the image, which are used as input data. It was found that the accuracy of the results increases with the increase in image resolution. The main feature of reference [56] is that it presents an analysis of the use of robotics in maxillofacial surgery, with the use of AI. The symbiosis of these two technologies (robotics, AI) provides very precise surgical interventions, and the path of the robotic arm is managed based on the image analysis of the diseased zone, which is determined on the basis of AI. This concept increases the understanding of the pathogenesis of the disease, improves the risk assessment strategy, increases the accuracy of the diagnosis, makes better prediction of the disease, which ultimately leads to better patient treatment outcomes. Digital transformation in dentistry, based on electronic health data, is recognized as one of the main trends in the 21st century, as a challenge in dental health care [57]. This opinion is based on the development and application of the following technologies in dental research: (a) artificial intelligence (AI) and machine learning (ML), (b) rapid prototyping (RP), (c) augmented and virtual reality (AR/VR), (d) personalized dental medicine and (e) telehealth. By integrating these approaches, we arrive at the concept of Augmented Intelligence (AeI) in dentistry. The algorithm for automatic segmentation of teeth is used in the analysis of CBCT images, and in these studies, an analysis of 433 randomly

selected images was performed [58]. It has been shown that the AI gives quite good results in relation to the dentist's diagnosis, with an accuracy of 0.9, which encourages clinicians in oral dentistry to apply this model. An accurate diagnosis and prognosis of an individual tooth must be determined comprehensively and carefully taking into account the broader treatment plan. The model developed and shown in [59], based on AI, uses the Harvard Handbook of Good Dental Practice for Treatment Planning (CTPC). He grades the state of the teeth over five levels, using 17 defined factors. Also, for the development of the learning model, three CNN models were used, on a sample of 2359, and the decision tree method proved to be the most accurate. The Dental Internet of Things (IoDT) is the latest approach for on-line monitoring of patient dental parameters [60], which was developed as an experimental model, supported by the R-CNN network. In this way, the Industry 4.0 model for dentistry (Dentistry 4.0) is being developed. Using AI, meaningful information can be extracted from dental databases, especially dental radiographs, all with the application of deep ML models [61]. This study analyzes ML models, which can help in the diagnosis of clinical conditions, such as: early childhood caries, numbering of primary teeth, periodontal bone loss, cysts, peri-implantitis, oral cancers, osteoporosis, locating a small apical opening, identifying orthodontic landmarks, temporomandibular joint disorders, etc. In [62], a meta-analysis of 9 studies showing the results of AI application, such as: segmentation and classification of teeth, maxillofacial bone segmentation and creation of 3D tooth surface models, was presented.The AI techniques included different CNN models, and the analysis parameters in these studies were specific to the respective dental cases and specialties.

The analysis performed in this chapter allows us to conclude that the development of an integrated extended model of AI (AeI) represents the latest direction of research in the field of AI applications in dentistry. Another research direction is Dentistry 4.0.

4. Artificial Intelligence in Dentistry - What's next [36,43,63]

Virtual (digital) dental assistants can already perform several tasks in the dental clinic today, with greater precision, with fewer errors, as well as less labor, all compared to humans. They can be used to help schedule appointments, manage paperwork, assist in clinical diagnosis or treatment planning, and predict treatment outcomes. They are very useful to quickly acquaint the dentist with the patient's medical history, as well as habits such as alcoholism and smoking of the patient in question. Also, when we have urgent conditions, the patient has the option of emergency teleassistance, especially when the dentist is unavailable. In this way, a virtual patient database is created, which helps in providing the ideal treatment service to the patient himself.

Diagnoses and treatment of dental conditions. AI can be used as an effective approach in the diagnosis and treatment of lesions of the oral cavity, and it can be used in the screening and classification of suspicious changes in the mucous membrane, which goes through premalignant and malignant conditions. Even tiny changes at the level of a single pixel are detected, which can go unnoticed by the naked eye. Applying a deep learning model also accurately predicts the genetic predisposition to oral cancer of a large population.

Oral and maxillofacial surgery. The most significant use of AI is the application of robotic surgery, where the movement of the human hand and elements of human intelligence (reasoning and reasoning) are simulated. Clinical application of this approach includes: oral implant surgery, removal of tumors and foreign bodies, biopsy and jaw surgery. Comparative studies of oral implant surgery indicate significantly higher accuracy compared to manual freehand surgery, even when performed by experienced surgeons. The operation time is shorter, safer manipulation around delicate tissue structures and greater intraoperative precision. Image-guided robotic surgery also provides detailed surgical resection, potentially reducing the need for revision procedures.

Prosthetics. The goaldentist is yesmake an ideal aesthetic prosthesis for the patient, but various factors affect it: anthropological calculations, errors in facial measurements, errors due to ethnicity and patient wishes. Therefore, in order to reduce or eliminate these errors, a virtual assistant for designing solutions in prosthetics, based on AI, is used here. It connects computer-aided design (CAD), knowledge-based systems (ES) and databases, using logic-based representation (AI) as a unifying medium for the ultimate case solution. CAD/CAM systems in dentistry provide ready-made dental solutions, through a fine milling process of finished ceramic models. These systems are used in the production of inlays, crowns and bridges. CAD/CAM technique, in this way, creates 2D and 3D models, which are translated into finished solutions by CNC machine processing. In this way, the long and laborious process of conventional casting was replaced, and the impact of human error in the final prosthesis was also reduced.

Orthodontics. Diagnosis and treatment planning can only be determined by analyzing X-rays and intraoral scanners and cameras. All this helps to build a virtual dental assistant, eliminating the need to take impressions of the patient. In this way, the procedure is reduced by several laboratory steps, and the results are much more accurate compared to the dentist's analysis and perception. The movement of teeth in the jaw and the final results of treatment can also be predicted using AI algorithms and statistical analyzes based on learning (ML), especially deep learning.

5. Conclusions and Further Research

AI is a research area in dentistry that is in intensive development, especially in clinical practice. Thanks to the current state of development of machine learning and BDA techniques, all the conditions have been met to translate the clinical procedures of the best practice of diagnosis and treatment of patients into virtual dental assistants, as the first stage of the development and application of smart dentistry. On the other hand, the aforementioned facts create conditions for the development and application of telestomatology or Dentistry 4.0.

6. References

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