JAZ INDIA

Journal of Advanced Zoology

ISSN: 0253-7214

*Volume **44** Issue **S-3 Year 2023** Page **549:558***

Artificial Intelligence in Maxillofacial Radiology by Leaps and Bounds

D. Bhavishya[1], Mahesh Kumar T.S.[2], Poornima C.[3],

[1,2,3]Department of Oral Medicine and Radiology Rajarajeswari Dental College and Hospital, Bangalore

Email: maheshtalkad.mk@gmail.com[2], drpoornichandra@yahoo.com[3]

**Corresponding author's E-mail: dbhavishya96@gmail.com*

Article History

Received: 06 June 2023
Revised: 05 Sept 2023
Accepted: 06 Oct 2023

Abstract

Artificial intelligence (AI) is a branch of computer science concerned with building smart software or machines capable of performing tasks that typically require human intelligence. AI is capable of mimicking human brain. Recent advances in machine learning have produced algorithms that allow automated and accurate detection, imaging, diagnosis, as well as other specialties of dentistry, which reduces stressful work and manpower. The AI plays a major role in Dental imaging by diagnosing the conditions based on the Radiographic or optical images. AI technology in dentistry could reduce cost, time, human expertise and medical error.AI in everyday life are growing by leaps and bounds. By no means there exists a doubt in the ascendancy of integrating AI into practice.

Keywords: *Artificial Intelligence, Maxillofacial imaging, Machine learning, Data mining*

1. Introduction

Digital transformations", "digitized workflows", "technical developments": these terms describe some of the game changers of the 21st century, both in social life as well as dental medicine.[1] Human brain is a unique structure composed of networks of interlinked neurons which transmit signals throughout the body.[2]

This nonpareil nature of human brain has always made researchers and scientists inquisitive from time immemorial. The act of constant search has given rise to what is known as artificial intelligence (AI), which is a highly evolved system capable of mimicking the human brain function.[2] A plethora of advancements in the field of technology during the last few decades have integrated these technological advancements in our day-to-day life.[3]

Currently, no surgical procedures are fully unmanned and completely machine driven. There is a team of trained doctors running the entire surgical operation, so there is a strong human element in this equation.[4] John McCarthy, a mathematician coined the term artificial intelligence in 1955, and widely recognized as the father of artificial intelligence. He chose this term to explain the potential of machines to perform tasks that can fall in the range of "intelligent" activities.[5]

The exponential growth in science and technology has introduced different applications that are used daily, such as Siri and Alexa.[6] These applications are found on the top of artificial intelligence (AI) and its components. The term AI is mostly associated with robotics. It describes how technology is used to develop a software or a machine that can easily mimic human intelligence and perform specific activities.

In the modern-day world, artificial intelligence refers to any machine or technology that can mimic human cognitive skills like problem solving. To understand AI, it is important to know few of these key aspects.[5]

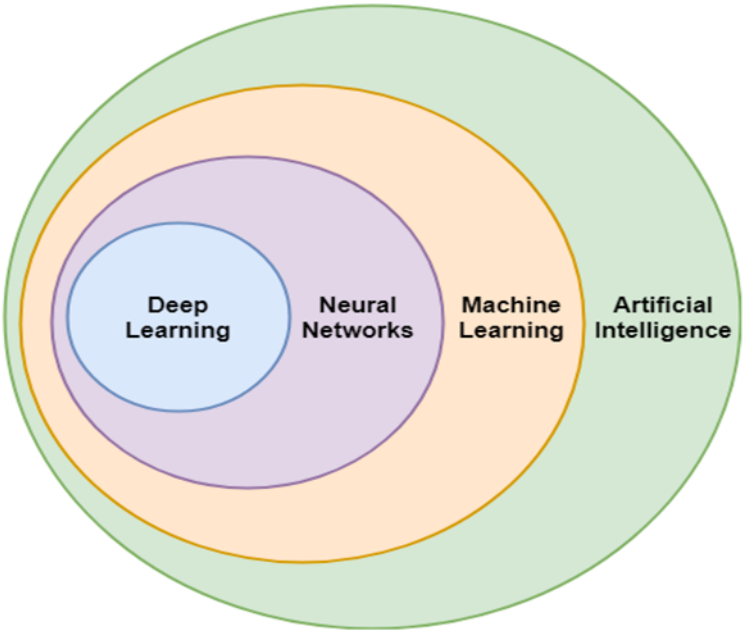

Fig 1: Key Aspects of AI

Artificial intelligence is termed as a capability of machines that exhibits a form of its own intelligence. The aim here was to develop machines that can learn through data so that they can solve the problems.[5]

Machine learning is a part of AI which enhances automated learning ability without being distinctly programmed. Its primary goal is to allow automated learning without human arbitration. Machine learning is part of AI, which depends on algorithms to predict outcomes based on a dataset. The purpose of machine learning is to facilitate machines to learn from data so they can resolve issues without human input.[5]

Neural networks are algorithm sets that compute signals via artificial neurons. The purpose of these is to create neural networks that function like the human brain.[5]

A popular field in machine learning is "deep learning," where multi-layered (deep) neural networks are used to learn hierarchical features in the data.[7] Deep learning is a component of machine learning that utilizes the network with different computational layers in a deep neural network to analyse the input data. The purpose of deep learning is to construct a neural network that automatically identifies patterns to improve feature detection.[5] They collect features from the abstracted layer of filters and are primarily used to process large and complex images.[5]

Review

Artificial intelligence, a major invention that imitates human cognitive capabilities, has captured the attention of scientists all around the world.[8] Human brain is a unique structure composed of networks of interlinked neurons which transmit signals throughout the body.[2] This nonpareil nature of human brain has always made researchers and scientists inquisitive from time immemorial. The act of constant search has given rise to what is known as artificial intelligence (AI), which is a highly evolved system capable of mimicking the human brain function.[2] Artificial Intelligence is a computer based process that aims at reproducing human or animal intelligence and finds applications in a wide range of fields (e.g., machine learning, natural language processing, and robotics).[9] AI, especially in the context of machine learning, is widely used in the field of mobile health and digital medicine. It serves different purposes from disease risk assessment to research on treatment efficacy and can take many forms such as robotic devices, machine learning, or other deep learning systems. The number of studies involving AI has quickly increased in the past 5 years.[10] However, even though recent publications seem promising regarding the performance of AI solutions for dentistry, all these hopes also raised numerous ethical questions.[11] A recent mapping review on AI in health care by Morley et al. (2020) highlighted that there is strong need for more ethical AI in health care; otherwise, it could ensue a loss of public trust and

unwanted results.[12] Dentistry is also affected by this risk: AI studies in dentistry are often bearing important methodological and reporting limitations that directly affect their transparency and replicability[13].

Concepts of artificial intelligence

There are two sub concepts that divide the entire range of meanings currently encompassed by the term "AI". Coexistence of the concepts of strong and weak AI can be seen as a result of the recognition of the limits of mathematical and engineering concepts that dominated definitions of AI in the first place.[14]

Strong AI describes a system "that was operated in the same way as human intelligence through non-natural, artificial hardware, and software construction".[1] These are theoretical form of machine intelligence which supports the view that machines can really develop human consciousness equal to human beings. To Replace the intellect of the person, a necessary premise is required. The premise is that human intelligence which can be digitalised completely through computing.[14]

If every thought of a person is implemented in a conditional and propositional way that can be unambiguously synthesized in a formal, logical manner, then, in principle, a computer has the potential to completely replace a person's mind. In other words, the computing machine can self-consciously reach the stage of recognizing and "understanding" the object in an autonomous and active way.[14]

Strong AI or actual thinking is only fictional at present. Computers attaining strong AI will be the biggest innovation in this field which will have a huge impact on human civilization.[15]

Weak AI, on the other hand, does not aim to mimic human intelligence in its entirety, but rather is a system, in which the advantages of medical and logical algorithms can be used by humans. Weak AI recognizes that computer-integrated technology is different from human intellectual performances.[1] We experience weak AI or simulated thinking in our day today life, starting with the basic computational language which we use to command the computer programme till the robotics.[15]

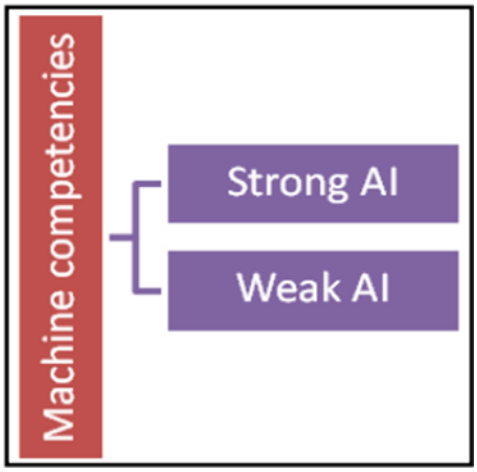

Fig 2 Concepts Of AI

Artificial intelligence in oral and maxillofacial radiology

Imaging modalities used in Dentomaxillofacial radiology are based on X-rays that are used to judge the hard tissue conditions, most of the AI models proposed were developed to solve clinical issues regarding teeth and jaws. Initially, 2-Dimensional images including periapical, panoramic and cephalometric radiographs were mainly used to build computer-aided programs for the assistance of clinical diagnosis. With more focus on diagnostic procedures in terms of digital RVGs/IOPARs, 3-Dimensional scans, and CBCT, AI is gradually making its way through radiology in dentistry. To create an AI that would aid in quick diagnosis and treatment planning, a lot of data may be acquired and processed. Dentistry is set to benefit from some of the most fascinating uses of AI. Studies suggest that AI can become a powerful decision-making tool within dentistry to promote clinical care.[10] Diagnostic imaging is the most notable use case for the use of AI in dentistry. Currently, applications and research in AI dental radiology focus

on the diagnosis of osteoporosis,[12] classification/segmentation of maxillofacial cysts and tumors,[12] description of periapical disease,[14] cephalometric landmarks detection,[1] etc.

Artificial neural networks (ANN) • Clinical Decision Support System (CDSS) • Principal Component Analysis (PCA) • Data Mining technique • Fuzzy Logic • Belief Merging • Genetic Algorithms (GA) • Probabilistic and General Regression Neural Network • Dynamic Bayesian Networks • Atlas based techniques • Deep Learning (DL) • Machine Learning (ML) these are the commonly used techniques in dentistry.

Artificial neural networks (ANN)

ANN has been extensively used in assessing the degree of aggressive activity of cancers and has impressively supported to bring out unique approaches to predict the course of the disease and prognosis and thus providing prospective suggestions to treatment modalities.[2,16]

The structure and function of ANN largely mimic the brain.[2] The core principle of ANN is to simulate the transfer of information through a neuron: weighted nodes receive the inputs (representing the synapses), sum them to produce an activation (representing the axon), and pass this activation to a nonlinear function called activation or transfer function, in order to generate the output signal. Each neuron acts as an elementary processing unit. The output signal of one unit will feed the other units, organized in layers, and so on, forming an artificial neural network (ANN)[17]. Basically, in ANN the input is entered into a set of algorithms and their output is re-entered to a different set of algorithms to reach the final output.

Convoluted neural network

Convolutional neural networks (CNN) are a special part of DL, used especially for image processing and analyses of radiological datasets. Convoluted neural networks (CNN) are specialised type of artificial neural networks that use a mathematical operation called convolution in place of general matrix multiplication in at least one of their layers they are specially designed to process pixel data and are used in image recognition and processing. Zhank et al.,[18] reported the use of AI-based CNNs and evaluated effective teeth recognition by relying on the label tree along with cascade network structure. The model demonstrated a high precision of 95.8%,[19] applied the CNNs to detect the teeth number in intra oral periapical films and then to identify the tooth. The model demonstrated very high precision. The results indicated that AI technologies make it convenient for clinicians to do their job. They do not have to enter the details manually. Using these automated systems dentists can enter their dental charts digitally, resulting in higher efficiency.[21] Casalegno et al.,[14] who used deep learning model designed for the detection and localization of dental lesions in near-infrared transillumination (TI) images which revealed promising results.[22] Lee et al.,[21] evaluated the efficiency and performance of AI in diagnosis and detection of osteoporosis. In this study deep convolutional neural network (DCNN) based computer-assisted diagnosis (CAD) systems was applied for detection of osteoporosis, using panoramic radiographs and exhibited very promising results. This was well above in par with experienced oral and maxillofacial radiologists in detecting osteoporosis.[23]

Clinical Decision Support System (CDSS)

A Clinical decision support system (CDSS) is a network between an extensive dynamic (medical) knowledge database and an inferencing output mechanism that are a set of algorithms derived from evidence-based medical practice implemented through medical logic modules. Currently, the interactive interphase with voice controls is designed to assist the health care professional to work more efficiently with time saving and cost effective clinical dental practice.[18, 24]

A CDSS include a dynamic knowledge base and an inferencing mechanism, implemented through medical logic modules

Machine learning

Machine learning is a subset of artificial intelligence. More specifically, machine learning refers to the scientific study of computer models that improve their performance by learning from experience without using explicit instructions.[25]

Machine learning explores algorithms that can learn and make predictions on data by strictly following static program instructions to make data-driven predictions or decisions. Machine learning teaches computers to do what comes naturally to humans and animals—learn from experience and retain memories to construct a response or reaction. This is probably what most radiologists do by constructing large virtual image libraries and applying their knowledge of pathophysiology to arrive at a differential diagnosis. ML allows processing and analysis of radiologic data in different means according to specific purposes and tasks. Radiology applications for image-based analysis, including computer-aided diagnosis (CAD) tools, radiologic imaging segmentation[26] and registration, medical images classification, or lesion detection and classification, are based on ML.[27]

Deep learning

Deep learning, a subset of machine learning, is able to automatically learn to extract relevant image features without the requirement of the manual design of image feature detectors, which is currently considered as the most suitable method to develop image-based diagnostic AI models.[28] Lee et al. proposed deep learning algorithms, respectively, using panoramic radiographs and CBCT images for the detection and diagnosis of periapical cysts, dentigerous cysts, and keratocysts.[29] It was reported that automatic edge detection techniques can segment cystic lesions more efficiently and accurately than manual segmentation.

Data mining

Data mining and machine learning process cumulative medical data through backpropagation and Bayesian inference methods. Data mining based on a large amount of restorative data was performed to reveal whether the material differences in the restorations serve as determinants of the lifespan of the restoration. Data mining of digital dental records provides possibilities for analyzing the variation between dentists when diagnosing caries.[14]

Fuzzy logic

Fuzzy logic is a known superset of the conventional logic found in the year 1965, widely used in mathematics in the name of "fuzzy" set. A fuzzy logic system (FLS) is defined as the non-linear mapping of an input data set to a scalar output data. An important advantage of fuzzy logic in medicine is the ability of this machine algorithm to introduce into the process of decision linguistic terms, easier for human users to understand and communicate with. A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier, used for detection and diagnosis of oral cancer, prediction of oral cancer risk assessment, and for diagnostic accuracy. [2]

Fuzzy logic in its simplest terms expands the dichotomy of true or not true to include a range of degrees of truth answers in between. Introducing partial truths, fuzzy logic is more appropriate in medicine where diagnosis implies complex data involving several levels of uncertainty and imprecision.[30]

Belief merging

Belief merging considers strategies for combining symbolic information, expressed in propositional logic from different sources. Every source is coded as a set of propositional formulae and known as a belief base, where the group of belief bases in conjunction may be inconsistent; the strategies aim at obtaining a consistent belief base representing the group. In particular explains in detail the works on belief merging of propositional bases and logic-based merging with relevant strategies known as merging operators. Brief merging is used in diagnosis of oral cancer.[31]

Principal Component Analysis (PCA)

The laser-induced fluorescence (LIF) spectroscopy and fluorescence imaging is a non-invasive diagnostic tool for differentiating normal and neoplastic oral tissues that involves illumination of tissue with monochromatic light and recording the fluorescence spectrum & utilize tissue fluorophores (autofluorescence) or exogenous fluorophores and classification is made using both PCA and artificial neural network (ANN).[32]

There are some of the advantages in PCA technique such as:

- Technique is fast
- Portable equipment
- Can objectively evaluate in a community screening program
- Low-cost equipment like an LIF system can be acquired even by small clinics in rural areas.
- Examination with such equipment using certified calibration sets provided can reduce the chances of a pre-malignant/ malignant situation being missed.[32]

Probabilistic and General Regression Neural Network (PNN/GRNN) models are helpful for the following decisions: To diagnose patients with malignancy and the type of malignancy based on demographic information, clinical symptoms, medical and personal history, and gross examination. To predict the stage and extent of oral cancer based on symptoms which are confirmed with the help of relevant tests and investigations. To predict the survivability of patients after appropriate treatments and follow-ups.[33]

Atlas-based

Atlas-based dosimetry relies on three sub-steps: the reduction of a set of imaging and contouring data into a subset of descriptive data points, the machine learning algorithm that relates the subset of descriptive data points to a corresponding patient, and a deformable image registration algorithm that warps a past dose volume to a novel patient geometry.[2]

Genetic Programming GP

GP reformulated the process of solving the problems of other machine learning methods by searching a highly fit individual program in a population of candidate programs. This space of searching consists of many functions and terminals, relevant to the problem domain. GP functions by searching for the fittest individuals in the program. GP breed populations of hundreds or thousands of computer programs using the Darwinian principle of survival and reproduction of the fittest, together with genetic operations during the process of evolution, namely, mutation and crossover. GP solves the problems given by the combination of natural selection and genetic operations. It is used in assessing the prognosis of oral cancer.[34]

Dynamic Bayesian Networks

The dynamic Bayesian networks take into consideration time-series gene expression data collected at the follow up study of patients that had or had not suffered a disease relapse. Based on that knowledge, to infer the corresponding dynamic Bayesian networks and subsequently conjecture about the causal relationships among genes within the same time-slice and between consecutive time-slices. This program aims to assess the prognosis of patients regarding oral cancer recurrence and provides important information about the underlying biological processes of the disease.[20]

Application of Artificial Intelligence in maxillofacial radiology:

Artificial Intelligence in Detecting and Diagnosing Oral Cancer

Several researches have carried out early detection of the advanced stage of Oral Cancer (OC) and have reported that OC arise from different subsites of the oral cavity such as tongue, buccal mucosa, etc. This heterogeneity of oral malignant growth makes it difficult to be analyzed. Sunny et al. conducted a study by ANN for early detection of OC, using tele cytology (TC), which is digitization of the cytology slides.[5] The efficacy of AI was compared with conventional cytology and histology; 11,981 prepossessed images were loaded for AI analysis, based on the risk stratification model. Results showed an accuracy of 80–84% in diagnosis, with no difference in tele cytology and conventional cytology detection, however, potentially malignant oral lesions were detected with low sensitivity, using tele cytology. The ANN-based model showed improved malignant detection accuracy to 93%, and a potentially malignant lesion to 73%. The study used the brush biopsy method for sample collection, which is less invasive, and this factor should also be considered while detecting cancer. Jeyaraj et al. conducted a study in which OC was diagnosed based on a regression based deep-learning algorithm for the characterization of oral malignant growth. [35]

A deep-learning algorithm of CNN was developed in a computer aided OC detecting system and 100 hyperspectral images (HIS) were analysed. They observed a 91.4% sensitivity in detecting cancerous lesions using the regression-based algorithm, and the results were compared to the traditional algorithm using the same images. improved quality of diagnosis was noticed for the proposed model of the algorithm, as compared to the conventional.

Uthoff et al. conducted a study on detecting OC by using smartphone-based images and AI technology.[53] Based on the concept of point of care, smartphone-based images were developed. Autofluorescence and white light imaging were added to the pictures, and these pictures were stacked to AI algorithms for recognizing oral malignancy.

Artificial Intelligence in Predicting the Occurrence of Oral Cancer

As of today, OC is treated with advanced treatment aids, but the reoccurrence rate of OC is very high. Treatment of oral malignant growth relies on the stage of the disease. Lack of an evidence on staging system may prompt deficient or pointless treatment. Different prognostic biomarkers and restorative targets have been proposed in ongoing periods, but they are not reproduced in the present cancer staging system. To date traditional statistical methods is used for predicting OC, for example, cox proportional hazard (CPH), and it is not suitable for predicting conditions like OC. Considering the complex 'dataset' of oral carcinoma, an AI-based anticipation prediction will give satisfied outcomes. Previous studies that used AI for predicting OC yielded excellent results.[5]

AI application to classify maxillofacial cysts and tumors

Accurate segmentation and diagnosis of various maxillofacial cysts and/or tumors are challenges to general dental practitioners. In some complicated cases, even radiologists can only provide tentative diagnoses, and must refer patients for a biopsy examination to reach a final diagnosis. Therefore, the application of AI for automated diagnosis of various jaw cysts and/or tumors will be of great value in clinical practice. Abdolali et al proposed a model based on asymmetry analysis to automatically segment radicular cysts, dentigerous cysts and keratocysts. Rana et al used an available surgical navigation software (iPlan, Brainlab AG, Feldkirchen Germany) to automatically segment keratocysts and measure their volume. Technically, the procedure of an AI model to classify cysts and/or tumors follows four main steps that are lesion detection, segmentation, extraction of texture features and subsequent classification. Currently, the first step of lesion detection in these models is still required to be performed manually so that these models can automatically perform the following steps. It remains a challenge to develop a fully automated model that can identify cysts and/or tumors.[6]

Following are the other applications of AI in dentomaxillofacial radiology:

1. Interpretation of radiographic lesions and automated interpretation of dental radiographs.[37]

2. Using the radiologists work as data, AI may enable programs to identify details of individual radiologists' practice pattern and categorizing them to create a sophisticated radiology report card. [38]

3. Caries detection: Logicon Caries Detector™ program (Logicon Inc., USA) is designed to assist dentists in the detection and characterization of proximal caries [39]

4. Diagnosis of vertical root fractures on CBCT images of endodontically treated and intact teeth[40]

5. To stage tooth development [41]

6. Computer based digital subtraction imaging [42]

7. Computer-assisted image analysis is useful to visualize and evaluate the bone architecture directly from the dental panoramic radiograph [43]

8. 3-dimensional orthodontics visualisation using patient models and OPGs [44]

9. Bone density evaluation to predict osteoporosis using OPGS [43]

10. Automatic segmentation of mandibular canal[45] Gerlach reported accuracy of automatic segmentation of the mandibular canal by the AAM and ASM methods is inadequate for use in clinical practice.

11. Forensic dental imaging: Personal Identification System Using Dental Panoramic Radiograph based on Metaheuristic Algorithm reported to have 97.7% precision [46]

12. Image quality improvement: Most medical images are prone to noise or streaking artefacts in the image acquisition and transmission process in particular, the geometry of CBCT makes it vulnerable to noise. The Image noise can be reduced by Machine learning techniques that includes Sparse-based or filtering methods.[47]

2. Conclusion

Applications of AI in everyday life are growing by leaps and bounds. Dental surgeons have always been at the forefront of implementing technology. Artificial intelligence has already had a profound impact on the world of medicine and is expected to continue to play a major role, particularly as the pressure on health care institutions to provide high-quality cost-effective care to an expanding patient base increase. However, there exists a doubt in the ascendancy of integrating AI into practice, it can never replace the role of a dentist since clinical practice is not only about diagnosing but also correlating with clinical findings and providing personalized patient care. The dentists can utilize the AI as an alternative tool to reduce the work load and to get a precise and accurate diagnosis, treatment planning and to predict the prognosis.

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