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Revolutionary dentistry: The synergy of artificial intelligence and patient-centric precision

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Abstract
Artificial intelligence (AI) is transforming dentistry by enhancing diagnostic accuracy, treatment planning, and patient care through applications like image analysis and risk assessment. AI, particularly using machine and deep learning models, can analyze radiographs to detect lesions, fractures, and diseases, and can assist in areas like endodontics, orthodontics, and restorative dentistry. While AI offers significant potential for precision-driven solutions and improved outcomes, its integration requires robust validation, addressing data privacy, and ensuring that final decisions are made by an experienced dentist.

Keywords: Artificial intelligence, precision dentistry, diagnostic imaging, machine learning

1. Introduction

Artificial Intelligence (AI) is broadly defined as the science and engineering of making intelligent machines. [1] It includes computational algorithms that can perform tasks considered typical of human intelligence, with partial to complete autonomy, to produce new beneficial output from specific inputs. [2]

Artificial Intelligence has a wide variety of applications in different sectors of our daily lives - from healthcare to business, education to finance, law to banking, manufacturing to transportation and security. [3]

Dentistry is not an exception to this. The amalgamation of technology and dentistry is not just innovative but also revolutionary as it has the ability to transform and reshape the approach of providing personalized and data-driven healthcare.

History of Artificial Intelligence

British mathematician Alan Turing postulated in 1950 that machines might be able to use information to reason, solve problems, and make decisions in the upcoming decade. [4] In Dartmouth Conference, 1955 the term "Artificial Intelligence" was coined by computer scientist John McCarthy. [4]

The year 1970-1980 marked the First AI winter due to the limited applicability of AI led to the backing away of funds by the government and corporations. 1980-1987 witnessed a renewed interest in AI. The second AI winter set in from 1987 to 1994 when AI could not meet expectations leading to a decrease in funding again.1994- present is a new era in the field of AI with renewed interests and huge potential and possibilities that lie in front of us. [5, 6]

Mechanism Of Action

The development of AI is largely based on the introduction of artificial neural networks (ANN) and their subsequent evolution from single to multilayer networks, introducing the concepts of Machine Learning (ML) and Deep Learning (DL).

Machine learning (ML) is a powerful tool within the field of Artificial Intelligence (AI) that allows computers to learn and improve without explicit programming. Unlike traditional programming where you provide every single instruction, machine learning algorithms learn from data to make predictions or decisions. This data can be anything from text and images to

numbers and sound recordings.

Machine learning is based upon the so-called "reverse training" [7] method in which a computer system requires a set of data known as the big data that helps and guides the computers to learn and perform tasks without being explicitly programmed. It enables the system to analyse data, identify patterns and make decisions as they evolve over time with new information.

A significant step forward from Machine Learning is Deep Learning, which is a subset of machine learning [8]. It is based on implementation of a large number of Artificial Neural Networks (ANNs). It mimics the structure and function of the human brain [9] utilising the artificial neural networks with multiple layers of interconnected processing units (neurons) inspired by biological neural networks.

The presence of numerous neural layers between input and output and use of several other techniques contribute to even more sophisticated performances. As a general rule, as more layers are added to the network, it gets “deeper” and performs more rounds of training thus improving the performance of the network. [8]

Deep Learning Applications

- **Image Recognition:** Deep Learning models can analyse pictures to identify objects in the picture or the context of the picture leading to various applications from Facial Recognition to Radiographic Diagnosis.
- **Natural Language Processing (NLP):** Deep learning can analyse text data for tasks like sentiment analysis (detecting positive or negative emotions in written text) and translation (converting text from one language to another).
- **Speech Recognition:** Deep learning models can convert spoken language into text, enabling applications like voice assistants and speech-to-text softwares.
- **Recommending Systems:** Deep learning algorithms find applications in e-commerce industry and streaming platforms where it is used as recommending systems for suggesting products or content to the users based on their past preferences and behavioural pattern of other users with similar attributes.

Artificial Intelligence in Dentistry

Numerous research studies [2] have already been conducted in the field of dentistry regarding the use of Artificial Intelligence across various specialities, like - Prosthodontics, Periodontics, Orthodontics, Oral Surgery, Oral Medicine and Radiology, Oral and Maxillofacial Pathology and Forensic Odontology. Yet there remains an ocean of opportunities for further exploration of the applications of AI in Dentistry that will reshape and transform the entire framework of this profession.

Symphony in Fusion of Artificial Intelligence and Dentistry

The fusion of Artificial Intelligence has a significant impact in the transformation of Dentistry.

It helps us bring about a revolutionary change in diagnostic precision, treatment planning and optimization thus providing a personalized patient care. [9] At the same time, this technology helps us augment our daily practices by enabling improved practice management, radiographic Image Analysis, personalized data driven treatment approaches, early detection of oral cancers and virtual simulation of treatment plans for better patient compliance.

This is not only about technology but a profound shift in our approach to welcome a future that will elevate our daily practice in a completely new dimension.

Let us start our journey of exploring the possibilities of AI in Dentistry with something that we all have come across or heard of the smart toothbrush.

A smart toothbrush is an advanced oral health care device that integrates technology and brushing. It connects the toothbrush with any smart device namely a smart phone and transforms routine brushing habits to personalized oral care. [10]

These high-tech toothbrushes transform the entire forte of oral health care by providing personalized brushing guidance with motion sensors and AI algorithms tracking brushing patterns, identifying missed areas providing real time feedback for effective cleaning [10].

Use of AI in General Dentistry

With time, AI is transforming general dentistry with refined X-ray analysis, personalized treatment plans and predicting patient risk factors. With enhanced disease diagnosis and customized care AI is making dentistry faster, more accurate and better. [9]

At the same time, AI chatbots improve practice management by managing appointments, scheduling patients and sending automated appointment reminders via emails or texts. AI also plays a very crucial role in recording proper medical and dental history by creating questionnaires prior to any procedure while focussing on areas of potential concern. Similarly, AI-powered tele-dentistry [11] allows virtual consultations. This method proved to be a boon at times of Covid-19 pandemic facilitating online consultation in cases where in person care was not readily accessible. Thus, AI is making dentistry smoother, faster, and much more accessible for everyone particularly in inaccessible and remote regions.

Using Deep Neural Network based recommendation systems, AI can be used to develop a program wherein patients can answer a series of questions about their symptoms and using a trained data set, AI will suggest the steps to be taken which may include emergency appointment or temporary home care until a proper professional advice is available.

Eun Yeob Kim, Kun Ok Lim *et al*. investigates the potential of using artificial neural networks to predict dental pain. Researchers developed a model trained on data regarding patients' oral health habits and their experiences with dental pain. The model achieved an accuracy of 80% in predicting whether a patient was likely to experience dental pain. [12]

Use of AI in Early Detection of Oral Cancer

AI is proving to be a game changer in early oral cancer detection. [13] It analyses images like X-rays, oral brush biopsies (images of cells collected through a brush), Optical Coherence Tomography (OCT) scans (detailed cross-sectional images), and medical history details to spot suspicious lesions leading to earlier diagnoses. It can also screen large numbers of patients, saving time and resources.

Trained AI algorithms on oral lesions can screen images like changes in colour and reflection of light of various wavelengths from the tissues, altered texture of tissues and irregular vascular patterns surrounding lesions thus identifying subtleties which may sometimes go unnoticed by the human eye. This allows earlier intervention and better prognosis in oral cancer cases.

Indian Oral Cancer Risk score is a numerical value that is developed by Arpita Chatterjee, Surajit Bose *et al*., is used to estimate the likelihood of developing Oral Cancer by

analysing several factors like Age, Tobacco Use, Betel Nut use, Family History, etc. There can be several systems assigning points to different risk factors thus giving an overall risk level - Low, Medium, High. Work is ongoing in enhancing this system with the use of AI, which will contribute to accurate scores leading to significant improvement in Cancer prevention and intervention. [14]

A recent work by Soumendra Singh, Surajit Bose *et al*. shows the potential to improve Oral Cancer screening through the development of a non-invasive device using Toluidine Blue and using Spectroscopic techniques for efficient detection of Oral Cancers. This method analyses the way Light interacts with Toluidine Blue by analysing the reflection patterns thereby identifying Malignant Changes in Oral Tissues without any physical interaction. [15]

A recent work by Dev Kumar Das and Surajit Bose *et al*. demonstrated how histological images of Oral tissues can be used for diagnosis of Squamous Cell Carcinoma. Making use of variations of epithelial layers and detection of Keratin Pearls AI demonstrated the ability of autonomous distinction between malignant and pre malignant lesions. [16]

Another work by Deb Kumar Das and Surajit Bose *et al*. shows a Research Study in which Deep Learning Neural Network can detect and define the borders of nucleus in Oral Histopathological images which can be a valuable tool for OSCC detection thus drastically improving the efficiency and accuracy of Cancer diagnosis ruling out the human error and improving the crucial time lost in the diagnostic process. [17]

In addition to images, AI powered biosensors can analyse saliva samples as cancer biomarkers that can be a non-invasive approach for earlier detection of the disease. [18]

A recent work by Tanriver *et al*. explores the use of deep learning, for automatic detecting and classification of oral lesions from images. This could be a valuable tool in identifying Oral Potentially Malignant Disorders (OPMDs), which are precancerous lesions. [19]

Use of AI in Cosmetic Dentistry

AI is revolutionizing cosmetic dentistry through integration with Digital Smile Designing (DSD) softwares. It creates customized smile designs using virtual simulations, predicts treatment prognosis for optimal results and might even recommend ideal materials for a natural-looking smile. This translates to happier patients with perfect smiles achieved through a more efficient process of AI Powered mockup using patient photographs and CBCT scans generating potential outcome and providing a "virtual try on" experience enabling enhanced precision. [20]

This technology not only analyses teeth but also considers the facial proportions and symmetry that complements the facial aesthetics. And with the realistic preview it can boost patient confidence in moving ahead with the treatment which is especially effective for patients who are apprehensive about cosmetic dentistry. This leads to reduced treatment sessions and optimum results.

Current Scenario of Artificial Intelligence in Dentistry

2016

China became one of the pioneering nations to successfully use an AI-powered robotic arm to assist a dental surgeon in dental implant surgery. This case demonstrates the potential for improved precision and ergonomics with the assistance of robots. [21]

Following this, several companies showed interest in developing AI-powered robots like YRobot and Medtronic. These devices are still mostly undergoing preclinical trials as they need rigorous testing and trials before widespread approval and release to ensure both patient and clinician safety.

Yomi implant robot is an advanced robotic system developed by Neocis that stands at the forefront of technological improvements in dentistry. It is the first FDA-approved surgical [22] robot to provide an innovative and advanced way to cater to patient needs.

Though this technology is comparatively new and needs significant advancements we can surely say that it was a massive breakthrough in the field of dentistry where robots are emerging as sophisticated dental assistants augmenting and complementing the expertise of the clinician.

2021

A research paper published in Journal Progress in Orthodontics demonstrated the role of AI in suggesting customized orthodontic treatment plans by analysing patient data. [23]

Another study published in Journal of Contemporary Dental Practice explored the use of AI in improving decision-making in root canal treatments highlighting the potential of AI to process complex root canal architecture with ease. [24] A research paper published in Journal of Prosthodontic Research explored the use of AI to customize denture designs ensuring better fit and comfort. [25]

2022

A recent study published in BMC Oral Health helped us explore the potential of caries detection in pedodontics patients. With the help of intra-oral photographs and deep learning models now it is easier to identify plaque build-up assisting in early detection of dental caries and subsequent problems in children. [26]

Another study published in the Journal of Endodontics showed the use of AI in accurate determination of working length suggesting the role of AI in the near future in assisting dentists during endodontic treatment achieving greater clinical precision. [27]

In 2022, another study published in the Journal of Dentistry elaborated how AI algorithms can analyse patient data and scans and suggest implant placement positions leading to improved clinical outcomes. [28]

In the same year, yet another study published in the Journal Scientific Reports explained the use of AI algorithms to analyse dental X Rays for identification of jaw bone pathology helping in the early detection of cysts, tumours, etc. [29]

2023

A study conducted using deep learning model showed AI algorithm could detect dental caries with precision comparable to experienced dentists. [30]

Another significant study published in The Journal of Prosthetic Dentistry demonstrated the potential of AI in detecting gingival inflammation. AI could detect gingival inflammation with more than 90% accuracy by analysing redness, swelling and bleeding gums through interpretation of intraoral photographs comparable to an experienced dentist. [31]

Yet another review article published in the same year in the journal, Computational and Mathematical Methods in Medicine depicted the use of AI models in detecting periapical lesions and root fractures using X Rays and CBCT

scans aiding early diagnosis and appropriate treatment strategies in the field of endodontic dentistry. [32]

Another study published in Frontiers in Medicine explored the use of AI algorithms for manufacturing of personalized prosthesis for patients with cleft lip and cleft palate thus delivering improved aesthetics, function, and customization. [33]

A study published in the Journal of the California Dental Association explained the use of AI for preoperative planning of orthognathic surgery by analysing facial scans and CT scans for better outcomes. [34]

Though AI holds immense potential in improving the accuracy and efficiency of treatment plans in dentistry while offering to be an even more promising diagnostic and surgical assistance tool, widespread use of robotic surgery still seems to be a distant future as we still need long-term research to validate the effectiveness of these devices while accessing the safety protocols at the same time.

Developments in India in the field Of AI Augmented Dentistry

The Post Graduate Institute of Medical Education and Research (PGI), Chandigarh is developing an AI tool that analyses X-Rays taken specifically in the region of Sella turcica to identify potential Craniofacial anomalies and orthognathic defects in children thereby allowing early intervention and treatment. [35]

A 2022 study conducted by researchers at IISc (Indian Institute of Science) in collaboration with a startup, Theranautilus, focused on developing nano-sized robots for improving the effectiveness of root canal treatments. These nano-robots coated with iron particles can be manipulated using an external magnetic field. The primary purpose of these nanobots is to reach targeted area inside dentinal tubules killing bacteria efficiently by generating heat using magnetic field manipulation thus improving the success rate of Root Canal Treatments (RCT) compared to traditional approaches. [36]

Future Prospects of AI In Dentistry

The future of healthcare lies in the integration of healthcare with AI and other emerging technologies.

Integration of AI and Nanotechnology

Nanorobotics is already a booming topic that is being explored by researchers across the globe. Research by researchers at Indian Institute of Science [37] can make Nanorobotics based targeted treatment inside intricate canals of the teeth a reality in the very near future. It may also be modified to be used as a vector for targeted drug delivery inside the root canals.

AI and genomic dentistry

AI can customize treatment plans and help in developing tailor-made medicine thus catering to a particular individual's genetic makeup. This will lead to improved treatment outcomes. [38]

Real-time monitoring with AI

In the future, we can see the use of smart dental implants [39] that can sense real-time data, pressure and temperature of the surrounding tissues thereby providing early warning against potential problems with implants and the surrounding tissues.

We have already discussed smart toothbrushes that are changing the idea of personal oral health care leading to improved oral hygiene among the general masses.

Customised Biomaterials

AI in the future can be used to develop customized biomaterials like dental cements or implants that will be catering to the specific needs or anatomy of the patients resulting in better long-term success rate and improved biocompatibility. Use of 3D printing [40] allows fabrication of customized dental prostheses with enhanced functionality, comfort, and aesthetics.

Integrated of Virtual Reality

Virtual simulation [7] can be beneficial to both doctors and patients [41]. Virtual Reality simulation can be used to train dental students [42] in a safe and controlled environment by providing realistic scenarios along with real-time monitoring and prompt feedback. It can also be used to evaluate their work against an ideal work done by an experienced dentist thus providing them with the opportunity to evaluate their own shortcomings and a scope for further improvement.

Virtual reality can also be used as a tool for enhancing the comfort of patients undergoing treatment as it can help reduce stress and anxiety leading to a more positive experience with improved cooperation.

AI & Future Dentists

Will AI Replace Dentists? The answer is simply **NO**. [8] Though AI will significantly pave its way into the amphitheatre of dentistry, the idea of AI replacing dentists seems to be quite impractical. Despite AI being a powerful tool, at the end of the day, it is merely a technology that can augment the precision of a clinician but can never replace him or her. We can consider it to be a co-pilot that will assist dental professionals in navigating through various diagnosis, treatment planning and help them enhance patient care and comfort, but can never be the actual pilot calling the shots.

Dentistry is an amalgamation of clinical judgement, technical skills, and patient management and it is an understatement to say that no technology will ever be able to understand a patient's anxiety, pain or concern the same way as a human. It cannot provide the same level of human support and empathy. [43] Dentists will always play a pivotal role in oral health care providing the indispensable human touch and expertise for the patient's wellbeing.

Current Challenges of AI

Artificial intelligence has made significant advancements across all specialities of Dentistry but there are still numerous hurdles for it to overcome to be widely accepted and used in regular practice. [1, 2, 9, 44]

- **Data Quality and Data Bias:** AI algorithms are based on trained databases using machine learning and deep learning to produce output. So, if the data is biased in any form, it may give inaccurate and unpredictable results leading to greater issues.
- **Data Security and Privacy:** As AI is hugely data dependent, ensuring data security and privacy is of immense importance as any breach will lead to grave consequences and can lead to trust issues.
- **Black Box Problem:** Many AI algorithms function in a complex way like “Black Boxes” which make it difficult to decipher how AI takes decisions and address potential biases.
- **Technical Limitations:** Although AI is hugely successful in carrying out specific tasks, it lacks

judgement and human reasoning which is a major drawback especially in medical disciplines.

- **Computational Cost:** The process of training and running AI models require significant computing power and cost, making it unviable at times.
- **Medico Legal Issue:** In applications where AI assists in diagnosis and treatment planning the pivotal question which arises is who will be accountable if anything goes wrong? Is it the clinician or the AI algorithm or the programmers who created this algorithm? Thus, we really need to think through and address these complex issues.

Robotic Dentistry

According to an online survey conducted in 2018, it is observed that patients are much more welcoming of the idea of robotic dentistry for non-invasive procedures like, teeth whitening and teeth cleaning as compared to other invasive procedures like Root Canal Therapy or implant surgery.[45]

The survey also unveiled a significant number of patients who are willing to undergo robot assisted procedures if they are offered discounts.

Although the concept of robotic dentistry is still in its infancy, it is bound to progress over the passage of time. As time passes, patients' acceptance towards robotic dentistry is also expected to increase exponentially owing to the superior results it is capable of achieving.

Conclusion

AI is transforming dentistry from the era of reactive treatment to proactive prevention. AI is capable of analysing X-rays, uncovering hidden issues and empowering dentists with early detection. Patient data allows AI to personalize preventative care for those at higher risk.[1] AI consultations will allow patients to virtually explore different smile options thus increasing customization through a virtual "try-on" experience.[46] The future holds even greater promise. AI will collaborate with advanced imaging tools, enabling dentists to visualize the oral cavity in intricate detail and recommend the ideal solution.

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