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Amplifying Artificial Intelligence in Dentistry: Contemporary Implementations and Future Expectations

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***Abstract*— Artificial Intelligence has enormous potential to transform the healthcare industry and enhance patient care. AI is being studied in dentistry for several reasons, including detecting normal and abnormal structures, disease diagnosis, picture analysis, and predicting treatment outcomes and decision-making. This paper discusses how AI is amplified in the dental field, its existing uses, and its potential for the future.**

The models of AI, such as convolutional neural networks (CNN) and artificial neural networks(ANN), have shown a variety of applications in operative dentistry, periodontics, orthodontics, oral and maxillofacial pathology, prosthodontics, Radiology and endodontics including studying the anatomy of the root canal system, forecasting the viability of stem cells of the dental pulp, measuring working lengths, pinpointing root fractures and periapical lesions and forecasting the success of retreatment procedures. Future applications of this technology were considered for scheduling, patient care, drug-drug interactions, prognostic diagnosis, and robotic endodontic surgery.

***Index Terms*— artificial intelligence, convolutional neural networks (CNN), AI, artificial neural network(ANN), applications of AI, artificial intelligence in dentistry.**

I. INTRODUCTION

The scientific community is still struggling to create a model that closely resembles the human brain. The development of "Artificial Intelligence" is the product of years of persistent labour and diligence on the part of researchers. The idea of creating machines that can carry out jobs that are typically performed by people is referenced by this word, which was first used in 1950. It is sometimes referred to as artificial intelligence.

AI advancements provide a peek of potential benefits for healthcare, including fewer surgical complications, better quality of life, better decision-making, and less needless treatments. Artificial intelligence (AI) has the potential to significantly improve diagnosis accuracy and transform healthcare when used in the medical and dental fields. AI is also becoming more and more prevalent in dentistry education and is widely employed in dental laboratories. This overview explains how artificial intelligence (AI) is applied in dentistry, its current uses, and potential future developments.

II. WHAT IS ARTIFICIAL INTELLIGENCE?

The field of computer science known as artificial intelligence focuses on developing computers that can mimic human intellect and problem-solving skills. They accomplish this by ingesting a vast amount of data, processing it, and using lessons learned from the past to expedite and enhance operations going forward.

In the 1950 edition of Mind, Alan Turing wrote the following in his paper "Computing Machinery and Intelligence" [1]: Turing described AI as “machines thinking”.

“I believe that at the end of the century (20th), the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted.”

A. Evolution of AI

Alan Turing addressed the central query, "Can machines think?" in his seminal work "Computing Machinery and Intelligence" (Turing 1950) [5]. Turing developed an imitation game that became known as the Turing test. The idea behind the test was that if a machine could have a conversation with a human that could not be distinguished from a human conversation, then it would be acceptable to conclude that the machine was intelligent. The initial experiment aimed at assessing computer intelligence was the Turing test. AI received its name and mission at the Dartmouth conference in 1956, marking the start of the first "AI period." McCarthy was the one who first used the term "artificial intelligence," which later became the name of the science.

According to Russell and Norvig (2016), the main claim made at the conference was, "Every aspect of any other feature of learning or intelligence should be accurately described so that the machine can simulate it." Attendees at the conference included Ray Solomonoff, Oliver Selfridge, Trenchard More, Arthur Samuel, Herbert A. Simon, and Allen Newell, all of whom went on to become influential people in the field of artificial intelligence. People were ecstatic because computers were now appearing clever and solving issues like humans for the first time. The original optimism within the larger AI research community was to make audacious promises and gain notoriety. Examples of issues that AI resolved included proving geometric theorems, translating languages, and solving algebraic application difficulties. Several significant advances in AI during that time are listed below:

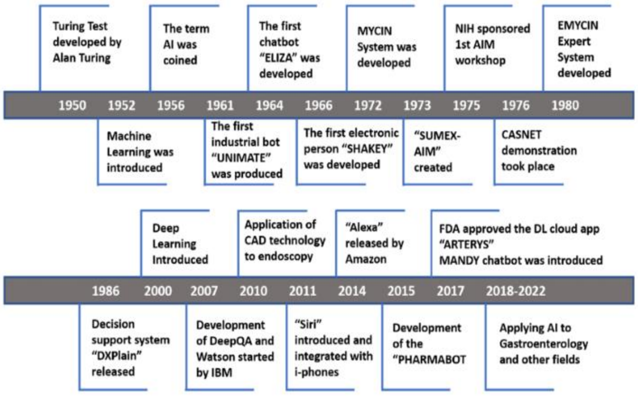

Figure 1. A Year-wise Evolution of AI in Healthcare(1950-Present)

B. Classifications of AI

Diverse types of AI may accomplish diverse jobs, and scholars have developed various methods for classifying AI. There are numerous ways to achieve AI.

The phrase artificial intelligence (AI) refers to all intelligence that is not human. Figure 2 illustrates how AI is further divided into weak and strong categories. A program designed to handle a single or particular task is used by weak AI, also known as narrow AI. Most AI in use today is weak AI. Personalized content recommendations on social media [6] and market customer analysis are two examples of data mining. Examples of computer vision include Face Recognition and Tesla Autopilot. Examples of reinforcement learning include AlphaGo and automated manipulation robots. Examples of natural language processing include Google Translate and Amazon chatbot. Strong artificial intelligence (AI) is defined as having human-level ability and intelligence, including human-like awareness and adaptability in behavior[7]. Strong AI seeks to develop a multitasking algorithm that can make choices across various domains. Strong AI research requires extreme caution since it may raise moral questions and be hazardous. Consequently, there aren't any Strong AI applications yet.

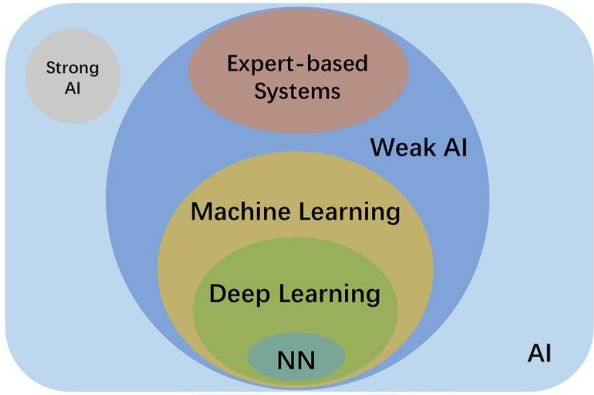

Figure 2. Classification of AI

Expert systems and machine learning are two distinct subsets of weak AI as depicted in Figure 2. Based on the theory behind the techniques, ML can be further divided into supervised, semi-supervised, and unsupervised learning. Labeled datasets are used in supervised learning as the "supervisor" of the algorithm during training. To forecast the unlabelled input, the algorithm learns from the labelled input and extracts, identifies, and uses its common features. [8]. Machine learning [9] and, more recently, deep learning [10] are the branches of AI that are most frequently used in medicine today.

Machine learning (ML): In the field of artificial intelligence (AI), machine learning (ML) teaches computers how to think like humans without the need for preprogrammed rules or past knowledge. Rather, the algorithms work independently of humans to find patterns in samples drawn from a huge dataset. To do this, set a target and maximise the system's adjustable functions to achieve it. An ML algorithm learns during this procedure, called training, by being exposed to random examples and gradually adjusting the "tunables" in order to get the right answer. Consequently, the programme finds patterns that it may use to analyze fresh photos. This method is similar to an adult showing a toddler multiple cat pictures. In time, the child picks up the patterns necessary to distinguish between a familiar cat and one in a new environment.

Deep learning (DL) In the subfield of machine learning known as "deep learning," systems are trained to learn a single pattern and a hierarchy of interconnected patterns. Stacking and combining patterns produces a "deep" system, making it significantly more potent than a "shallow" or simple one. When a toddler sees a cat, for example, they do not recognize it in one single, indivisible step of pattern-matching; instead, they notice the object's edges and a specific grouping of these edges produces a textured outline with simple shapes, like eyes and ears. Larger groupings like heads and legs emerge among these parts, and a specific combination forms the entire cat.

Neural Network (NN): One of the most often used classes of deep learning algorithms is the artificial neural network (ANN), which is made up of several layers of tiny neurons

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that communicate with one another. The input, output, and hidden layers that lie between are the building blocks of a neural network.[11] As seen in Figures 3a and b, a shallow neural network (NN) or a deep neural network (DNN) can include one or more hidden layers. The fact that the values of these layers are not predetermined or externally visible is why they are called hidden. To compute the right value of the visible output layer, they seek to enable the hierarchical building of information retrieved from the visible input layer. The architecture of a given neural network is determined by the arrangement of connections between its neurons; the neural network's weights are the finely adjusted strengths of those connections.

Convolutional neural network (CNN) is one of the most often used subclasses of artificial neural network (ANN) in the medical and dental fields (**Figure 3c**). Digital signals including sound, picture, and video are processed by a CNN using a unique neuron connection architecture and the mathematical function convolution. CNNs scan a narrow area of inputs at a time, from top to bottom and left to right, using a sliding window in order to analyse a larger image or signal. They are the most used image recognition algorithm because they are incredibly well-suited to the task of image recognitions [11].

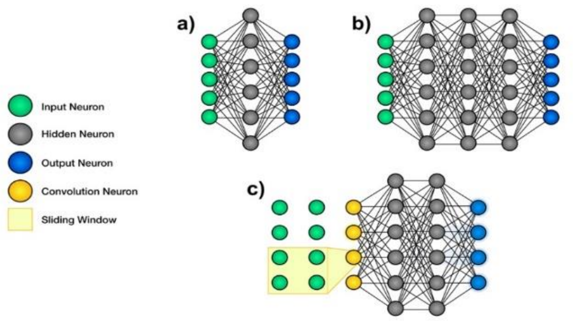

Figure 3.

Schematic representation of the architecture of neural networks. Artificial neural networks are structures used in machine learning. They contain many small communicating units called neurons, which are organized in layers. **a.** Shallow neural networks are composed of an input layer, a few hidden layers and an output layer. **b.** Deep neural networks have an input layer, multiple hidden layers and an output layer. **c.** Convolutional neural networks use filters to scan a small neighborhood of inputs.

III. HOW DO ARTIFICIAL INTELLIGENCE MODELS WORK?

AI operates in two phases: "training" in the first phase and "testing" in the second. The parameters of the model set are determined by the training data. Retrospectively, the model makes use of data from prior examples, such as patient data or data from data sets containing various examples. These parameters are then applied to the test sets [12].

Artificial intelligence models were considered “black boxes” because earlier, they provided output without any explanation of why and how they arrived at it (as shown in Figure 4 [a]). On the contrary, today’s AI takes an input (for example, any image as shown in Figure 4 [b]), generates a “heatmap” and provides a prediction (for example, “cat” as shown in Figure 4[b]). This generated heatmap visualizes which input variables (for example, “pixels” as shown in Figure 4) decided the prediction. This makes it possible to discriminate between safe and relevant prediction techniques, such as categorizing cat photos by focusing on the cat's ears and nose [13].

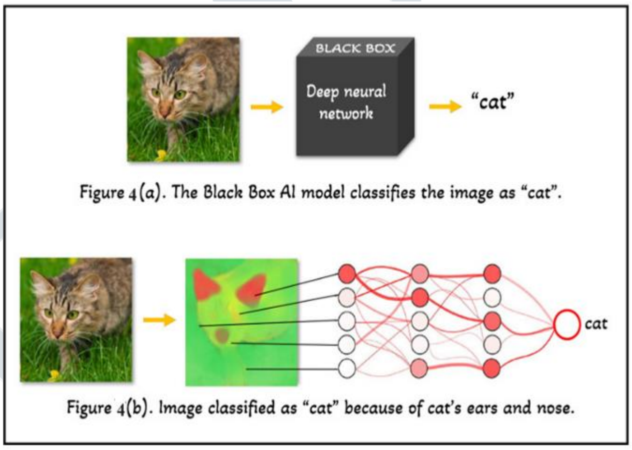

Figure 4(a). The Black Box AI model classifies the image as “cat”.

Figure 4(b). Image classified as “cat” because of cat’s ears and nose.

Figure 4. Schematic representation of working of Artificial Intelligence models.
(a) Black box AI model. (b) Recent AI models generate heatmaps.

IV. CONTEMPORARY IMPLEMENTATIONS OF AI IN DENTAL CARE

Dentistry has begun to use AI more and more in recent years, much like other sectors. Applications of AI in dentistry can be categorized into four areas: diagnostic, treatment planning, decision-making, and treatment result prediction. In the field of dentistry, diagnosis is the most widely used AI application. The effort for dentists can be reduced by AI's ability to diagnose conditions more quickly and accurately. Dentists are using computers more and more to make decisions, on the one hand [14, 15]. However, dental software is becoming increasingly sophisticated, accurate, and dependable through computer programming. Artificial Intelligence (AI) research has expanded to all dental specialties.

It is still challenging to compare dental AI journal articles with respect to study design, data allocation (training, test, and validation sets), and model performance, despite the fact that a significant number of these publications have been published.

The following section discusses how AI has advanced in several fields of dentistry.

A. AI in operative dentistry

Dentists typically diagnose cavities using a thorough set of criteria, either by a visual and tactile examination or a radiological examination. When deep fissures, strong interproximal contacts, and secondary lesions are present, it can be difficult to detect lesions in the early stages. When dental caries progresses, it becomes more difficult to treat the lesions, necessitating the use of dental crowns, root canal therapy, or even implants. The diagnosis of dental caries is primarily based on the experience of dentists, even though dental radiography (whether panoramic, periapical, or bitewing views) and explorers (also known as dental probes) have been used extensively and are considered very trustworthy diagnostic techniques.

Research on the identification of dental caries, vertical root fractures, apical lesions, pulp space volumetric assessment, and assessment of tooth wear has been conducted in the field of operative dentistry (16–21).

Each grayscale pixel in a two-dimensional (2D) radiograph has an intensity, or brightness, that indicates the object's density. An AI algorithm can recognize patterns in the aforementioned traits and make predictions to segment teeth, identify cavities, and other tasks. To identify dental caries on periapical radiographs, for instance, Lee et al. [22] created a CNN algorithm. A CNN method was devised by Kühnisch et al. [23] to identify dental caries on intraoral pictures. When Schwendicke et al. [24] compared the cost-effectiveness of AI with dentists diagnosis for proximal caries detection, the findings indicated that AI was more economical and effective.

B. AI in periodontics

- One of the most prevalent illnesses is periodontitis. If left untreated, it can cause tooth movement and possibly tooth loss, which is a problem for billions of people. Early diagnosis and therapy are essential to preventing severe periodontitis. Gingival recession and pocket probing depths are the primary factors used in clinical practice to diagnose periodontal disease. To measure clinical attachment loss, the Periodontal Screening Index (PSI) is widely utilized. The screening process for periodontal disease is still dependent on dentists' experience, which means that they may overlook localized periodontal tissue loss, contributing to the low reproducibility of this clinical examination [25].
- AI has been used in the field of periodontics to identify potential periodontal disease types and diagnose periodontitis [26, 27].
- Furthermore, in order to identify periodontal bone loss (PBL) in panoramic radiographs, Krois et al. [25] used CNN. The accuracy and potential utility of a suggested CNN algorithm to automatically identify teeth with periodontal deterioration were assessed by Lee et al. [28].
- Yauney et al. [29] asserted that a CNN algorithm created by their study team employing data pertaining to systemic health could assess periodontal diseases.

C. AI in orthodontics

Treatment planning for orthodontics is typically determined by the orthodontists' experience and preferences. The course of treatment is decided upon jointly by the orthodontist and the patient because each is unique. In the past, orthodontists have had a difficult time diagnosing malocclusion because a cephalometric examination requires a number of considerations that make it challenging to decide on a course of treatment and forecast its outcome. When it comes to orthodontic issues, AI is a perfect tool. Artificial Intelligence (AI) is being used in orthodontics to help with treatment planning and result prediction. One such use is the simulation of facial picture alterations before and after treatment. Artificial intelligence (AI) algorithms considerably facilitate communication between patients and dentists by making it possible to clearly perceive the influence of orthodontic therapy, skeletal patterns, and anatomic landmarks in lateral cephalograms.

- Xie et al. (30) proposed an ANN model to evaluate whether extractions are needed from lateral cephalometric radiographs;
- A similar evaluation system was proposed by Jung et al. (31). Apart from the application in predicting the
- extractions needed for orthodontic purposes, AI has been adopted to locate cephalometric landmarks.
- Park et al. [32] demonstrated a DL algorithm for automatically identifying cephalometric landmarks on radiographs with a high accuracy.
- Bulatova (33) et al. and Kunz et al. (34) developed similar AI algorithms, with accuracy comparable with human examiners' identification of those landmarks.
- An automatic system for skeletal classification using lateral cephalometric radiographs was proposed by Yu et al. (35).
- Besides locating multiple cephalometric landmarks and classification, AI systems have been used in orthodontic treatment planning.
- Choi et al. (36) proposed an AI model to judge whether surgery is needed using lateral cephalometric radiographs.
- A basic task for orthodontic treatment planning is to segment and classify the teeth. AI has also been used for these purposes on multiple sources, such as radiographs and full-arch 3D digital optical scans (37, 38).
- Cui et al. proposed several AI algorithms to automatically segment teeth on a digital teeth model scanned by a 3D intraoral scanner (37) and CBCT images (38). In addition to tooth segmentation, they also segmented alveolar bone, the efficiency exceeded the radiologists' work (i.e., 500 times faster).

D. AI in oral and maxillofacial pathology

Diagnostic and pathological disorders related to the oral and maxillofacial region are the focus of the specialty known as Oral and Maxillofacial Pathology (OMFP). Oral cancer is the most serious kind of OMFP. Over 657,000 persons worldwide receive an oral cancer diagnosis each year, and more than 330,000 of those patients pass away [39]. These statistics are provided by the World Health Organization (WHO).

- In OMFP, AI has been researched mostly for tumor and cancer detection based on radiographic, microscopic, and ultrasonographic images.
- I can also detect abnormal locations from radiographs [40], such as nerves in the oral cavity, interdigitated tongue muscles, and parotid and salivary glands. CNN algorithms were demonstrated to be a suitable tool for automatically detecting cancers [41, 43].
- It is worth mentioning that AI also plays a role in managing cleft lip and palate in risk prediction, diagnosis, pre-surgical orthopedics, speech assessment, and surgery [44].
- Warin et al. (42) used a CNN approach to detect oral potentially malignant disorders (OPMDs) and oral squamous cell carcinoma (OSCC) in intraoral optical images.
- In addition to intraoral optical images, OCT has been used in identify benign and malignant lesions in the oral mucosa.
- James et al. (45) used ANN and SVM models to distinguish malignant and dysplastic oral lesions.
- Heidari et al. (46) used a CNN network, AlexNet, to distinguish normal and abnormal head and neck mucosa.
- Abureville et al. (41) used a CNN algorithm to automatically diagnose oral squamous cell carcinoma (SCC) from confocal laser endomicroscopy images; the study showed that the CNN algorithm used in the study was especially suitable for early diagnosis of SCC.

E. AI in prosthodontics

A dental crown is typically prepared in prosthodontics by a series of steps that include tooth preparation, impression taking, cast trimming, restoration design, fabrication, try-in, and cementation.
AI is mostly used in restoration design in prosthodontics. Digital design work has been made possibl e by CAD/CAM in commercial solutions such as Sirona, CEREC, 3Shape, and others.

Using a tooth library to build crowns has significantly improved process efficiency, but it is still unable to produce a unique design for each patient (47).

- With the development of AI, Hwang et al. (48) and Tian et al. proposed novel approaches based on 2D-GAN models to generate a crown by learning from technicians' designs
- Integrating AI with CAD/CAM or 3D/4D printing can achieve a more desirable workflow with high efficiency. AI has also been used in shade matching (49) and debonding prediction of CAD/CAM restorations.
- Apart from fixed prosthodontics, the design in removable prosthodontics is more challenging as more factors and variables need to be considered. No ML algorithm is available for the purpose of designing removable dentures while several expert (knowledge-based) systems have been introduced. Current ML algorithms are more focused on assisting the design process of removable dentures, e.g., classification of dental arches and facial appearance prediction in edentulous patients.

F. AI in Radiology

Anatomical structure identification and detection using CNNs has proven to be a promising capability. Some have been trained, for instance, to recognize and label teeth from periapical radiographs. In terms of finding and classifying teeth, CNNs have shown a correctness rate of 95.8–99.45%, nearly matching the 99.98% precision rate of clinical experts.

Dental caries has also been diagnosed and detected using CNNs. A deep CNN algorithm identified carious lesions in 3000 posterior tooth periapical radiographs with a sensitivity and accuracy of 74.5–97.1% and 75.5–93.3%, respectively. With sensitivity range from 19% to 94%, this is a significant improvement above the diagnosis made by professionals using radiographs alone.When combined with their speed, deep CNNs can significantly increase the sensitivity of dental caries diagnosis, making them one of the most effective tools in this field.

G. AI in Endodontics

While root canal designs of mandibular molars are generally identical, there are a few uncommon variances that can happen. Cone-beam computed tomography (CBCT) has emerged as the gold standard for minimizing treatment failures associated with morphological disparities and optimizing the clinical outcomes of endodontic therapy. CBCT is not routinely utilized, nevertheless, due to its increased radiation dosage when compared to traditional radiography. AI has been used to solve these difficulties by classifying the provided data using a CNN to detect whether or not the distal root of the first mandibular molar has one or more additional canals. 760 mandibular first molar radiographs obtained using dental CBCT were examined.

After determining whether the atypia was present or not, a deep-learning system was used to categorize the morphology of image patches of the roots taken from corresponding panoramic radiographs. Despite having an accuracy rate of 86.9%, the CNN has a number of drawbacks when it comes to clinical integration. The pictures need to be manually split, which takes a long time. In order for the system to concentrate on the item under study, the acquired images also need to be of a suitable size and should concentrate on a limited region while covering enough space to incorporate relevant information.

V. FUTURE EXPECTATION

despite the fact that artificial intelligence in dentistry is transferring in a promising course, there are nonetheless a number of thrilling things to sit up for. here are numerous feasible paths for AI improvement in the dental enterprise. even though predictive AI's first-rate can be quantified, generative AI fashions offer awesome responses to the same question every time, which makes validation tougher.

• superior picture analysis: artificial intelligence (AI) structures will get even better at identifying complex oral problems, early-stage tumors and minute irregularities. better affected person consequences and in advance intervention could be made viable using this.

• Tele dentistry: Superior AI-powered platforms will enable distant consultations, treatment planning, and follow-ups. This may make dental treatments more accessible, specifically to underprivileged groups.

• Tailor-made care: AI can make it possible to layout individualized remedy regimens depending on a patient's genetic and way of life characteristics. detrimental effects could be avoided and remedy effectiveness may be maximized.

• Robotic-assisted Dentistry: By combining robotics and synthetic intelligence, it could be feasible to create robot dental assistants that could carry out precise duties. this could reduce the physical pressure of dental paintings and enhance the abilities of dental practitioners.

• Big data insights: AI can leverage huge datasets to find new trends and insights in oral fitness. Researchers will take advantage a deeper expertise of disorder mechanisms and remedy responses.

• patient engagement: AI-pushed chatbots and digital assistants can engage with sufferers, provide data and even agenda appointments. This enhances affected person conversation and pleasure.

• Administrative performance: AI can automate administrative duties, including appointment scheduling and billing, reducing the administrative burden on dental practices.

• New advances in era, e.g., rising out of neuroscience might hyperlink human–sensor interfaces with robots or nano-robots, which would possibly offer amazing non-invasive remedies, which in any other case might be a threat for the patient. prospective studies may want to address the areas of neuroscience and nano-technology.

• nevertheless, traditional AI research topics are nevertheless in progress, inclusive of picture processing and pattern reputation. Advances in these areas would suggest a great advance in the fine of pre-diagnostics and assembling, resp. upscaling, of records nice used for photograph processing. Advances in data excellent might bring about a sizable boom in treatment best.

• inside the vicinity of philosophy, trans-humanism is an emerging discipline of study. linked to the software of AI in dentistry, the philosophical questions arising out of questions on the limits and capability threats of AI implemented to the treatment of the human frame could be challenged.

• some of the most thrilling packages of AI are predicted to help dentistry. An essential part of any dental office is the dental chair, which underwent a major transformation from a hydraulic pressure chair with a guide pump and physiologic layout to a digital chair with many sensors connected. The most up-to-date technological development is a voice-activated dental chair that eliminates the need for the physician to touch patients. All operations are accomplished with the usage of voice instructions. Dental chairs will soon have the capacity to tune a patient's weight, essential signs and symptoms, diploma of tension, and the length of the method in addition to providing comfort, alerting the operating physicians to any deviations, and so on. this is a result of the diligent paintings that each one vibrant minds are putting into AI.

VI. CONCLUSION

The dentistry industry is one that develops and uses new technologies quickly. When unbiased training data is used and an algorithm is correctly trained, artificial intelligence (AI) has some of the most promising characteristics, including great accuracy and efficiency. In order to lessen their burden and increase precision and accuracy in diagnosis, decision-making, treatment planning, treatment outcome prediction, and disease prognosis, dental practitioners might recognize AI as an additional tool.

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