Artificial intelligence and dental clinical practice

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ABSTRACT

Artificial intelligence (AI) has gained notoriety in the dental field, since the emergence of several tools that help dentists in the performance of their activities and clinical routine, contributing to the early diagnosis of diseases, personalization of treatments, and data management. The objective of this chapter is to address the impact of artificial intelligence on clinical dental practice, based on the literature of the last 5 years, available in the PUBMED, SCIELO and Google Scholar databases. Intelligent systems that have the potential to transform clinical practice in dentistry, support the professional in the quality of the diagnosis and reduce the cognitive wear of the professional, contributing to the reduction of neglected information, leading him to the best treatment decision. In this sense, the conscious and ethical use of AI in dentistry is essential for an adequate and responsible integration of AI systems into the clinical routine of the dental surgeon. Although there are limitations and flaws presented by AI resources that still need to be addressed, the advantages presented by these tools stand out and show promise in the dental field. The development, implementation, and receipt of AI in dentistry must be based on well-being, privacy, the law, and respect for autonomy and decision-making.

Keywords: Artificial intelligence, Dentistry, Evidence-based clinical practice.

INTRODUCTION

In dental practice, the use of Artificial Intelligence (AI) has been growing rapidly, optimizing processes, improving efficiency, and aiding decision-making through advanced data analytics. In addition, AI assists in the early diagnosis of diseases, personalization of treatments, and data management (AGRAWAL and NIKHADE, 2022).

It is evident that artificial intelligence has become a promising tool in dentistry (RASTEAU *et al*., 2022; MIRAGALL *et al*., 2023). With the advancement of technology, the application of its tools in various areas of health has become commonplace, and in the dental field this was no different. The various tools that artificial intelligence presents have been of great help to dentists in the performance of their activities and clinical routine (GHODS *et al.*, 2023). Performing simple tasks ranging from patient scheduling to more complex ones can currently be developed using AI (THURZO *et al*., 2022; GHODS *et al*., 2023).

A relevant aspect is the use of AI in patient communication, training (continuing and continuing education of professionals), and monitoring treatment progress, constituting a new domain for AI implementations (THURZO, 2021). Data and combinations of data are essential to AI processing algorithms. Therefore, the greater the range of data, the better the learning input to the machines, enabling better decisions (HENDI et al., 2024).

The success of the use of intelligent systems in dentistry is due, in particular, to Convolutional Neural Networks, which are deep learning algorithms capable of capturing an input image, assigning importance (weights and biases that can be learned) to various aspects or objects of the image and being able to differentiate one from the other. (Data Science Academy, 2022; TANDON and RAJAWAT, 2020).

These intelligent systems have the potential to transform clinical practice in dentistry by supporting the practitioner in the quality of diagnosis and reducing the number of images to be manually examined. In this way, *machine learning* reduces the cognitive wear and tear of the professional, contributing to the reduction of neglected information, leading to the best treatment decision (ARSIWALA-SCHEPPACH *et al.* 2024; SONG *et al*., 2022).

There are some fears on the part of some professionals regarding the use of these technologies, some of them being related to providing the high amount of data that AI systems need to perform functions efficiently and accurately. Although health data are personal and sensitive and need protection throughout the use process, the possibility of data leakage in the previous training of these systems is an issue raised by health professionals (FATIMA *et al*., 2022; RASTEAU *et al.*, 2022).

This is in line with the guidance of the conscious and ethical use of AI in dentistry, which must consider when to apply AI and how to use it appropriately and responsibly, as as many dentists

are accelerating towards the integration of AI systems into their daily clinical routine, legal and ethical issues are becoming even more pertinent. (ROGANOVIĆ, RADENKOVIĆ and MILIČIĆ, 2023).

The incorporation of AI in the clinical practice of the most diverse dental specialties can help in the early detection of diseases, optimization of the dental workflow, time management and cost reduction) for patients, which should lead to treatments with better cost-benefit and high quality resolution (WANG *et al*., 2020; TANDON and RAJAWAT, 2020; HENDI *et al*., 2024).

The objective of this chapter is to address the impact of artificial intelligence on clinical dental practice, in its most diverse specialties, based on the literature of the last 5 years, available in the PUBMED, SCIELO and Google Scholar databases.

APPLICATIONS IN DENTISTRY

Caries is one of the leading clinical conditions in the world and early diagnosis is critical, especially considering the socioeconomic challenges that affect access to dental care (WANG *et al.*, 2020). To locate and determine the extent of caries, the dentist should integrate the clinical examination with the complementary examination with radiographs. However, interproximal radiographs have low sensitivity for enamel-restricted lesions (CARVALHO *et al.*, 2021) and primary caries on proximal surfaces (ARSIWALA-SCHEPPACH *et al.* 2024). The potential of incorporating AI into restorative dentistry is noted, as early detection and treatment can preserve tooth structure and prevent the cycle of invasive treatments (DEVLIN *et al*., 2021).

Due to the progressive and irreversible nature of caries injury, AI-driven diagnostic tools potentially improve diagnostic accuracy, facilitate early detection, and support treatment decision-making (AL-NAMANKANY, 2023). In this way, it is possible to diagnose and intervene in lesions regardless of their stage and location, such as secondary caries, installed adjacent to the restorations, compromising the useful life of the restorative treatment (CHAVES *et al*., 2024). The findings reveal that AI algorithms may be a promising way to improve caries prediction, detection, and management (AL-NAMANKANY, 2023).

Specially designed for image processing to capture spatial relationships in two-dimensional input data (CHAVES *et al.,* 2024), convolutional neural networks can be used as an aid in the diagnosis of caries during radiographic analysis. Interproximal radiography, for example, which is used for the diagnosis of caries, is a two-dimensional image and can be easily processed by neural networks, optimizing clinical practice (ARSIWALA-SCHEPPACH *et al*. 2024).

Studies that evaluated the observation time of dentists until the diagnosis of caries showed that professionals who were assisted by software arrived at the report in less time (DEVLIN *et al*., 2021; ARSIWALA-SCHEPPACH *et al.* 2024). It was also observed that the convolutional neural

network was able to detect 92.5% of caries, providing the patient with appropriate intervention (KÜHNISCH *et al*., 2022). Machine learning will gradually enable minimally invasive treatments (GOMEZ *et al*., 2022) and in cases of major tooth destruction; technologies such as CAD/CAM are used for restorations, such as inlays, onlays, crowns, and bridges (TANDON and RAJAWAT, 2020).

AI is expected to be fully incorporated into dentistry. Considering that the programs are based on mathematical models influenced by human neurons, AI does not pose a risk to the professional class, since it is the responsibility of dentists to foster research and feed software for full use (TANDON and RAJAWAT, 2020). However, it is crucial to be aware of potential errors in the interpretation of data by AI programs, and combining the technology with conventional methodologies can minimize these errors (CABRAL *et al.*, 2021).

Although it demonstrated the accuracy of AI in diagnosis, the study by Chaves *et al.* (2024) pointed out the presence of false positives when diagnosing caries lesions on healthy surfaces, wrongly attributing the diagnosis of secondary caries to residual caries, and erroneously classifying ill-adapted restorations, in addition to false negatives for caries lesions restricted to enamel (CHAVES *et al*., 2024). This event results from the low performance of the software in the presence of impacted, crowded teeth, dental implants, and areas of greater contrast, such as overlapping, enamel, external oblique crest, and pulp stones, in addition to the anatomical variability of molars (PETHANI, 2020).

The inability of the operating system or even less theoretical deficit can lead the patient to unnecessary or inefficient restorative treatments. Bringing to light the relevance of adequate training for the reproducibility of new diagnostic systems by CD (DEVLIN *et al.*, 2021). The incorporation of AI and maintenance of the database, such as the increment of neural layers, for example, is indispensable for greater diagnostic sensitivity (TANDON and RAJAWAT, 2020). Their products assist in early disease detection, dental workflow optimization, time management, and cost reduction (HENDI *et al.*, 2024), for patients - because early detection of caries is more cost-effective than treating advanced conditions (WANG *et al.,* 2020).

APPLICATIONS IN ORAL PATHOLOGY

In oral cancer and precancerous conditions, AI has aided on a large scale in anamnesis and diagnosis, a product of neural network processing, in the screening and comparison of test results, such as MRI and CT scans, to assess potential for metastasis (AHMED *et al.,* 2020; BONNY *et al.,* 2023; TANDON and RAJAWAT, 2020). With the supply of the image bank, neural networks allow the processing of two-dimensional images, whether they are radiographs, MRIs, or even photographs (CHAVES *et al*., 2024), providing sensitive and assertive diagnoses, in some cases, surpassing human professionals in comparison efficiency (PETHANI, 2020).

In terms of diagnostic by image comparison, neural networks can be trained to identify different types of cysts, bone lesions, and oral cancer in diagnostic images; in addition to predicting the dosage of radiation to the jaw for oropharyngeal cancer treatment, with high accuracy comparable to human specialists (PETHANI F, 2020). Studies show the competence of unsupervised learning models for diagnosing clinical conditions, including soft tissue calcifications, tissue tumors, and anomalies, such as taurodontia (SONG, 2022).

Deep learning techniques support the early detection of dental anomalies, given that, if ignored, they can lead to serious systemic complications (LEE *et al*., 2022). In histology, intelligent systems also make it possible to improve diagnosis, by virtue of their application to identify malignant character and specific features in histopathological sections, such as cell morphology, nuclear atypia, and tissue architecture (GHODS *et al*., 2023; GONZÁLEZ, 2021; DHOPTE et *al.*, 2023). In addition to image processing, AI is able to predict the occurrence of pathologies, such as squamous cell carcinoma, based on clinical and genetic data (PETHANI, 2020; DHOPTE *et al*., 2023).

Intelligent systems have the potential to transform clinical practice in dentistry, in the sense that *machine learning* reduces the cognitive wear and tear of the professional, contributing to the reduction of neglected information, leading them to the best treatment decision (ARSIWALA-SCHEPPACH *et al.,* 2024; SONG, 2022). In addition to reducing human errors due to the concealment of data in the anamnesis or medical history, such as the diagnosis of bisphosphonate-related osteonecrosis before extraction (AHMED *et al.*, 2020).

With the range of results greater than 80% in favor of AI accuracy in oral pathology, educational institutions need to be prepared to offer ongoing AI training in dentistry (DHOPTE *et al.*, 2023; GHODS *et al*., 2023). Considering the complexity of oral anomalies, AI should be used as an additional benefit to be controlled by the dentist, and not replace him (BONNY *et al*., 2023).

APPLICATIONS IN PERIODONTICS

In periodontics, Artificial Intelligence already enables the analysis of diagnostic data, such as clinical parameters, radiographs and intraoral images, to assist in the diagnosis and classification of periodontal diseases from electronic medical records and datasets inserted into AI software that learn patterns and indicators of periodontal disease, assisting in decision-making and planning for the best possible treatment (DHOPTE and BADGE, 2023).

In this specialty, in particular, international studies show continuous development of intelligent tools and systems useful to complement the dentist's decision-making. *Deep Learning* algorithms associated with Neural Networks have high potential for usefulness and accuracy in the diagnosis and prediction of clinical conditions based on values of probing depths, insertion levels,

and bleeding points, extracted from patient records (BONNY *et al*., 2023; DHOPTE and BADGE, 2023).

Through the techniques of learning systems from a database of existing and defined characteristics in the classification of periodontal diseases, it is possible to benefit periodontists and patients in the accurate and quality diagnosis while saving time and resources, in addition to reducing human error. Despite this, it is understood that these systems are still far from replacing the knowledge of the health professional, and should be applied in a safe and complementary way to the judgment of the dental surgeon (BONNY *et al.*, 2023).

A 2024 primary study evaluated the accuracy of an AI algorithm trained to analyze signs of periodontal disease through image records from 60 patients. In their results, the authors found a sensitivity of 91%, specificity of 86% and an overall accuracy of 88% of the algorithm, demonstrating the use of AI as a promising tool in the early identification of periodontal diseases through intraoral imaging and favoring the reduction of diagnostic variability and support of more timely interventions (ALAM *et al*., 2024).

In addition, it has also been published that AI has the ability to identify patterns and models that may be difficult for humans to discern or that would require a significantly longer time, such as the identification of periodontalally compromised premolars and molars with 90% and 95% accuracy, respectively. This information is of great relevance to support treatment protocols, leading to positive impacts on diagnostic accuracy and overall treatment outcomes (HENDI *et al.,* 2024).

Despite the promising prospect of these tools, it is important to take into account that, as much as they can detect pathologies and direct diagnoses accurately, it is the practitioner's treatment recommendations based on the patient's overall context, available treatment options, and the patient's adherence to treatment that determine the true impact on clinical outcomes (PETHANI, 2021).

Chawla *et al*. (2023) published a study conducted in 2023 that evaluated the understanding and acceptability of periodontists regarding the use and application of AI in this area of expertise. The study reveals that there was great acceptability among professionals for the use of AI in the diagnosis of periodontal diseases, but resistance to its use in the predictability of clinical loss of insertion.

Despite understanding the basic factors of the concept of artificial intelligence and expressing a desire to incorporate such systems into the processes of diagnosis and therapeutic planning of periodontal conditions, part of the interviewees believe that their use for diagnosis is not more accurate than that of the professionals themselves to the point of replacing them (CHAWLA *et al.*, 2023).

Also from this perspective, it is a fact that the investigation of periodontal diseases and conditions is linked to complex contexts that require a multidimensional understanding of the factors that are associated with their manifestation and progression.

Currently, despite the possibility of teaching an AI about the scenarios that comprise periodontal diseases and subsidizing a positive impact on the diagnostic process, these tools are still incapable of reproducing the nature of the doctor-patient relationship, built from bonding and humanization. And second, in the process of integrating medical history associated with physical examination in situations characterized by ambiguity and uncertainty, which is beyond the current reach of AI technology (CHAWLA *et al.*, 2023; SACHDEVA *et al.*, 2021).

Although the development of AI within health scenarios and, more specifically, in periodontics is still moving at a short pace, it is observed that dentists understand and visualize the use of intelligent systems as facilitating resources for clinical practice and decision-making, assisting professionals in the correct interpretation of oral anomalies and minimizing human error. therefore, a modality of inevitable development and integration in dentistry (AHMED *et al.*, 2021).

APPLICATIONS IN DENTAL IMAGING

Radiological examination is a fundamental component in the management of patients in dentistry. It is widely used to complement and assist in the clinical diagnosis of pathologies affecting the teeth and adjacent structures. Accuracy and the ability to provide detailed insight into oral conditions make this examination indispensable for planning and executing proper dental treatments (GHODS, 2023).

Review studies have shown that the most frequent application of artificial intelligence in dentistry is largely concentrated in the areas of radiology and oral imaging. The integration of AI in these areas has shown significant potential to improve image interpretation, facilitating diagnoses, providing greater speed and accuracy (CHAN, 2018).

In this sense, the primary goal of using AI in dental radiology is to increase the efficiency and quality of services provided. AI can analyze large volumes of data faster and more accurately than traditional methods, allowing healthcare providers to focus on more complex and personalized aspects of patient care. In addition, it can assist in standardizing diagnoses and reducing human errors, increasing sensitivity and promoting safer dental practice (THURZO, 2022).

Many studies are committed to improving the classification and segmentation of oral radiographs based on machine learning. Mathematical morphology, active boundary models, level definition methods, Fourier descriptors, textures, Bayesian techniques, linear models or binary support vector machines are used. Classification includes a broad spectrum from the detection of the absence or presence of a pathology or object of interest, to its classification. For the efficiency of AIs

in the use of images, large banks, the so-called "big data", are needed. These are increasingly robust, especially with CT scans (GHODS, 2023).

Recently, several authors (RASTEAU, 2022; MONTERUBBIANESI, 2022; FERRO, 2019) began to conduct studies focused on evaluating the use of AI in imaging technologies, specifically applied to diagnostic protocols in dentistry. These studies have investigated the implementation in several areas of oral medicine. The use of AI has been reported in a wide range of radiographic examinations, including periapical radiographs, bite-wing (interproximal) radiographs, cone beam computed tomography (CBCT), magnetic resonance imaging (MRI), and panoramic radiographs. The application of AI in these exams has shown the potential to significantly improve diagnostic accuracy, the efficiency of clinical processes, and the overall quality of dental care.

The use of AI for the analysis of CBCT and MRI has revolutionized the way facial anatomy is evaluated and pathologies are visualized in oral and maxillofacial surgeries. These technological advancements allow for automatic and sensitive visualization of craniofacial structures, providing a more accurate understanding of clinical conditions and facilitating decision-making. The application of AI is particularly effective in assessing cystic lesions and locating included third molars, allowing surgeons to plan interventions with greater precision. The identification of osteoporosis in the jaws is also enhanced with the use of this technology, offering valuable insights into bone density and overall health of the jaw bones (CHOI, 2022).

In addition, AI significantly improves the detection of soft tissue calcifications and anomalies in areas surrounding dental elements, such as mucosal thickening in the maxillary sinus and the presence of radiopacities in the jaw. These advanced imaging capabilities assist in the accurate diagnosis of pathological conditions, the formulation of well-informed therapeutic decisions, and the design of detailed treatment plans (DESHMUKH, 2018).

AI also enables better prediction of health outcomes, optimizing treatment outcomes and improving patients' quality of life. Thus, the integration of AI in the analysis of CBCT and MRI represents a significant advance in dentistry, promoting safer, more effective, and personalized interventions (LEE, 2022).

The integration of AI with periapical radiographic examinations, panoramic examinations, and cone beam computed tomography scans is being widely used for the evaluation of periapical lesions in teeth with necrotic pulp, location of the apical foramen, and the working length of the canal. The dental surgeon, by analyzing the exams in digital format, can automatically identify abnormal points in the region of interest and obtain the information that is necessary for the treatment, complementing the information obtained by the anamnesis and the clinical examination (FERRO, 2019).

In oral rehabilitation, based on *machine learning*, it is possible to merge data from 3D images of CT scans, intraoral scans, and facial scans, which result in the proper visualization of the patient's morphology. The role of AI in implant dentistry is synchronized with the advancement of three-dimensional computerized cone beam imaging and intraoral digital scans. They are useful for methodically designing and manufacturing the implant prosthesis. Periapical and panoramic examinations are also used to assess morphological structures in the planning of surgeries (EKERT, 2019).

APPLICATIONS IN ORTHODONTICS

Artificial intelligence (AI) is revolutionizing the paradigm of orthodontics, positioning itself as one of the dental specialties with the highest number of collaborations with this technology. Among all the skeletal and soft tissue structures available for orthodontic diagnosis, the face stands out as one of the most important, although it is also the most challenging for scientific understanding by professionals. Automated AI facial surface analysis, coming from cone beam computed tomography (CBCT) or any other type of facial scanner, can be used to increase the accuracy and efficiency of diagnosis at any stage of life (IMPELLIZZERI, 2020)

There are reports in the literature about the usefulness of AI-managed tools during the COVID-19 pandemic, especially in the orthodontic retention or pre-treatment phase, allowing clinical conditions defined by experts to be regularly assessed through patients' home videos.

AI algorithms could analyze cephalometric radiographs to automatically identify and measure key anatomical landmarks used in orthodontic diagnosis and treatment planning. AI-powered software assists orthodontists in creating cephalometric tracings, analyzing facial and dental measurements, and simulating treatment outcomes based on established protocols (DHOPTE, 2023).

Recent studies have used AI to predict the need for tooth extractions based on clinical features and cephalometric measurements. The decision between extraction and non-extraction has been widely debated in orthodontics. In some studies (LI, 2019), AI demonstrated an 80% efficacy in determining the best treatment approach for 200 patients with malocclusion, aged 11 to 15 years.

In addition, there are reports on the use of CAD/CAM for 3D printing of orthodontic brackets and custom aligners. These printed devices are accompanied by algorithms that intelligently determine how the teeth should be moved, the force to be applied, and identify specific pressure points (SAGHIRI, 2022).

In dentofacial orthopedics, the use of Deep Learning for automated tooth segmentation in 3D models of the jaw allows the reconstruction of teeth with their roots from CT scans. Iterative closest-point algorithms are used to form a complete digital dental model, providing essential information for the simulation of orthodontic treatment (BONNY, 2023).

APPLICATIONS IN ORAL AND MAXILLOFACIAL SURGERY AND TRAUMATOLOGY

The use of AI in Oral and Maxillofacial Surgery and Traumatology (CTBMF) has grown significantly in recent years, helping to improve the performance of several areas of this specialty (RASTEAU *et al*., 2022; ESCHERT *et al.*, 2022). It has been used for the development of tasks ranging from patient triage, diagnosis, treatment plan to postoperative projections (SHAN, 2021).

Among the advances provided by this technology, the identification and accuracy of characteristic anatomical points in panoramic radiographs and cone beam computed tomography (CBCT), through specialized software, has been one of the most significant advances in AI in CTBMF (RASTEAU *et al.*, 2022). The algorithms that work in these software are able to accurately and quickly identify radiolucent bone lesions in the maxilla and mandible region.

Previous studies have reported that through models with specific image analysis algorithms, the diagnostic accuracy made by AI was as efficient as those performed by a specialist (CHEN, STANLEY, and ATT, 2020; RASTEAU *et al.*, 2022). In addition, another important point is the ability to early identify premalignant lesions in the mouth and pharynx region by means of autofluorescence measurement and photo analysis, which correlates high-dimensional parameters with clinical diagnoses and prognostic factors, thus constituting true radiological biomarkers revealing characteristic points in the detection of these lesions (RASTEAU *et al.*, 2022).

The *machine learning tools* involved in this system, in addition to providing the early identification of these lesions, may be able to predict the evolution of the disease, project the prognosis, as well as assist, through the data from electronic medical records present in their databases, in the choice of the most appropriate treatment for each case (FONTENELE *et al.*, 2023).

Another important advance of these tools is found in Orthognathic Surgeries. The location of cephalometric points is a crucial factor for accurate orthodontic diagnosis and treatment procedures. Errors in the identification of these reference points are directly linked to misdiagnosis and flawed treatment results (VILA-BLANCO *et al*., 2021; FONTENELE *et al.*, 2023;). In this context, seeking to prevent the occurrence of these damages, automated detection of landmarks using *machine learning* techniques on lateral cephalometric radiographs has emerged as a promising approach (ESCHERT *et al*., 2022; FONTENELE *et al.*, 2023).

The literature has recorded the various methods employed by authors in relation to precision and efficiency in the detection of these points, such as the "random forest technique". However, these more traditional spot detection techniques have limitations (MIRAGALL *et al.*, 2023). When compared to automated detection systems, traditional techniques are time-consuming procedures, have a higher risk of presenting potential biases and inaccuracies associated with detected reference point data that can be influenced by the observer's experience (MIRAGALL *et al*., 2023).

Still dealing with aspects related to AI advances in orthognathic surgery, the possibility of projections of the postoperative profile of patients is currently provided (ROKHSHAD, KEYHAN and YOUSEFI, 2023). In addition, AI-aided planning based on images and 3D models, makes it possible to simplify cephalometric analysis and operation simulation, as well as offer a more accurate visualization of dental abnormalities, occlusal plane inclination, and body length and mandibular branch (VILA-BLANCO *et* al., 2021).

The extraction of impacted third molars was also another procedure that gained prominence with the implementation of more current technologies. This can be considered as one of the most performed procedures in the specialty of CTBMF. The artificial neural networks that have been introduced to optimize and guide the procedure of extracting these teeth can predict the surgical outcome, difficulties, angulation of the tooth, as well as the relationship of the tooth to the mandibular canal. Although neurological complications cannot be entirely avoided in cases with a higher level of complexity, still the use of AI preoperatively significantly reduces the chances of neurological injury. In addition, this type of technology allows a prediction for postoperative edema complications, providing the patient with a greater level of knowledge for postoperative care (RASTEAU *et al*., 2022; MIRAGALL *et al*., 2023).

Despite the great advance that artificial intelligence has been providing for dentistry, its limitations in CTBMF are still strongly debated. Issues related to the limited explanation and lack of transparency of diagnostic development provided by these technologies become factors that corroborate the skepticism of some professionals in the field (AHMED *et al*., 2021). As this technology becomes more accurate in results, its complexity also seems to evolve, limiting not only the understanding of healthcare professionals, but also of patients (KRISHNAN, 2022; MIRAGALL *et al*., 2023).

There is a study that highlights the limitation in scientific content regarding AI tools in reputable journals. In addition, they recommend that CTBMF uniprofessional residency programs incorporate essential AI curricula into their educational offerings to improve practitioners' understanding of AI models and algorithms (MIRAGALL *et al.*, 2023).

In short, although the implementation of the tools provided by AI are still recent in the field of Oral and Maxillofacial Surgery and Traumatology, their aid in diagnosis, therapeutic decision, preoperative planning, or prediction of the outcome of surgery is of significant importance in daily clinical practice (RASTEAU *et al*., 2022; ALZAID *et al*., 2023). Although there are some situations that need to be resolved in terms of ethics, data protection and diagnostic transparency, the implementation of this technology in the dental environment can be considered as a permanent aid.

APPLICATIONS IN ENDODONTICS

Endodontics, a dental specialty dedicated to the diagnosis and treatment of pathologies of the dental pulp and periapical tissues, has benefited enormously from technological advances, especially because it is an area that requires numerous associated skills (KAROBARI *et al.*, 2023). Among the most promising innovations is the application of artificial intelligence, since its ability to analyze large volumes of data offers powerful tools to improve the accuracy of diagnoses, optimize treatment plans, and increase the efficiency of endodontic procedures (MORAES *et al.*, 2019).

Despite advances in treatment techniques, instrumentation, and materials, epidemiological studies reveal a high prevalence of radiographic periapical lesions and the persistence of periapical pathology in endodontically treated teeth, which makes the use of AI relevant to assist not only in dental clinical practice, but also to contribute to the personalization of patient care, ensuring faster, safer, and more effective treatments, which represents a significant advance, aligning with the global trend of incorporating cutting-edge technology to enhance patients' health care and well-being (KAROBARI *et al.*, 2023; PAULINO *et al*., 2023; SAVEGNAGO *et al.*,2024).

Saeed Asgary (2024), in a literature review, explored recent advances in artificial neural networks in endodontics. This neural architecture framework comprises neurons with interconnected robust systems that function primarily as information systems to determine problems. The results indicated that artificial intelligence models have a great utility in analyzing the anatomy of root canals. They allow both the early detection of periapical lesions and the precise determination of the working length.

In addition, AI models have shown an exceptional ability to recognize landmarks and lesions in cone-beam CT scans while maintaining consistently high accuracy rates. In addition, they have been shown to be effective in predicting the success of treatments, identifying various conditions such as dental caries, pulp inflammations and vertical root fractures, as well as offering second options for non-surgical root canal treatments.

In a systematic review, Boreak (2020) pointed out that there is a range of applications of AI implemented in endodontics, but highlighted the effectiveness of artificial intelligence applications developed for endodontic diagnosis, decision-making support, and prognosis prediction. The study also addressed the use of neural networks in endodontics, based mainly on convolutional neural networks (CNNs) and artificial neural networks (ANNs). These AI systems have been applied in the precise location of the apical foramen, prognoses related to the need for retreatment, prediction of periapical conditions, accurate detection and diagnosis of vertical root fractures, in addition to the thorough evaluation of root morphologies. Investigations indicate that neural networks showed results comparable to those of experienced professionals in terms of accuracy and precision.

Savegnago *et al*. (2024) gathered some relevant data when conducting a narrative review of the literature. In the review, an innovative apical foramen localization system was highlighted that achieved a 93% success rate in accurately locating the apical foramen by extracting radiographic features and processing them in artificial neural networks. In the results regarding the detection of periapical lesions, it was found that software using artificial intelligence presented high accuracy rates, reaching 93% accuracy with cone beam computed tomography (CBCT) images and 85% with panoramic radiographs. In the analysis of studies focused on root fractures, AI obtained a diagnostic accuracy of 70% with periapical radiographs and 96% with cone beam computed tomography (CBCT) images.

These advancements represent a remarkable opportunity for endodontics, with the potential to radically transform the way dental professionals approach the diagnosis and treatment of endodontic conditions. However, it is crucial that practitioners are prepared to integrate AI into their practice ethically and responsibly, ensuring that the advantages are maximized for the benefit of patients. In this regard, we can expect AI to continue to play an increasingly important role in the evolution of endodontics and improving clinical outcomes for patients (KESKIN, 2021; BOREAK, 2020).

APPLICATIONS IN IMPLANTOLOGY AND PROSTHODONTICS

Implantology and Dental Prosthesis are areas of dentistry responsible for replacing lost and/or artificially compromised dental elements. With the improvement of dental restorative materials and AI, it is possible to deliver better results to patients and with greater efficiency in dental clinical practice (HENDI *et al*., 2024).

In this context, AI has been shown to be a great ally of dentistry and especially of the rehabilitation areas of oral health, as it plays a fundamental role in diagnosis, offering support for treatment decisions, in addition to managing complex situations, increasing the predictability of cases and indicating possible negative outcomes during oral rehabilitation. However, a complete transformation from the conventional workflow to the digital workflow is required (DHOPTE *et al.*, 2023; FERRO *et al.*, 2019).

From the perspective of implant dentistry, AI is commonly used to assist in diagnosis and treatment planning, as it analyzes cone beam computed tomography images and intraoral and facial digital scanning images of the patient, being able to simulate the installation of dental implants and provide virtual treatment plans, displayed through three-dimensional simulations the ideal placement position and angulation of dental implants to obtain predictable results from the biomechanical and aesthetic point of view (FERRO *et al.*, 2019).

The case treatment plan is carried out in software, such as DTX Studio, Blue Sky Plan, NeoGuide System, DIOnavi and Simplant, among others, according to the information on the three-

dimensional anatomical and occlusal positioning of the prostheses on the implant, digitally planned through reverse planning. Some of these software are available free of charge for digital planning (FERRO *et al.*, 2019).

AI helps in the identification of dental anomalies by comparing patient data and examinations with established norms and standards, these algorithms can flag deviations and abnormalities and notify the operator of potential problems. They collaborate in decision-making, predictability of treatment, preoperative planning (preparation of surgical guides), recognition of implant types through image recognition using periapical and panoramic radiographs (FERRO *et al.*, 2019; DHOPTE and BAGDE, 2023; TURZHO *et al.*, 2022).

With the AI algorithm, it is possible to calculate and minimize the stress on the implant-bone interface by observing three implant variables (the length of the implant, the length of the thread, and the pitch of the thread), in addition to accurately calculating the modulus of elasticity of the implant-bone interface. AI increases the predictability of osseointegration through the analysis of risk factors and bone anatomy, along with finite element analysis calculations (HENDI *et al*., 2024; DHOPTE et *al.*, 2023; REVILLA-LEÓN *et al*., 2021)

In dental prosthesis, there is a total immersion of the specialty in AI, from the capture of images of the arches via intraoral and bench scanners to the prosthetic production from milling machines, through CAD/CAM technology. The evolution of AI in this specialty has been intense, especially in the manufacture of removable and fixed prostheses, the highlighting of prosthetic margins, the selection of colors, the manufacture of prostheses on implants and maxillofacial prostheses, in addition to the establishment of a facilitated maxillo-mandibular relationship (HENDI, *et al*., 2024).

The AI flow in dental prosthesis starts with the use of intraoral scanners. AI is used during the scanning process to automatically remove excess soft tissues and materials (TURZHO *et al.*, 2022).

In the software, the algorithm has the ability to process data and associate the relevant clinical information of the patients entered into the system, such as fingerprints, x-rays and facial scans, to create 3D virtual models of the patient's oral anatomy for an optimal diagnosis (DHOPTE *et al.*, 2023)

The software also performs the classification of dental arches in removable prosthesis, as well as autonomously suggests different designs of structures considered more appropriate for the clinical case, assists in the design of the prosthesis, in the determination of its type (removable or fixed) and in the selection of components, identify periodontally compromised teeth, in addition to delimiting the areas of end of the margin of preparations with onlay ceramic purposes, fixed inlays, crowns and bridges requiring only minor adjustments at the operator's expense, improving the accuracy of final

dentures and decreasing the need for manual adjustments (THURZO *et al.*, 2022; FERRO et al., 2019; DHOPTE et *al*., 2023)

The data generated by three-dimensional machines is used by AI to design the prosthesis on implant in reverse planning, thus determining the most convenient position and angulation for implantation and fabrication of precise surgical guides (AL HENDI, *et al.*, 2024).

In conventional prosthetics, the integration of AI has increased accuracy, precision, and reliability, positively impacting clinical outcomes. During digital design, the CAD/CAM tool is used for the manufacture of fixed and removable dental restorations. In this process, a virtual library with millions of natural crowns can be used to create the best possible crown design for the various clinical situations, in addition to the software making it possible to recreate acceptable intermaxillary relationships, configuring the correctly designed teeth, evaluating occlusal relationships and identifying interferences in search of the appropriate functional dynamics. Virtual analysis of the joint and occlusion can assist in the planning of prosthetic treatment, ensuring proper occlusal alignment and harmony for appropriate functional and aesthetic outcomes (DHOPTE *et al*., 2023; TURZHO *et al.,* 2022).

The models made in the software serve as a reliable diagnostic tool for selecting the color of the tooth, presenting varied shapes and enabling adjustments in aesthetics in search of the best results for the patient during the digital design of the smile, in addition to predicting facial changes in patients with removable dentures and design of removable partial dentures. The software is also able to predict the color change of prosthetic restorations in various lighting conditions (DHOPTE *et al*., 2023; BONNY *et al.*, 2023).

In addition to the models, smile design uses 3D facial scanning and virtual resources along with segmented computed tomography, intraoral scans, and facial scans, resulting in the virtualization of the patient's morphology, producing a facial design with the patient's smile (TURZHO *et al*., 2022).

CAD/CAM software not only designs, but is also responsible for manufacturing, printing, or milling the prosthesis. Commonly used to manufacture inlays, onlays, crowns and fixed bridges. Resulting in savings in time, resources, and energy for the dentist, prosthetist, and patients, in addition to reducing the chances of human error in the final prosthesis and performing unnecessary procedures (HENDI, *et al.,* 2024).

APPLICATIONS IN FORENSIC DENTISTRY

Forensic Dentistry, also called Forensic Dentistry, is a specialty of dentistry that employs technical-scientific processes to assist in human identification in forensics focused on the head and neck. This includes the analysis of dental arches, the comparison of dental records, facial

reconstruction, and the identification of other anatomical structures in the region, making a crucial contribution to legal and judicial investigations (RAMOS *et al.,* 2021).

The importance of the forensic dentist has become crucial in forensic science, particularly due to the histological characteristics of teeth that make them resistant, such as not sustaining damage when subjected to temperatures of 600°C and remaining intact for long periods after the body has deteriorated. Thus, when a body is found in conditions such as skeletonization, charring, advanced stages of decomposition, or other situations that make identification difficult or impossible by traditional methods, such as dactyloscopy, the analysis of the tooth structure becomes fundamental for individual identification (BIANCH, 2019).

Advances in computer science and radiology refinement have played a significant role in achieving greater accuracy and detailed image analysis, providing enlargements without loss of quality, reducing image processing time, and offering various adjustment options. These advances have enabled more accurate identifications and facilitated the comparison between ante-mortem and post-mortem radiographic examinations (RAMOS *et al*., 2021; BIANCH, 2019).

Nascimento Neto *et al.* (2019) conducted a research in order to map and categorize forensic knowledge, with the purpose of developing a methodological plan to support the creation of a tool based on artificial intelligence specific to Forensic Dentistry. The study presented a proposal that uses artificial intelligence to store dental records, perform comparisons and recognize radiographic images, ensuring the legitimacy and authenticity of the data.

The software developed in the study had the participation of the dental surgeon, the radiology companies and the forensic dentist, and consists of a graphical interface that acts online and allows the user (dental surgeon) to enter the dental documentation register, consisting of medical records, radiographs, odontograms and photographs. In this way, it is possible to create a database with accurate information on an individual, which allows the identification of the level of similarity between ante-mortem and post-mortem examinations and, based on this, to be able to give a report confirming or not the identification of the victim, which helps and optimizes the work of the forensic dentist (NASCIMENTO NETO *et al*., 2019; BIANCH, 2019).

At the same time, (MOLLO FILHO; MELANI, 2022), demonstrated through a literature review the relevance of the use of intraoral scanners and their applicability in the practice of forensic dentistry. The resource is capable of generating three-dimensional digital models of the oral cavity that can be stored, analyzed, and compared using proprietary applications.

With the application of the technique, records are obtained with agility and precision and the data can be obtained, if necessary, in the very place where the body is located during the expert evaluation. Research shows that intraoral scanners have as a differential the possibility of

differentiating monozygotic twins by analyzing palatine roughness, an anatomical detail that is also capable of individualizing each person (GIOSTER-RAMOS *et al.,* 2021; Bianch, 2019).

Thus, artificial intelligence combined with imaging exams and comparison algorithms have proven to be extremely important resources in the human identification process.

PERSPECTIVES OF AI IN DENTISTRY

With the advent and applicability of AIs in healthcare, the possibility of virtual care through teledentistry has been highlighted as promising and has the potential to reach patients in more remote regions with limited access to dental care, so that they can, from this new resource, receive consultations more quickly and efficiently (AGRAWAL and NIKHADE, 2022; GHODS *et al.,* 2023).

Among the branches of dentistry with the greatest applicability of these technological resources, without a doubt, diagnosis and treatment have been the most impacted. Machine *learning* algorithms are capable of analyzing radiographic images, CT scans, and other imaging tests, providing faster and more accurate identification of conditions such as caries, fractures, periodontal diseases, and even premalignant lesions, which has been helping in early diagnosis and may soon be considered an essential tool for clinical use to minimize the chances of a poor prognosis for the patient (CHWENDICKE, SAMEK and KROIS, 2020).

In addition, software that provides augmented reality and 3D images reveal that AI is a promising tool for the evolution of more effective dental diagnoses (PETHANI, 2021; BONNY *et al*., 2023). A study demonstrated the efficiency of an artificial neural network in providing a diagnosis with good accuracy. In this study, a comparison was made between the diagnosis made by a specialist and by ANN, the result showed that AI had a high sensitivity and specificity in the diagnosis presented (TANDON, RAJAWAT and BANERJEE, 2020).

With regard to the individualization of treatments, advanced algorithms are able to analyze previously provided data on each patient's oral health and medical-dental history, allowing, which will allow dentists to create personalized treatment plans in daily clinical practice (SHAN, 2021).

Regarding monitoring and prevention, the literature reports that through RNA it was possible to create a model capable of predicting the possibility of toothache in patients. This study used the association between toothache, frequency of brushing, flossing, and other factors such as diet and physical activity. The model made in this study was able to recognize proper eating habits, oral hygiene, and stress prevention as the most important factors in the prevention of dentistry (TANDON, RAJAWAT, and BANERJEE, 2020).

In addition to the above-mentioned points, advances in surgical planning have shown promise for application in the dental environment (ALZAID *et al*., 2023). Through software specialized in

machine learning , it is possible to perform complex surgeries, such as implant placement or orthognathic surgeries, with greater precision. This software aims to make procedures less invasive, which will reduce recovery time and provide greater safety for the patient (RODRIGUES, KROIS and SCHWENDICKE, 2021; ALZAID *et al*., 2023).

Despite the promising results that artificial intelligence provides for the dental environment, several authors still debate the difficulties and flaws presented by this technology. Among the main issues raised are the high complexity of understanding these systems and the high number of health data used in previous tests for the development of these systems, which are at risk of leakage (CHWENDICKE; SAMEK; KROIS, 2020).

Some authors also highlight the automation bias that occurs when some professionals underestimate the possibility of error in the information presented by AI (GLICK *et al.*, 2022). The fact that the information was generated by a computer is enough for the professional to adopt the result as an absolute truth, even if he sometimes has doubts about the result, this prevents him from investigating further, allowing the chance of error (GLICK *et al*., 2022).

LEGAL ASPECTS OF AI IN DENTISTRY

Currently, there are no laws specifically set for the use of AI in dentistry. (ROGANOVIĆ and RADENKOVIĆ, 2023; ROGANOVIĆ, RADENKOVIĆ and MILIČIĆ, 2023; ROKHSHAD *et al*., 2023).

Medical liability currently defined under the law is inadequate and therefore may not encourage the safe use of AI in clinical decision-making. It can be stated with certainty that the use of AI in clinical decision-making needs dental surveillance, and the role of dentists is crucial in preventing dental complications as well as reviewing AI systems (ROGANOVIĆ and RADENKOVIĆ, 2023).

To respect the interaction between man and technology in a clinical setting, AI in medicine and dentistry must have a complementary role in the work of clinical professionals. In dentistry, various software-type algorithms are used as the basic application of AI, which is supposed to improve the accuracy of dental diagnosis, provide visualization of anatomical guidelines during treatment, and, due to the possibility of analyzing large amounts of data, predict the occurrence and prognosis of oral diseases. The conscious and ethical use of AI in dentistry should consider: (1) when to apply AI and (2) how to use AI appropriately and responsibly. Patients should be notified about how their data is used, also about the involvement of AI-based decision-making, especially if there is a lack of regulatory policy if AI is used to decrease costs rather than improve patients' health or if the dentist has a conflict of interest. As many dentists are accelerating in the direction of integrating AI

systems into dental diagnostics, prognosis, and treatment, the legal and ethical issues are becoming even more pertinent. (ROGANOVIĆ, RADENKOVIĆ and MILIČIĆ, 2023).

Notably, particularly for AI, considering a network of multiple stakeholders, including patients, clinicians, software developers, and society, as well as the specific requirements, needs, and constraints of the target medical specialty may be relevant; existing guidelines applied to medicine will not be entirely applicable to dentistry. A specific framework and *guideline* on dental AI is needed, which should facilitate dissemination to the dental domain and help optimize dental AI in relation to its ethical foundations (ROKHSHAD *et al.*, 2023).

FINAL THOUGHTS

AI has become an excellent tool for dentistry, providing several advantages that have improved both clinical practice and the patient experience. The potential of AI to transform the way dentists deal with the diagnosis, planning, and treatment of their patients is remarkable.

Although there are limitations and flaws presented by AI resources that still need to be addressed, the advantages presented by these tools stand out and show promise in the dental field. Still, the employment of these technologies in clinical dental practice is a challenge and the lack of acceptance of these tools can be attributed to the complexity of dealing with new technologies and the difficulty of acquiring new skills.

All stakeholders in this process, such as dentists, patients, and system developers, should consider and prioritize, among other factors, well-being, privacy, the law, and respect for autonomy and decision-making when developing, implementing, or receiving dental AI.

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