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Present and future of artificial intelligence in dentistry

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ABSTRACT

The last decennary has marked as the breakthrough in the advancement of technology with evolution of artificial intelligence, which is rapidly gaining the attention of researchers across the globe. Every field opted artificial intelligence with huge enthusiasm and so the field of dental science is no exception. With huge increases in patient documented information and data this is the need of the hour to use intelligent software to compile and save this data. From the basic step of taking a patient's history to data processing and then to extract the information from the data for diagnosis, artificial intelligence has many applications in dental and medical science. While in no case artificial intelligence can replace the role of a dental surgeon but it is important to be acquainted with the scope to amalgamate this advancement of technology in future for betterment of dental practice.

1. Introduction

Ever since the field of science has originated, researchers and technologists have been busy in solving the complexity of the human brain that is a maze of neurons interconnected with each other and transmitting signals to the whole body.[1] To design a model that will mimic just like the human brain has remained a big puzzle to solve for the scientific community. Constant effort and hard work of researchers from several years results in the evolution of 'Artificial Intelligence'. The term was coined in 1950 and refers to the idea of designing machines that are capable of performing tasks that are normally done by humans. It is at times called as machine intelligence.

In Machine Learning (ML), a subfield of AI, algorithms are applied to perform tasks by learning patterns from data. Machine learning technique involves parameter adjustment with regards to underlying technique such as, number of neurons, layers in a neural network technique; population size, rate of mutation and crossing over rate in genetic algorithms technique etc.[2] ML models like Genetic algorithm, Artificial Neural Network (ANN), Fuzzy logic can learn and inspect the data to execute various functions. Out of these, the most popular model is ANN.

The major components of any ANN are the artificial neuron, which is a mathematical model system that was influenced by the human neuron. By assembling artificial neurons and connecting the layers of these artificial neurons by several mathematical operations, a network is engineered that is capable of solving specific tasks like image classification (e.g., radiographic image showing a decayed tooth, locating canals during RCT)(Fig. 1).

Moving on to a subset of ML which is called Deep Learning (DL), refers to ANN with a complex multilayer system. This system hasa complex arrangement of layers and a greater number of interconnected neurons which makes it capable of visualizing simple features like lines, edges, corners and macroscopic patterns in a hierarchical structure.[3]

In the last seven decades, AI and its applications were regarded both as boon and curse. During this period several times the technology doesn't meet the expectations. But last decade is regarded as the decade of extraordinary achievements in the field of AI. The state of art which is the AI based natural language model became so convincing that the readers did not even distinguish whether it is human written, or system written. The other advancement is the face recognition system. Finally, AI based technologies move from curse to boon, impacting every part of society, healthcare and politics. Dentistry is one amongst them.

1.1. AI methodologies

Artificial Intelligence methodologies have immense capability to detect and diagnose the lesions of oral cavity also, which may usually go unnoticed by the human eye, therefore making their way towards dental practice.[4] The various methodologies of AI which are being applied in dentistry include artificial neural networks (ANN), genetic algorithms (GA), and fuzzy logic.

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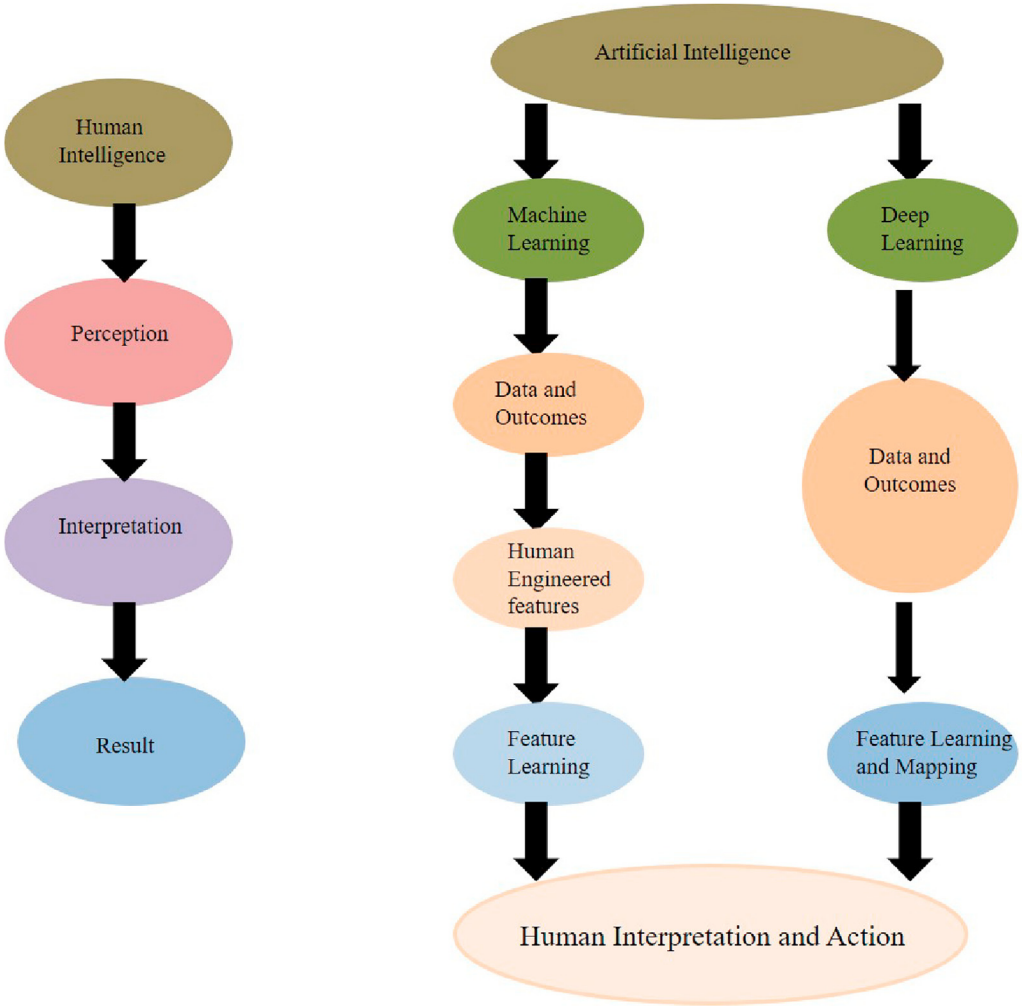

Fig. 1. Human and Artificial Intelligence: Human intelligence is denoted by perception, interpretation and biological result. In comparison, Artificial intelligence which cannot replace Human Mind in any ways, but largely supports human interpretation and action. In Artificial Intelligence there are two categories- Machine learning the features are firstly engineered by human experts and then learned., In deep learning, relevant features are learned and mapped in one step, this makes it more capable of handling complex data sets.

1.2. Artificial neural networks

Artificial Neural Networks were invented keeping the structure of the brain as its basis and it has the ability to imitate human brains.[5] In 1951, Minsky and Dean Edmunds developed the stochastic neural analog reinforcement calculator, which is recognized as the very first neural network in its developmental history.[6] In 1955, Allen Newell and Herbert Simon developed programs of AI for the first time in records.[7]

The greatest advantage of these systems is that they have capability to solve the problems that are too complex to be solved by conventional methods. They are useful in various areas of medicinal science like diagnosis of diseases, biomedical identification, image analysis and data analysis.[8] In dental practice also the clinical support systems are actively progressing.

A study done by *Kim* et al. used Artificial neural network to build a model that can predict toothache on the basis of association between toothache and daily toothbrushing frequency, toothbrushing time, use of dental floss, toothbrush replacement pattern, undergoing scaling and other factors like diet and exercise.[9] This successful study aided development of a toothache predictive model with great accuracy. This model recognizes adequate eating habits, oral hygiene, and stress prevention as the most important factors in preventing toothaches.

Another research used Bayesian network analysis to identify relationships between various factors affecting the diagnosis and final treatment outcome of impacted maxillary canines. In this study all the pretreatment and posttreatment data of the patients was gathered along with patient related variables to identify links between these variables. The study inferred that Artificial intelligence could be used in dentistry to assist dental professionals.[10] Some researchers made a model using the Artificial neural network to predict the necessity of extraction during orthodontic treatment regime.[11]

Data mining analysis done on bulk of restorative data of patients revealed that differences in material of restoration of tooth serve as important factors determining the lifespan of restoration.[12] The strength of data mining lies in its ability in finding causal relationships and comparisons that are innate in existing data.

Study done by *Kakilehtoet al.*observed that the mean and median survival time (MST) of the amalgam restorations for the occlusal surface was 16.8 years within the 1960 cluster, 13.6 years within the 1970 cluster, and 7.9 years with in the 1980 cluster. For glass ionomer and composite resin restoration on the occlusal surface MST was 4.9 years within the 1970 cluster and 7.3 years within the 1980 cluster. The observations were obtained by data mining analysis, the only role of dental professional was to collect and tabulate the data.[11]

All the above studies proved the application of AI in the current dental field to diagnose and make prognosis through extrication of useful information from large amounts of medical records. So, Artificial intelligence is basically concentrated on making strong systems to

facilitate dental professionals to make decisions as well as to help patients understand their diseases and its prognosis.

In conclusion, the actual examination, diagnosis and treatment is done by dentists and AI only plays a role in assisting the dental professional.

1.3. Genetic algorithms

Genetic algorithms have also gained success during the last decade as optimization methods for complex problems. They are stochastic search methods which are based on the principle of survival of the fittest in natural selection. It includes approaches such as mutation, inheritance, selection and crossover to search for a better option of the problem. The greatest advantage of genetic algorithms over conventional methods is that it works on the basis of problem solution instead of analytical relations concept of conventional methods. Despite being a powerful optimization tool, it works on simple rules, which makes it easy to implement.

Łodygowski T and coworkers used genetic algorithms for optimization of dental implant system to reduce the problem of mechanical fracture and to provide long term strength to the implant.[12] Another study done by *Li H* et al.used genetic algorithm along with back propagation neural network to improve the tooth color matching which is one of the greatest challenges in prosthodontic dentistry.[13] A recent study reported the genetic algorithm based approach to detect dental caries in early stages in order to avoid the severity of decay.[14,15]

Also, Genetic algorithm is employed in reconstruction of missing parts of the tooth by optimizing a set of control points in computer aided design. This study showed that there is a good scope of geometric modeling and optimization techniques using genetic algorithms to regulate the reconstructed surface and to maintain the overall smoothness.[14]

1.4. Fuzzy logic

The term Fuzzy means the things which are not clear or vague. In our daily life, we may come across a situation where we are not able to decide whether the statement is true or false. At that time, fuzzy logic provides very valuable reasoning for the fuzzy problem. The term fuzzy logic was coined by Lotfi Zadeh. Fuzzy logic is flexible and uncomplicated to execute machine learning technique. Fuzzy Logic system has four important parts 1) Rule Basse 2) Fuzzification 3) Inference Engine 4) Defuzzification.

The idea behind fuzzy logic is to imitate human reasoning ability that works with not so clear terms. *Mago* et al. designed a fuzzy logic based expert system that accepts imprecise values of dental sign-symptoms associated with mobile teeth to assist dental professionals in decision making.[15]

Oral and dental diseases are common in every age, but patients ignore these problems. The reason being the fear of going to the dentist or the costly treatment. *Ambara and collegues* designed a fuzzy logic based expert system that is time and cost friendly and consultation can be done without using any tools that reduces fear of the patient.[16] *Hererra and coworkers* used a fuzzy logic based system that predicted the color change after tooth bleaching on the basis of tooth's initial chrome values.[17] The fuzzy logic system has a set of rules that corresponds to prebleaching shades of the well-known Vita commercial shade guide.

1.5. Augmented and virtual reality

Nowadays the use of computer aided technologies has gradually increased to assist the dental professionals in treatment and diagnosis of oral diseases. Two such technologies are:

Augmented Reality (AR) is the first application that is used widely. This is an interactive experience with the real world in which a 3D virtual object is consolidated in a 3D real environment. This leads to superimposition of computer generated virtual content over real environment.[18] The term augmented reality was coined by Caudell and Mizell in 1990 and the first system that was recognized as AR was developed by Sutherland in 1968.[19] Augmented reality has many applications in laproscopy as well as plastic and neurosurgery. On the other hand, Virtual reality is the combination of many technologies that allows the operator to interact with virtual objects in real time.[20] It has two important functions: *Immersion* that means the sense of occurrence in virtual environment and *Interaction* that means ability of user for modification.[21]

AR is more commonly used technology applied in various medical and dental science areas. Some of the applications of AR in Dentistry includes 1)The oral and maxillofacial branch of dentistry is one of the complicated areas due to complex anatomy of the craniofacial region. Any surgery in this area requires a perfect planning with high precision which is quite difficult. AR assists dental surgeons by providing clear graphical information of operative sites that is then modified from a data source.[22] 2)The positioning of dental implants that is one of the difficult steps in dental implantology is made easy by graphically obtained results of AR. The AR system used in dental implantology is considered as most effective as it reduces the time and cost of the dental implant.[23] 3) Used in orthognathic surgery by expansion in facial skeleton osteotomy via partial visual immersion employing a head-mounted display.[24] 4) Besides all these applications AR is also used in dental education by combining digital variables with real learning domain. 5) AR also made learning live anatomy easy by visualizing the operator's own body by using augmented mirrored images.[25]

1.6. Clinical decision support system [CDSS]

Due to continuous increments in patient data, clinical decision support systems are becoming important tools for healthcare providers. CDSS are computer programs that are proposed to provide expert support to health professionals making clinical decisions. They use in-built clinical knowledge to analyze the data of patients and assist dental health professionals in taking decisions regarding diagnosis, prognosis, treatment and prevention of disease. Like for example if a patient comes to a dentist complaining of toothache then immediately CDSS classify the patient according to caries risk assessment by filling a short questionnaire that includes sugar intake history, fluoride exposure history, past restoration history, last visit to dentist etc. After this a suggested treatment plan is generated automatically by CDSS.[26] CDSS thus provides valuable information to dental personal, patients or individuals or populations to produce faster, more systemic and superior dental health outcomes.[27]

1.7. The scope of AI in healthcare

Artificial Intelligence in the healthcare sector provides a new transfiguring drive that will bring about advancements for diverse clinical specialties as well as hospital operations. With the fact that modern healthcare facing a lot of challenges in collecting, analyzing and applying structured and unstructured data to diagnose and treat diseases, AI systems with their data mining and recognition abilities provides adequate methods for patient care and an effective treatment at correct time.[28] AI provides several benefits over clinical and conventional analytic decision-making techniques. With the help of AI, algorithms obtained will be more accurate and clearer that will help clinicians to provide unprecedented diagnosis treatment and care to the patients.[29]

Medical Diagnosis involves three major steps: 1. Observation and examination of the patient, collection of patient information, interpretation of the information obtained from the patient on the basis of clinician's knowledge and experience, 2. formulation of a diagnosis 3. Therapeutic plan by the physician. If we assume this diagnostic cycle as an intelligent agent system then clinician is the intelligent agent, the

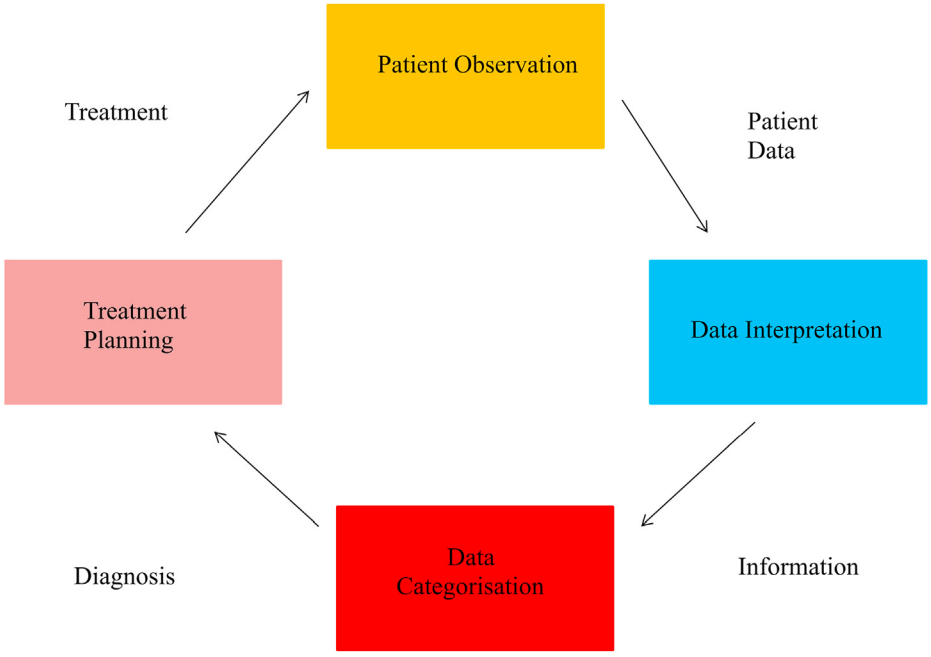

Fig. 2. Medical diagnostic cycle.

patient data is the input and the diagnosis is the output (Fig. 2).

There are various benefits of implementing AI based systems in healthcare:1) AI enable more curated, systematic and structured collection of patient's data.2)AI is specially suitable to overcome the variations in patient's examination and facilitate effective care while lowering costs of the treatment by reducing routine tasks. 3) AI facilitates research and development by introducing *insilico* experimentation options. 4) Reduces tedious task of collecting patient's details before treatment thus increasing more time of face to face discussion between patient and clinician. 5) AI promises to make healthcare more participatory. 6) Diagnostic and treatment costs are reduced.[30]

1.8. Challenges for AI in healthcare

Despite the fact that application of AI in healthcare has a very promising role but challenges both in technical and ethical aspects exist. AI based systems are machine based and controlled and conducted by computer scientists without any medical training which led to a very problem oriented approach of AI application in healthcare delivery.[31] AI also can't replace Contemporary healthcare delivery models whose working completely depends on clinician skills and patient-clinician communication. Use of robotic assistants has also created various issues in healthcare.[32] Dental professionals are reluctant in accepting AI based technologies. Preferable suggestion is a model which accommodates both AI and human elements so that the process of data collection and categorization becomes easy and at the same time preserve the human aspects of clinical care.

2. Implementation of artificial intelligence in dentistry

Artificial intelligence in Dentistry started procuring its role with emergence of data computation and availability of large amounts of patient data. Like for example, in radiology a definite kind of algorithm is generated which further helps in diagnosis and treatment of oral pathology/disease.

2.1. Artificial intelligence and diagnostic dentistry

Proper diagnosis of any disease is the basis for successful treatment. Artificial neural networks work well for this purpose especially in cases where the etiology of disease is multifactorial. Taking one example of Recurrent apthous ulcer, a condition whose precise etiology is not known, and the diagnosis is made on its reoccurrence and by exclusion of other factors. Another one is internal derangement of temporomandibular joints where clinical and radiological diagnosis is considered as gold standard. When in several studies the diagnosis given by a dental surgeon is compared with the one obtained by ANN, results inferred high specificity and sensitivity of ANN. Thus, revealing the importance of AI in diagnosis of even complicated oral diseases and reducing the chances of human errors.[33] Even in radiology when vast amounts of patient data is recorded through digital IOPA (Intra Oral Peri Apical X ray), 3D scans etc., AI is then needed to gather and compute the data for prompt diagnosis and treatment of oral disease. ANN is also the gold standard to identify the patient at risk of development of oral precancers or oral cancers. Hence, AI could be able to satisfy the ever-existing requirement of a method to diagnose oral cancers at their early stage.[34] Genetic Algorithms and ANN are also useful in predicting the sizes of unerupted canines or premolars[35] and can also be standardized for predicting the tooth surface loss.[36]

2.2. Artificial intelligence in patient management

Virtual Dental assistants based on Artificial Intelligence can perform various tasks in dental clinics with less error and more precision. It can be needed to book a patient's appointment in the clinic, taking proper medical and dental history of the patient, managing insurance as well as assisting the dental surgeon in adequate diagnosis and treatment planning. It also works by warning the dental professional about the habitual details of patients like use of tobacco or alcohol and medical history of the patient. In this way a virtual database of every patient is created which then helps the dentist in diagnosis and treatment of disease. It will also be beneficial in patients follow up and online emergency health consultancy.

2.3. Artificial intelligence and orthodontics

The most talked about and recent revolution in orthodontic dentistry is AI driven customized orthodontic treatment. Artificial

Intelligence is now used in various phases of orthodontics starting from diagnosis to treatment planning and follow-up monitoring. 3D scans and virtual models are useful in assessing craniofacial and dental abnormalities.[37] With the help of these 3D scans, aligners can be printed, and treatment can be customized. After these printed aligners a data algorithm is created that intelligently decides how the teeth or tooth of the patients should be moved, how much pressure should be applied and even also recognize the pressure points for that specific tooth/teeth. The AI conjugated aligners not only provide precise treatment but also reduces the chances of error and time for treatment.

2.4. Artificial intelligence and radiology

AI provides the additional capability to learn more to be a dental professional. When integrated with imaging methods like MRI and cone beam computed tomography it can identify even the minute deviations from normal which remains unnoticed by human eye.[29] For example, ANN is used by dental professional teams to localize minor apical foramen thereby magnifying the precision of working length determination by radiographs and in diagnosis of proximal caries.[38,39] ML algorithms can detect an abnormal or normal lymph node in head and neck image provided a trained Radiologist who can interpret by analysing thousands of such images which are labelled as normal or abnormal.[39]

2.5. Artificial intelligence and restorative/prosthetic dentistry

In order to provide perfect prosthesis to the patient, there are several factors which a dentist has to keep in his mind like anthropological calculations, facial measurements, esthetics and patient preferences. The use of computer aided technology for precise fit of prosthesis is yet another breakthrough of Artificial Intelligence in dentistry. Also, CAD/CAM based systemsare used in dentistry to attain finished dental restorations with great precision. Furthermore, AI based systemsare used to design inlays, onlays, crowns and bridges. This system has replaced the conventional method of casting the prosthesis, reduces time and errors.[40,41]

2.6. Head and Neck Cancer

A study on Head and Neck Cancer attempts to use Convolutional Neural Networks for performing segmentation of organs at risk from head and cancer in CT images.[39] Another study was performed which demonstrated that genetic programming (GP) performed the best in oral cancer prognosis when the features selected are tobacco smoking, alcohol drinking, tobacco chewing, histological differentiation of squamous cell carcinoma (SCC), and oncogene p53. [42,43] The Artificial Neural Network may be of great importance for the identification and grading of patients with a high risk of oral cancer or precancer and further to plan a treatment regime.

2.7. Artificial intelligence in periodontics

Wang et al. developed a Digital Convolution Neural Network based system that consists of 16 convolution layers and two fully connected layers for detecting periodontitis of premolars and molars.[44]

ANN can also effectively be used in categorizing patients into aggressive periodontitis and chronic periodontitis based on their immune response profile.[45]

Besides all these applications of AI the most prevalent and easy to understand is our dental chair which a dentist uses all day for his patients. AI has drastically changed the dental chair from conventional hydraulic chair to electrical and fully automatic dental chair operated through sensors. The recent and an additional advancement is voice command operated dental chair which needs no physical efforts from the dentist. That future is not very far when a dental chair can calculate patients weight, vital signs and anxiety as the patient sits on the dental chair for treatment.

2.7.1. Benefits of AI in dentistry

1. Performing tasks in almost no time.
2. Logical and feasible decisions which results in an accurate diagnosis.
3 Procedures can be standardized

2.7.2. Shortcomings of AI use in dentistry

1 Mechanism/system complexity
2 Costly setup
3 Adequate training is required
4. Data is often used for both training and testing, leading to “data snooping bias”.
5. The outcomes of AI in dentistry are not readily applicable.

In conclusion Artificial Intelligence is not a myth but our future in dentistry. Its applications in every area is growing day by day. While in no way it can replace the role of dentist as dental practice is not about diagnosis of disease, but it also includes correlation with various clinical findings and provides treatment to the patient. Nevertheless, a clear understanding of the techniques and concepts of AI surely have an advantage in the coming future. We soon hope to see AI to be completely implied in orthodontics, endodontics and restorative dentistry (reconstructive surgeries). The only limitations to use of AI presently is the availability of insufficient and inaccurate data. Hence, it's the responsibility of dentists and clinicians to focus on collecting and entering the authentic data in their database that will be fully utilized for AI in dentistry in near future.

Declaration of competing interest

The authors declare No conflict of interest.

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