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Artificial Intelligence in Dentistry: Literature Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author SA supervised the study. Authors SA and IB helped in study conception and performed study design. Authors TBM and IB did data collection. Author IB wrote first draft of the manuscript. All authors reviewed and approved the final version of the manuscript.

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ABSTRACT

Artificial Intelligence has exploded as a research subject in the 21st century as the hardware requirements of theoretical Artificial intelligence in the 19th and 20th century have translated into reality. This has led to rapid progress with the realization of multiple kinds of neural networks, as well as improvements along classical Machine Learning models like Decision Trees, Support Vector Machines etc. Most recently, the focus in Machine Learning has now shifted towards generative networks with Variational Autoencoders (VAEs) and Generative Adversarial Networks (GANs) leading modern research topics.

With advent of the Internet of Medical Things (IoMT) and modern time leaps in the domain of Artificial Intelligence with the explosion of Machine and Deep Learning, Medical AI has grasped the central stage in modern research. Applications of Medical AI vary from detections of various cancerous tumors to prediction of arrhythmia attacks. The augmentation of such AI embedded techniques into the medical profession has streamlined analysis as well as aided professionals in

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reaching a more efficient and accurate diagnosis. This has also translated in the field of dentistry where strong deep learning architectures such as Convolutional neural networks in the form of Resnet, Inception, GoogleNet etc have been used to process raw images and detect a range of dental diseases.

This paper aims to provide an overview of progress made in the field of Machine Learning particularly focusing on its medical and dental applications. Different facets of Machine Learning are discussed with respect to their strengths, shortcomings, and the way artificial intelligence has been used to tackle problems in the medical field. Finally, a descriptive overview about state-of-the-art machine learning reliant applications that are being used in different dental subfields is discussed along with current challenges the industry faces today.

Keywords: Machine learning; dentistry; analog digital conversions; supervised learning.

ABBREVIATION

AI : Artificial Intelligence

1. INTRODUCTION

The idea of a machine being capable of doing human tasks is known as artificial intelligence [1,2]. Artificial intelligence has been developing since 1943 [1]. In the health care system, artificial intelligence has successfully been incorporated for data collection and mammograms for breast cancer screening [2]. It has assisted doctors in the fields of ophthalmology, dermatology, and radiology [3]. In orthopedic and trauma surgery artificial intelligence has shown high accuracy in the detection of bone fractures [4]. Narrow artificial intelligence is commonly being used in the health care system. Narrow artificial intelligence cannot make complex decisions such as treatment plans, and medicine prescriptions like humans. However, artificial intelligence augments human decision power [2]. Artificial intelligence is at its optimum ability and still improving day by day. For instance, Robo text, and chatbots are so well developed that it is hard to distinguish them from human writing, and facial recognition, biometric security, and many more features of artificial intelligence are bringing change in all fields of walk of life including dentistry. Artificial intelligence has shown promising results in imagery applications for the detection and analysis of the data [4]. In recent years artificial intelligence is rapidly expanding and is improving its applications in medical and dental health care systems.

A dentist's ability to read the radiograph in the conventional method increases the risk of misdiagnosis [5]. According to recent studies, 40 percent of dentists misinterpreted the depth of carious lesions, and 20 percent of dentists misinterpreted the tooth as diseased on the conventional radiograph [5]. Recently software has been introduced to detect early carious lesions and facilitate their prevention and management with higher sensitivity [6]. Randomized controlled trials of artificial intelligence have proven to improve the accuracy of caries detection and its management [6]. Recent research has been focused on developing artificial intelligence tools to aid in diagnostic and therapeutic roles [5,7,8]. Computer-generated centrally located health care data collection has been a mainstream line to provide better diagnosis, treatment plans, and prognosis [9]. Tele-dentistry with remote consultation is also bringing a positive impact on society. With the increase in age, the dental issues and oral disease incidence increases therefore remote consultation facilitates old patients [9]. However, limited interactivity between technical and dental field disciplines hence acts as an obstacle for applicable dental AI [2].

2. METHODOLOGY

For a comprehensive analysis of artificial intelligence role in dentistry, Islamabad Dental Hospital library, and online database was used, such as pub-med, google scholars, etc. Literature in English from year 2017 – 2022 highlighting the role of artificial intelligence and its impact on the dental community was included. We evaluated 30 peer-reviewed literature.

3. DISCUSSION

3.1 History of Artificial Intelligence

AI has seen many ups and downs. The period when artificial intelligence did not produce the expected result, is referred to as “artificial intelligence winter” (Table 1).

Table 1. Timeline of artificial intelligence

Beginning of Artificial Intelligence	1943s
Term was coined	1950
First Boom in Artificial Intelligence	1960-1970
First Artificial Intelligence Winter	1970s
Second Boom in Artificial Intelligence	1980s
Second Artificial Intelligence Winter	1990s
Progression in AI	Since 2000

3.2 Machine Learning

Artificial intelligence has many subfields one of them is machine learning. Deep Learning is the strongest aspect of Machine Learning, it uses multi-layer non-linear mathematical operations for collecting information and inferring complex unseen data [2]. Machine learning comprises many subdomains. The three most common subdomains of machine learning include:

3.2.1 Supervised learning

It is the most common learning strategy. Data and target labels are provided to the system to learn a relationship between them, thus helping the model to develop a relationship capable of interpreting unseen data [2,3]. For example, pictures of the cat, labeled as the cat, will allow machine learning to develop an inference to interpret unseen data as yes or no. Supervised learning is challenging in the medical and dental field as it requires large labeling of the dataset [2].

3.2.2 Unsupervised learning

Unsupervised learning does not require labeling of the dataset, rather unsupervised learning clusters together the input data to learn hidden structures and relationships between different samples of the data [2]. For example, e-commerce uses an unsupervised learning algorithm and matches their recommendation on basis of your past search and purchase history.

3.2.3 Reinforcement learning

Reinforcement learning is different from unsupervised and supervised learning. It is based on error and trial [2]. As the name suggests, reinforcement learning relies on learning from decisions made by the model in order to make better decisions in the future. It relies on reward and punishment in order to learn these decisions.

Among all three subdomains, supervised learning is most commonly used in the health care system [2]. The data set is split into two usually unequal sets namely the training set (larger), used for training the model to learn the inferences and relationships between the data, and the test set (smaller), which is used to validate the model in terms of its performance on unseen data which indicates the generality of the machine learning model [2].

Machine learning can use both simple and complex data. However, for complex data sets the artificial neural networks are employed. A neural network is the implementation of Deep Learning and has been inspired by the human neuron network [1,2]. As shown in Fig. 1, the neural network is a non-linear model, an intricate network, engineered to use mathematical operations to solve specific tasks such as radiographic images showing a decayed tooth or not [4]. A neural network is iteratively optimized via backpropagation to improve the prediction outcome of new unseen data by passing it through the network model [1,3]. Neural network based learning is referred to as “Deep Learning” [1,2]. One type of deep learning is “Convolutional neural networks” (CNNs). In 2015, Convolutional neural networks had their first published application in dentistry [3]. It is the network system that uses raw images to process complex data [2]. They analyze the image by extracting the imagery features such as corners, edges, shapes, patterns and intensity maps etc. One obstacle is the absence of a gold standard for data labeling [2,3]. Therefore, multiple experts label the same data however it may result in the fuzzy ground truth due to contextual differences [2,3]. It may persist the limitation beside majority votes for the labeling of the same image [2]. The trained convolutional neural networks are validated by the percentage of accuracy of detection per all labels, F1 score, or may be associated with specificity and sensitivity [3].

3.3 Augmented and Virtual Reality

Augmented reality is the simulation of live imagery and videos in the real world of the user. Augmented reality is the interaction of virtual simulation in their natural surroundings [9]. Such as if someone points their mobile phone toward

the street it may show names of cafes, gas stations, and shopping stores name of that street. Augmented reality enhances the objects of the real world by using algorithms and computer-generated models. Virtual reality creates a simulation in an artificial environment by using users' emotions, perceptions, and reactions to the given scenario [9].

Abundant software is available for these systems in the market that facilitates the dental practitioners and specialists in providing total patient care [9]. Development of oral scanners, cone-beam computed tomography (CBCT), and radiograph machines facilitates the advancement of dental procedure techniques. Augmented and virtual reality will aid in the enhancement of knowledge of undergraduate dental students by virtual simulation of an interacting teaching environment [9,10].

3.4 Clinical Decision Support System

Clinical Decision Support System (CDSS) helps to keep the track of patients' data and information and is readily available. For example, Use of CDSS in the medication management process (
Fig. **2**).

3.5 Artificial Intelligence in Dentistry

Artificial intelligence in dentistry can help to improve the quality of care such as the use of diagnostic imaging, improves the efficacy, and is cost-effective and time-efficient [1-3,6-9]. The collection of digital health data allows artificial intelligence to provide suitable interaction between different levels of data. With the fast-paced life, artificial intelligence helps dentists to keep records and provide their recorded data actively [1,11]. Continuous non-invasive digital monitoring helps the patients to learn about their health and the importance of their visits to their practitioner [12]. Artificial intelligence cannot replace dental surgeons' skills or cognitive decisions however, AI can act as an adjunct to improve planning and decisions [13].

3.6 Oral and Maxillofacial Surgery

A panoramic radiograph is commonly used in the oral and maxillofacial surgery departments [5]. Cone-beam computed tomography provides the best knowledge of periapical lesions, cysts, granulomas, and tumors, however due to cost it cannot be used on daily basis. Hence machine learning assists the surgeons in better diagnosing periapical lesions on a panoramic radiograph as compared to their conventional method of radiographic analysis [2,5].

Convolutional neural networks show high performance in the analysis of tooth segmentation and bone evaluation for dental implant planning [2]. Convolutional neural networks aid in the interpretation of maxillary sinusitis on a panoramic radiograph [2]. Deep convolutional neural network automated algorithms and models are efficient in determining dental implant shape, dimensions, and length [4]. Periapical images provided much

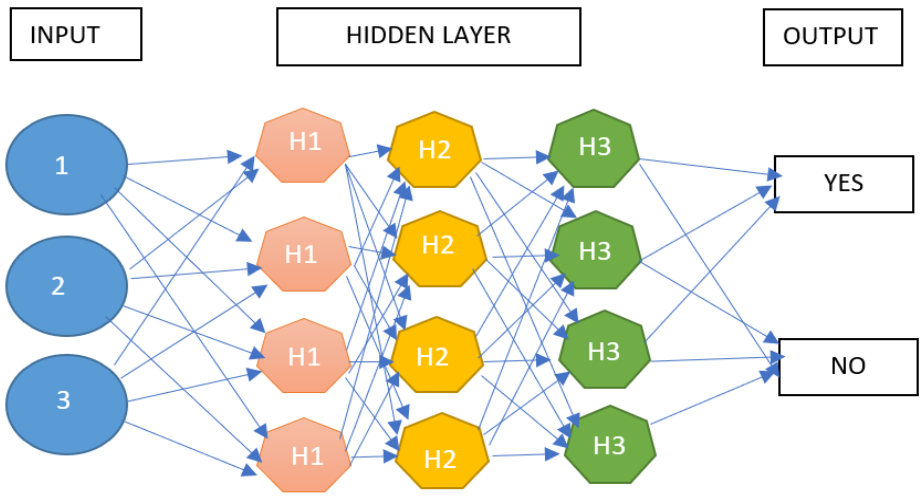

Fig. 1. Artificial neural network

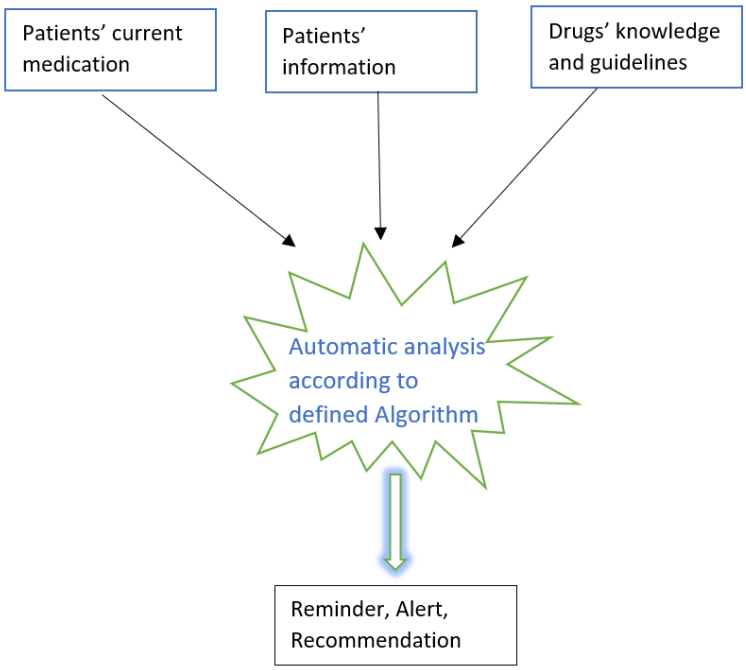

Fig. 2. CDDS in the medication management process

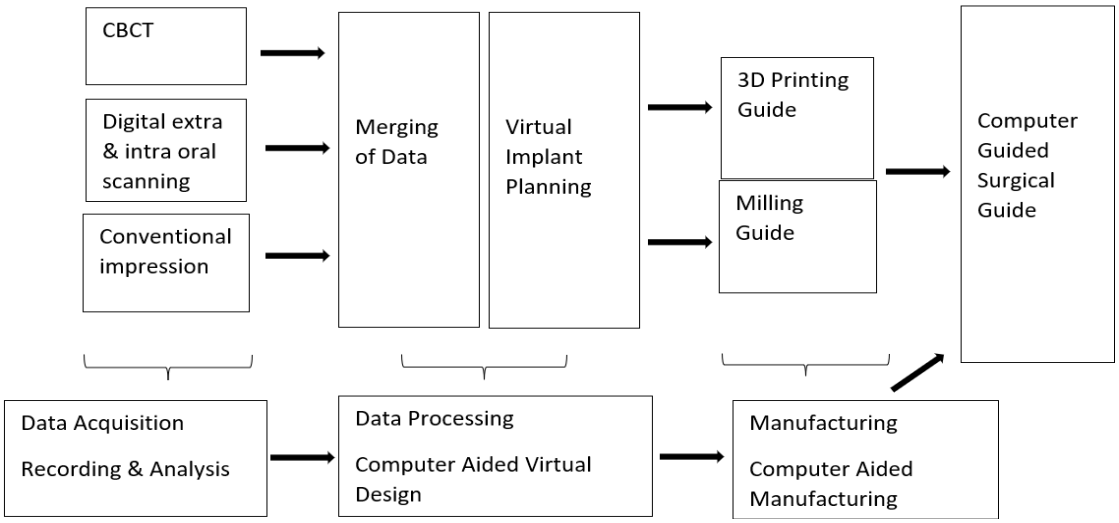

Fig. 3. Schematic diagram of computer-guided surgical guide

better resolution than panoramic radiographs for artificial intelligence algorithms, and models therefore periapical radiographs should be utilized as data sets for dental implants [4]. Augmented and virtual reality helps to develop a template for surgery plans hence helping to reduce human error and contamination in the surgical field as shown in Fig. 3 [9]. Dynamic navigation implant systems are the software in the market that assists in dental implant placement some software are Navident, X Guide, Image-Guided Implant (IGI) Dentistry System [9].

3.7 Oral Medicine

Oral medicine and diagnostics are a specialty focusing on the definitive diagnosis of a disease. Temporomandibular joint disorders can be diagnosed based on clinical history and examination however, artificial intelligence techniques can be used to differentiate between the disorders that mimic temporomandibular joint dysfunctions [14]. In 2019 Shoukri et al study showed the neural network analyzed the association of temporomandibular joint

osteoarthritis with gene markers and condylar morphology [15].

3.8 Operative Dentistry and Endodontics

Operative dentistry has incorporated artificial intelligence at many levels. Caries detection on bitewing radiographs is processed by software [2,5,6]. In 1998 the Logicon caries detector tool was approved by Food Drug Authority (FDA) [5]. The Logican caries detector tool is used to date for detection and depth associated with interproximal carious lesions [5]. With improved sensitivity and specificity software were launched for caries detection in the European Union market, dentalXrai Pro (dentalXrai Ltd., Berlin, Germany) [6]. Other convolutional neural network architectures used for caries detection are ResNet 18, and ResNet50 [9]. Hung et al have proven in their study that on large population artificial intelligence can be applied for the root caries prediction thus the early detection and intervention will help to reduce the risks [16]. Shivani et al have developed an algorithm support vector machine, that helps to predict the difficulty of the case according to "American Association of Endodontists (AAE) Endodontic Case Difficulty Assessment Form" [17]. Incorporation of machine learning will aid in the cognitive decision of the clinician and endodontist. Periapical pathosis can be well determined by a deep convolutional neural network [18]. Machine learning has also been used for working length determination and has been giving promising results [19]. Standardized caries risk assessment model includes, Cariogram, Caries Management by Risk Assessment (CAMBRA), Caries-Risk Assessment Tool (CAT), and American Dental Association (ADA) [20].

3.9 Orthodontics

Orthodontics require calculations and accurate measurements for their procedure and treatment planning. Artificial intelligence has helped the orthodontist in the calculations and analysis of tooth segmentation [2,3,5]. Artificial Intelligence is time efficient and has improved patient care, and treatment prognosis. Cephalometric landmark detection can be achieved by convolutional neural networks. An artificial intelligence algorithm can predict the future tooth movement [21]. Clean aligners are also being made accurate by using 3D scanning and model on the principles of artificial intelligence. Computer-aided design and computer-aided manufacturing (CAD-CAM) have aided in the manufacturing of retainers [9].

3.10 Prosthodontics

In prosthodontics, artificial intelligence helps in the planning, reconstruction, design, and rehabilitation of prostheses without any invasive procedure [9]. Convolutional neural networks can classify and predict dental arches [22]. CAD-CAM development has brought advancement in the field of prosthodontics [23]. CAD-CAM has an advantage over the conventional method of impression-taking procedure. It is time-efficient and has fewer cross-contamination risks [24]. Intraoral scanner and CAD CAM has been used for manufacturing prosthodontic implant.

3.11 Periodontics

Periodontal health depends on bone and its supporting structures. Artificial intelligence helps to detect bone loss and the periodontal status of the tooth [2,9]. VGGNet-19 and GoogLeNet Inception-V3 architecture models are efficient to show and predict periodontal health outcomes [4].

3.12 Genetic Algorithm

Correlation has been found between dental diseases and genetic disorders. A system has been developed comprising a genetic algorithm that predicts genetic disorders [25]. Genetics plays a significant role in the prevalence of caries therefore models containing genetic and environmental algorithms should be inculcated to predict caries. Patient care can be improved by using caries risk prediction models (CRPMs). CRPMs facilitate the dentist to choose the invasive or non-invasive intervention [26].

3.13 Challenges

In dentistry, artificial intelligence has not been used widely. From 2015 onwards only neural network has been introduced in the research setting [1]. Radiographic imaging is an essential part of dentistry hence recording of these images and use of artificial intelligence can help to interpret complicated unseen data by using previously provided input. First and foremost, a challenge that is faced in dentistry is the availability of data as it is not readily available due to limited resources, patient confidentiality, and lack of trusted sharing. No specific data that is provided as input can be used as the gold

standard [1,27]. It can lead to selection bias. Similarly, the same data is sometimes used for testing and training hence causing “snooping bias” [28]. Artificial intelligence has to be regulated carefully to avoid type 1 error and overtreatment by dentists [6]. With a constant increase of data continuous upgrades and maintenance are required [14,29].

Recent studies on artificial intelligence, has used smaller datasets. Therefore, for further studies, large datasets should be used to optimize the results and to develop a benchmark for data. Expansion of data will help to strengthen the generalizability [2,3]. Dentists need to address the automation bias while using artificial intelligence machines [30]. Automation bias is the inability of the user to question the error produced by the machine. The training and testing dataset for the model should be separate. Testing dataset for the model should be independent, and the data set should be planned and designed in advance [2].

4. CONCLUSION

Artificial intelligence is being widely used in dentistry in terms of imagery analysis, however, its other uses are still unclear and need further research. Reference tests should be established by the dental community in collaboration with technical science. Periapical radiographs used as data sets in the deep convolutional neural network have provided better results and should be incorporated into dental implantology. In the era of COVID-19, tele dentistry and consultation can help the dentist and patient to avoid interaction and attain maximum health care. Use of artificial intelligence and electronic digital data will be an exalted source of an interdisciplinary approach. It will provide an opportunity for the patient, dental assistant, dental practitioners, and specialists to collaborate and deliver optimum health care.

CONSENT

It’s not applicable.

ETHICAL APPROVAL

It’s not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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