Review Article

Applications and Perspectives of Artificial Intelligence, Machine Learning and "Dentronics" in Dentistry: A Literature Review

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ABSTRACT

Objective: The aim of this study was to describe artificial intelligence, machine learning, and "Dentronics" applications and perspectives in dentistry. **Materials and Methods:** A literature review was carried out to identify the applications of artificial intelligence in the field of dentistry. A specialized search for information was carried out in three databases such as Scopus, PubMed, and Web of Science. Manuscripts published from January 1988 to November 2021 were analyzed. Articles were included without any restriction by language or country. **Results:** Scopus, PubMed, and Web of Science were found to have 215, 1023, and 98 registered manuscripts, respectively. Duplicates (191 manuscripts) were eliminated. Finally, 4 letters, 12 editorials, 5 books, 1 erratum, 54 conference papers, 3 conference reviews, and 222 reviews were excluded. **Conclusions:** Artificial intelligence has revolutionized prediction, diagnosis, and therapeutic management in modern dentistry. Finally, artificial intelligence is a potential complement to managing future data in this area.

KEYWORDS: *Artificial intelligence, machine learning, virtual*

INTRODUCTION

Artificial intelligence (AI) uses machine performance to replicate human behavior. In health care, the rise of modern, digitized technology to perform a medical examination has proven to simplify the processes of collecting and analyzing clinical data. Software-like algorithms used on AI are the main components used in the dental field. However, truly autonomous medical robotic systems are still not available. Due to their powerful data analysis, dental diagnosis accuracy and efficiency are expected to be enhanced by these virtual algorithms.[1-5] Digital dentistry requires modern technology to enable specialized processing of these data. Specifically, in the field of dentistry there are some applications of AI such as scanners: TRIOS which is superior to CEREC and SHINING in accuracy punctually in the intraoral option. Being clinically significant, it is consolidated as a standard reference.[6]

Since the development of science, scientists have sought to decipher the complexity of the human cerebrum, which is a maze of interconnected neurons that transmit signals throughout the body.[1] Therefore, it remains a challenge to design a model that mimics the activity and processing of the human cerebrum. The constant hard work and effort of researchers over several years result in AI evolution. This term was first used in approximately

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1950 and refers to the concept of creating machines that can perform tasks conventionally performed by humans.[2] As learning is an essential part of the human cerebrum, AI focuses on the simulation of human intelligence that machines adopt from the collection of information they gather and/or feed.[3-5]

The main advances in AI have been restricted to disease diagnosis and prognosis. In this regard, promising results have resulted from the use of these technologies, further encouraging their applicability.[5-9] For example, some previous studies mentioned that the development of AI seeks to optimize the accuracy of specialists and if possible, surpass it. With the application of AI in the field of implant dentistry, the improvement and performance of dental implants are intended. AI is also often used in models for the correct location of the apical canals and thus be able to make a correct prediction of endodontics, and help in the diagnosis of certain periapical pathologies and possible root fractures. radicular fractures.[10-12]

It is important to conduct a narrative review that summarizes the current knowledge on the characteristics, applications, and uses of AI in dentistry. In this way, it will be possible to identify what could be researched on this topic of interest, understanding the complex processes of information for decision-making in the health sciences. Therefore, the objective of the present literature review was to describe the applications and perspectives of AI, machine learning (ML), and *Dentronics* in Dentistry.

Materials and Methods

Study design

A literature review was carried out to identify the applications and perspectives of AI in dentistry.

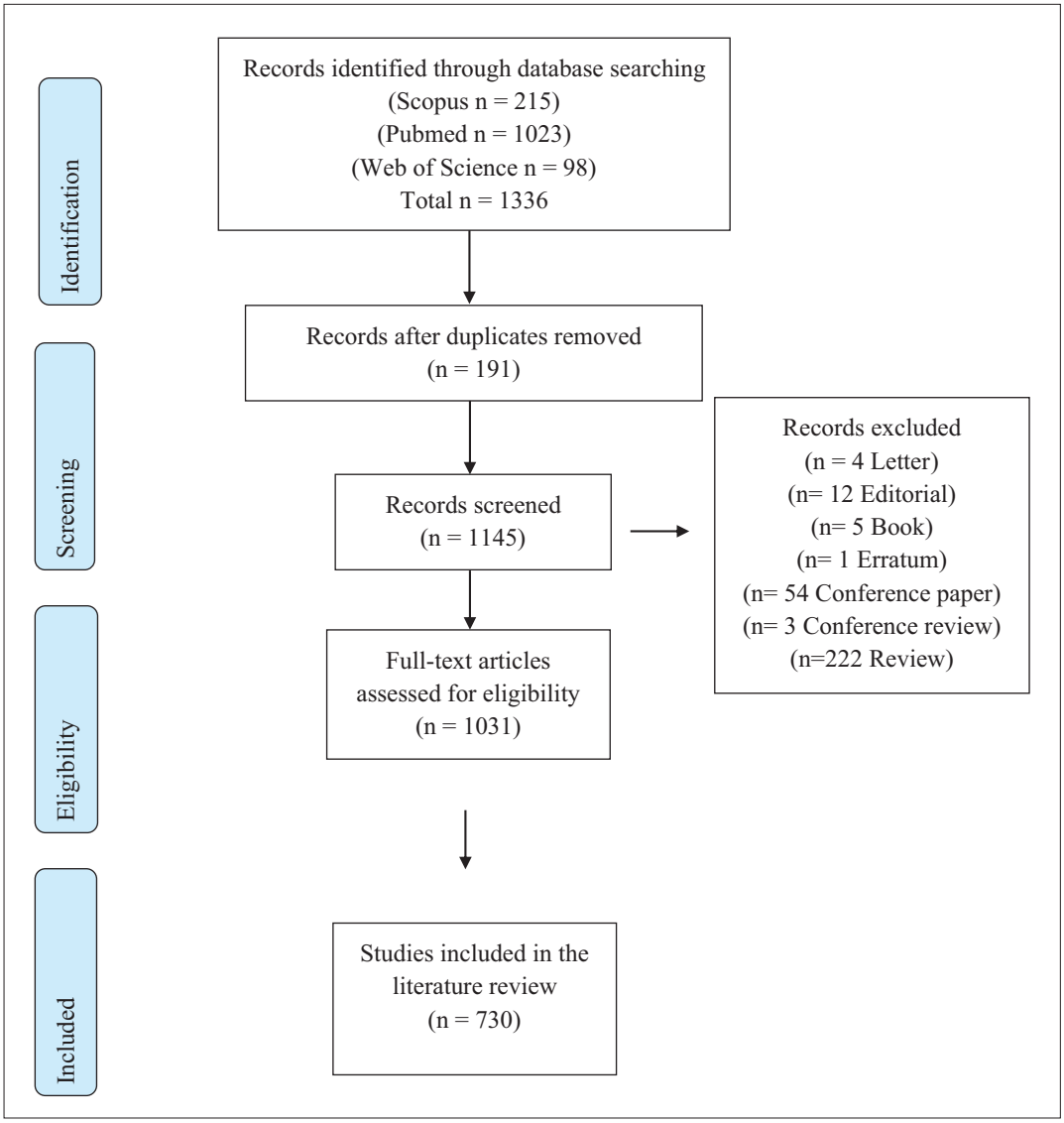

Figure 1: Flow diagram

A narrative review was developed through the Scopus, PubMed, and Web of Science databases [Figure 1]. All manuscripts published from 1988 to 2021 were included. Therefore, the following research question was posed: What are the applications and perspectives of AI, ML and "Dentronics" in dentistry?

The data were obtained following the PICO question:

P: Patients with dental needs.

I: Dental care with artificial intelligence

C: None

O: Type of uses and applications

Selection criteria

Inclusion criteria

Studies published in any language

Original studies

Studies published between 1980 and 2021

Exclusion criteria

Non-dental studies

Animal studies

Studies not indexed in Scopus, Web of Science, and PubMed

Systematic reviews, meta-analyses, and/or literature reviews

Search strategy

The following search formula was used For Scopus: TITLE-ABS-KEY("Intelligence Artificial" OR "Computational Intelligence" OR "Intelligence Computational" OR "Machine *Intelligence" OR "Intelligence Machine" OR "Computer Reasoning" OR "Reasoning Computer" OR "Artificial Intelligence" OR "Computer Vision System*" OR "System* Computer Vision*" OR "Knowledge Acquisition Computer" OR "Acquisition Knowledge Computer" OR "Knowledge Representation* Computer") AND TITLE-ABS-KEY ("Dental medicine" OR "Dental specialties" OR "Dental specialty" OR "Dental system" OR "Occupational dentistry" OR "Dentistry").

For PubMed: ("Intelligence Artificial"[All Fields] OR "Computational Intelligence"[All Fields] OR "Intelligence Computational"[All Fields] OR "Machine Intelligence"[All Fields] OR "Intelligence Machine"[All Fields] OR "Computer Reasoning"[All Fields] OR "Reasoning Computer"[All Fields] OR "Artificial Intelligence"[All Fields] OR "computer vision system*"[All Fields] OR "system computer vision*"[All Fields] OR ("Artificial Intelligence"[MeSH Terms] OR ("artificial"[All Fields] AND "intelligence"[All Fields]) OR "Artificial Intelligence"[All Fields] OR ("knowledge"[All Fields] AND "acquisition"[All Fields] AND "computer"[All Fields])) OR ("Artificial Intelligence"[MeSH Terms] OR ("artificial"[All Fields] AND "intelligence"[All Fields]) OR "Artificial Intelligence"[All Fields] OR ("acquisition"[All Fields] AND "knowledge"[All Fields] AND "computer"[All Fields])) OR (("knowledge"[MeSH Terms] OR "knowledge"[All Fields] OR "knowledges"[All Fields] OR "knowledgeability"[All Fields] OR "knowledgeable"[All Fields] OR "knowledgeably"[All Fields] OR "knowledges"[All Fields]) AND "representation*"[All Fields] AND ("computability"[All Fields] OR "computable"[All Fields] OR "computating"[All Fields] OR "computation"[All Fields] OR "computational"[All Fields] OR "computations"[All Fields] OR "compute"[All Fields] OR "computed"[All Fields] OR "computer s"[All Fields] OR "computers"[MeSH Terms] OR "computers"[All Fields] OR "computer"[All Fields] OR "computes"[All Fields] OR "computing"[All Fields] OR "computional"[All Fields]))) AND ("Dental medicine"[All Fields] OR "Dental specialties"[All Fields] OR "Dental specialty"[All Fields] OR "Dental system"[All Fields] OR "Occupational dentistry"[All Fields] OR "Dentistry"[All Fields]).

For Web of Science: TS=("Intelligence Artificial" OR "Computational Intelligence" OR "Intelligence Computational" OR "Machine Intelligence" OR "Intelligence Machine" OR "Computer Reasoning" OR "Reasoning Computer" OR "Artificial Intelligence" OR "Computer Vision System*" OR "System* Computer Vision*" OR "Knowledge Acquisition Computer" OR "Acquisition Knowledge Computer" OR "Knowledge Representation* Computer") AND TS=("Dental medicine" OR "Dental specialties" OR "Dental specialty" OR "Dental system" OR "Occupational dentistry" OR "Dentistry").

Results

Specifically in dentistry, AI can cover a wide variety of applications in the future, such as (a) improving the organization of information from dental medical records, through a database that is updated in real time. In that way, it would be possible to have access to data on the patient's diagnosis, treatment and evolution. (b) Diagnose certain oral diseases such as dental caries by means of intraoral cameras such as the "DIAGNOdent™ pen". In this example, the diagnosis is accurate because it uses laser fluorescence technology.

(c) Apply the Big data concept in dentistry, as it will facilitate scientific research, because having correlated the complete patient's data will allow the construction of algorithms that quickly facilitate the construction of a diagnosis. (d) Finally, the manufacture of dental prostheses by ML applied to CAD/CAM systems.[5-9]

Artificial intelligence

AI is defined as the machines' capacity to mimic the cognitive activity of humans. It achieves tasks such as learning and problem-solving based on computer algorithms. According to the Barcelona Declaration for the use of AI in Europe, virtual AI methodologies are divided into knowledge-based AI and data-driven AI.[10-12] Knowledge-based AI aims to mimic human knowledge and is developed from self-reported concepts. However, knowledge acquisition and formalization are two main barriers, consuming development time and requiring significant initial endeavor. In contrast, data-driven AI, referred to as ML, depends on the input signal or feedback given to the learning system.[10-15]

On the contrary, as a historical background, Minsky and Dean Edmunds developed the first neural network calculator in 1951. Allen Newell and Herbert Simon first developed AI programs. These systems are useful in various areas of medical sciences, such as disease diagnosis and biomedical identification.[8] Different clinical support systems have been actively improved in the dental field.[15-20]

Machine learning

The last few decades had a rapid growth in data recording due to the capacity of computer systems. This information explosion has become important to develop new mechanics for critical analysis and interpretation of data sets and to achieve effective predictions.[9,10]

Most ML futures in the dental field suggest to be connected to diagnostic capacities. Furthermore, ML algorithms have enabled optimizing and improving the use of Orthodontics available data, with important contributions to the maxillofacial dental anomalies diagnosis by using training datasets containing radiographic images[19-23] [Table 1]. For example, in periodontics, good ML algorithms performance have been shown using molecular profile data, immunological parameters, bacterial profile data, and radiographic data. Bone level identification and bacteria in subgingival fluid samples, are also important to obtain evidence in periodontal disease diagnosis. This diagnosis can be difficult for first-time clinicians. The majority of these studies allow to perform disease analysis and diagnosis.[9,22-24] Although existing methods can be very robust, ML in dentistry may not replace the dentist but is a method to develop an informed second diagnosis based on a mathematical prediction.

Table 1: Distribution of artificial intelligence, machine learning, and virtual reality topics by journal and authors

Topic	Authors
Artificial intelligence (AI)[1-3,10-14,25-33]	18
Machine learning (ML)[4-9,15,21]	8
Virtual reality (VR)[15,25,34-37]	6

Virtual reality

Computer-assisted technology application has gradually increased to help dentists in oral diseases diagnosis and treatment. Augmented reality (AR) is an interactive experience in which a virtual 3D object is integrated into a real 3D environment. The first system known as AR was developed by Sutherland.[19] Many applications including laparoscopy, plastic surgery, and neurosurgery have been attributed to AR. On the contrary, virtual reality (VR) has two important parts: Immersion, that is, the feeling of being in the virtual environment and interaction, which means the user's competence to modify himself/herself.[24,25,38-40]

In the dental field, there are several software such as Trios, Cerec, Shining, Moons, and Omnicam, which use ML, AI, and VR applications. This technology is applied through intraoral cameras, scanners, CAD/CAM, on which the concepts of VR, AI, and ML are used [Table 2].

Dentronics

Dentronics is the hyperonym for medical specialized robot systems and AI. This technology will increase our knowledge of disease pathogenesis and improve strategies leading to better treatment outcomes. On the contrary, this can lead to other problems during medical examinations, diagnosis, or treatment. Moreover, robotic assistants are capable of indefinitely repeating their workflows. Hence, human resources could focus on other tasks, such as interaction with patients or other tasks with higher cognitive demands.[11]

There are several modes of human–robot interaction. Physical human–robot interaction will play an important role in Dentronics appliances. All this should be followed by safety requires collaborative and responsive robots, as well as appropriate behavior only possible by the application of appropriate controllers.[1,25,26]

For example, there are various studies[19-22,27,31-33,37] that evaluated different applications of ML, AI, and VR in dentistry. According to Xie *et al.*,[19] the artificial neural network constructed in their study had 80% accuracy in determining extraction or non-extraction procedures. Although Leonardi *et al.*[18] mentioned that

Table 2: Machine learning, artificial intelligence, and virtual reality application features

	Trios	Cerec	Shining	Moons	Omnicam
Machine learning (ML)[4-9,15,21]	Trios 3D is an intra-oral scanner by which the dentist can take a digital impression of the patient's mouth.	CEREC (CEramic REConstruction) CAD/CAM dental method developed by W. Mörmann and M. Brandestini at Zurich University for dental restorations manufacturing.	3D scanners are found in many sectors mainly in dentistry, by means of the scanner dental specialists can create entirely customized	It performs an intraoral scan, which emits a representation of the patient's dentition in a three-dimensional format.	The software is designed for digital printing and data export through the Connet Case center, which is
	The system provides a digital impression of the patient's mouth and offers functionalities such as tooth shade measurements and HD photographs.		prosthetic appliances for patients, either by scanning from the patient's mouth or from plaster models.	This scan allows to see a replication of the oral anatomy with micrometric precision.	included by default with the delivery of Omnicam.
Artificial intelligence (AI)[1-3,10-14,25-33]	3Shape's open system includes 3Shape TRIOS Studio applications with seamless integration, reliable connections to leading third-party milling machines, and compatibility	Artificial intelligence can now define the outcomes of diseased dental implants.	Emerging AI technologies may continue to influence everyday life.	About design, it is important to emphasize that a specific aligner has to be created for each tooth movement, since, from an orthodontic point of view,	The key is data-driven algorithms. AI works with algorithms that teach the machine and instruct it.
	integration, reliable connections to leading third-party milling machines and compatibility with all 3D printers.	The term science fiction is literally one hundred years old; however, its concept is nearly four hundred.	AI evolution makes possible big data analysis, with reliable information and improving decision-making.	professionals must know which tooth has to be moved first so that the smile is aligned.	And, once it has learned, it can even make variations, deductions and think about whether there might be an alternative solution that is related.
	with all 3D printers.	Published in 1638 Man on the Moon is a novel by Bishop Francis Godwin of the Church of England.			
Virtual reality (RV)[15,25,34-37]	Inexpensive virtual reality solutions, such as Google Cardboard, could be a "safe, portable, and cost-effective way to alter perception and improve pain tolerance."	The virtual events platform allows us to develop VR and 3D events. The element that characterizes these platforms are the customizable avatars.	One of SHINING 3D's main missions is to create highly efficient and affordable digital manufacturing solutions.	Machines can learn to sense: listen (Alexia, Siri) or see (facial recognition); machines can understand based on data and predict situations; and machines capable of acting on their own (self-driving cars, surgical robotic system.	Intraoral scanners have AI systems to allow patient's mouth scan.
		Within a virtual environment of graphics and sound, the avatars can go all over the event space such as fairs, networking, interacting with other avatars; greeting, starting conversations, exchanging business cards, attending conferences, etc.			

Table 3: Characteristics of the studies

Author	Country	Sample	Methods	Findings
Xie *et al.*[19]	China	20 patients	Subjects were selected for orthodontic treatment with extraction and non-extraction treatment.	Effective artificial neural network for extraction or non-extraction decision-making, with 80% accuracy.
Leonardi *et al.*[18]	Italia	40 lateral cephalometric radiographs	Lateral cephalometric radiographs.	More accurate algorithms may be designed to validate this feature for clinical or research purposes.
Moghimi *et al.*[20]	Iran	106 patients	Dental cast analysis. A hybrid GA-ANN algorithm was tested.	Mandibular first molars and incisors were selected by the proposed algorithm. Mesiodistal measurements (canines and premolars) were predicted using maxillary central incisors as reference.
Jung *et al.*[21]	Korea	156 patients	A backpropagation algorithm was used to construct four neural network machine learning models for the diagnosis of extractions.	AI systems and neural networks could be useful in orthodontics.
Pauwels *et al.*[27]	Brazil		A questionnaire that included statements about the future role of IA in oral radiology and dentistry was completed by the participants in two different moments.	A generally positive attitude toward IA was reported.
KılıK *et al.*[32]	Turkey	421 images	The algorithm was trained and tested with panoramic images.	AI models based on deep learning are valuable in forensic identification.
Shimpi *et al.*[22]	USA	11,048 subjects were randomly selected.	Five algorithms performance were compared using retrospective clinical data: Naïve Bayes (NB), Logistic Regression (LR), Support Vector Machine (SVM), Artificial Neural Network (ANN) and Decision Tree (DT).	A high sensitivity and specificity was found for the predictive model. Individuals stratification was developed (low and high-risk levels) as a clinical decision support tool.
Solovyh *et al.*[19]	Russia	The DICOM-formatted images (n=200)	Model based on two convolutional neural networks. Anatomical structures identification based on cone beam tomography images.	Medical reports were generated by the model showing reasonable efficiency.
Başaran *et al.*[33]	Turkey	1804 dental panoramic radiographs	The CranioCatch AI model based on a deep CNN method was evaluated (Turkey).	Promising results were found using the proposed AI model.
Kasimoglu *et al.*[37]	Turkey	200 children	Robotic distraction techniques were evaluated using the parent's Corah Dental Anxiety Scale, Facial Image Scale (FIS), physiological pulse rate and Frankl's Behavior Rating Scale.	Dental anxiety and stress were solved using robotic technology to help children behave better in the dental office.

the accuracy level for cephalometric point analysis was not improved using these applications. There is a need for the investigation of more accurate algorithms, the implementation of new features will improve studies with different clinical or research purposes [Table 3].

Discussion

This narrative review provides a detailed overview on the current use of AI and the ethical challenges in dentistry. The present review described its increasing use in dentistry for various clinical applications.[1]

AI in health care is receiving increasing attention because AI-based applications are more efficient, affordable and, therefore, accessible. However, the study quality of "AI for health" is low, and reports are most of the time insufficient to fully understand and replicate the study's design.[26]

Currently, there is a plethora of computer software for predicting dental caries, most of which are based on standardized multifactorial questionnaires.[15] Although Xie *et al.*[19] were visually able to quantify the consequences of the effect of malocclusion during

facial perception. Also, an artificial neural network reported 80% accuracy in determining the usefulness of no extraction or extraction treatments on patients aged 11–15 years old. On the contrary, Leonardi *et al.*[18] mentioned that the design of algorithms was accurate for nonclinical purposes. Several specialties have reported promising results in this area. Moghimi *et al.*[20] mentioned a technique to predict unerupted canines and premolars sizes by linear regression. Jung *et al.*[21] expressed that AI systems using neural network ML are vital in orthodontics because the reviewed studies presented sample sizes among various patients revealing an average that puts into observation some of the assertions that can be recommended.

Moreover, in the oral radiology field AI is expected to save considerable time for the practitioner improving the diagnostic process. The time needed by the oral radiologists to check the AI's performance is somewhat unclear. Furthermore, the AI can point out hotspots in images that warrant further attention, which could not only help the primary clinical indication but may increase the number of incidental findings. Although it can be expected that this evolution of the radiologist's role will happen organically to some extent, a more proactive approach toward the future of the radiological profession would facilitate and speed up this process. The clinical applications of AI are endless, with ongoing active research. These systems have a promising and bright future in the dental field.

The application of AI on oral health in preventive dentistry is mainly applied during the detection of dental caries because diagnostic strategies should be performed with the help of AI. This can help dentists in image evaluation, for example, in caries detection generating a high health and economic impact on dental diagnosis. It is also important to recognize how technology enables the development of new products and biomaterials.[1-3,41,42]

Conclusions

The use of AI and ML has recently been extended to different medical specialties including dentistry. These tools have shown promising futures toward the use of these resources in dental clinical practice. Although rapid advances can be overwhelming for some sectors. It is important to stand out from these obstacles arising from data acquisition, interpretation with an ever-increasing ability to handle big data.

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Conflicts of interest

There are no conflicts of interest.

Author contribution

FMT and AMD: conception. ADM, SL, and FMT: design of the manuscript, review for relevant intellectual content, writing-review and editing, and final approval of the version to be published. FMT, AMD, SL, FC, JBO, and MEG: writing original draft.

Ethical policy and institutional review board statement

Not applicable.

Patient declaration of consent

Not applicable.

Data availability statement

Not applicable.

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