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ARTIFICIAL INTELLIGENCE IN PROSTHODONTICS: A NEW ERA OF INNOVATION

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ABSTRACT

Artificial intelligence (AI) is revolutionizing the field of prosthodontics, which focuses on restoring oral function, aesthetics, and health for patients with missing or damaged teeth and oral structures. This review explores AI's transformative role across prosthodontic practice, supporting diagnosis, treatment planning, and the production of dental prostheses, such as removable dentures and complex maxillofacial appliances. By harnessing machine learning (ML) and deep learning (DL) technologies, AI significantly enhances clinical precision and efficiency through innovations like digital impressions, intraoral scanning, and CAD-CAM systems. In implantology, AI contributes to accurate implant placement, improving patient satisfaction with these treatments. Core concepts of strong and weak AI, along with machine learning algorithms and neural networks, drive these developments, enabling refined decision-making, image analysis, and personalized prosthetic design. Although perspectives on AI's role in healthcare vary, its capacity to integrate predictive analytics with clinical expertise highlights its potential for enhancing diagnostic accuracy and expanding remote care capabilities. In conclusion, AI is advancing prosthodontics by minimizing human error, improving prosthetic functionality, and fostering progress in both dental and general healthcare outcomes.

KEYWORDS: Artificial Intelligence, Prosthodontics, Machine Learning, CAD-CAM, 3D printing.

INTRODUCTION

Prosthodontics is a specialized field of dentistry that combines both art and science. It focuses on the diagnosis, treatment planning, rehabilitation, and maintenance of oral function, comfort, appearance, and health for patients with clinical issues due to missing or deficient teeth and oral and maxillofacial tissues. This is primarily achieved by replacing missing teeth and related structures with artificial substitutes.[1,2,3,4,5]

Terms like "digital transformations," "digitized workflows," and "technical developments" encapsulate some of the major innovations of the 21st century, impacting both social life and dental medicine. The widespread use of mobile devices, tablets, smartphones, and the easy access to technology and the internet have significantly altered societal cultural habits. Unsurprisingly, more advanced technologies, such as artificial intelligence (AI), are becoming increasingly integrated into everyday life. AI, in general, emulates the cognitive processes of human intelligence through the use of machines and software algorithms to handle complex tasks.[6]

AI applications have become a routine part of daily digital life, exemplified by virtual assistants like "Siri" and "Alexa." Additionally, AI technologies are utilized across various engineering disciplines.[7]

An artificial neural network (ANN) is a DL algorithm that simulates a biological system. It consists of three layers: an input layer (that receives the input signals), several hidden layers, and an output layer.[8]

HISTORY

The concept of using computers to simulate intelligent behavior and critical thinking was first described by Alan Turing in 1950.[9] In the book Computers and Intelligence, Turing described a simple test, which later became known as the "Turing test," to determine whether computers were capable of human intelligence.[10] Six years later, John McCarthy described the term artificial intelligence (AI) as "the science and engineering of making intelligent machines."[11,12]

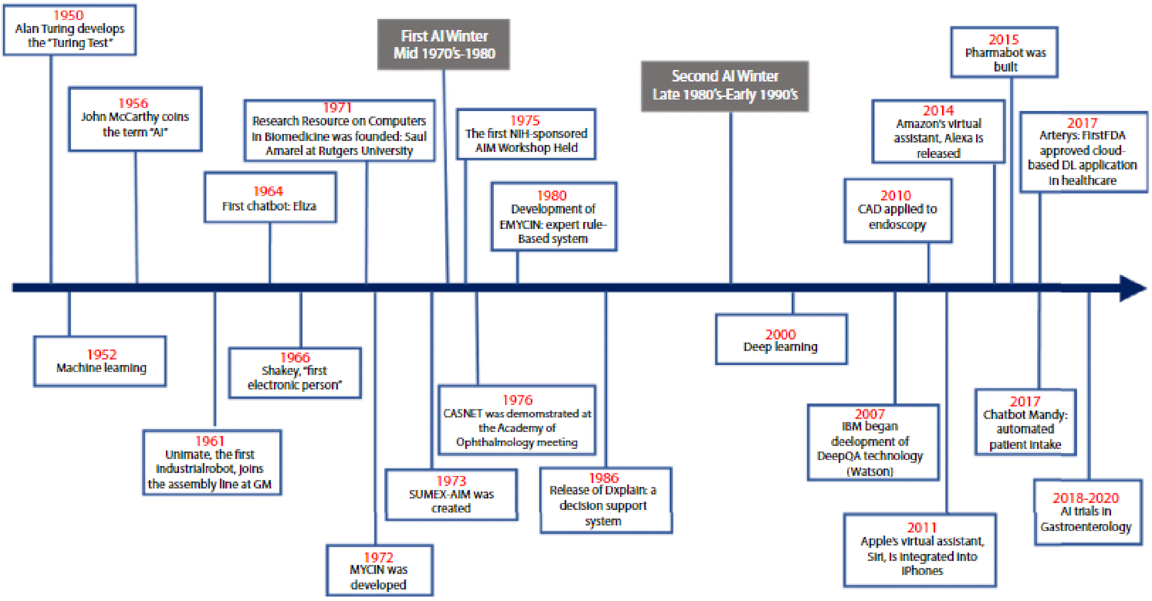

Figure 1: Timeline of the development and use of artificial intelligence in medicine. AI, Artificial intelligence; DL, deep learning; FDA, U.S. Food and Drug Administration; CAD, computer-aided diagnosis.[9]

AI in medicine (AIM) has significantly evolved over five decades, enabling personalized medicine and improving diagnostics and patient outcomes. Early AI innovations like Unimate (1961) and Eliza (1964) paved the way, with medicine adopting AI in the 1960s through data digitization. Despite "AI winters" from the 1970s to 2000s, collaborations advanced AIM with models like CASNET and MYCIN. From 2000 to 2020, breakthroughs such as IBM Watson and deep learning algorithms revolutionized AIM, enhancing clinical decision-making and image processing.[13]

SUBFIELDS OF ARTIFICIAL INTELLIGENCE

Table 1: Subfields of artificial intelligence.[13]

Subfields of Artificial Intelligence
Machine Learning (ML): pattern identification and analysis; machines can improve with experience from provided data sets
Deep Learning (DL): composed of multi-layer neural networks which enable machines to learn and make decisions on its own
Natural Language Processing (NLP): process that enables computers to extract data from human language and make decisions based on that information
Computer Vision (CV): process by which a computer gains information and understanding from a series of images or videos

SUB-CONCEPTS OF AI

The term "AI" now encompasses two sub-concepts: strong AI and weak AI. This distinction emerged from recognizing the limitations of AI's original mathematical and engineering definitions.

Strong AI

Initially, "AI" referred to systems that operated like human intelligence through artificial hardware and software, known as strong AI. Strong AI requires redefining intelligence as "the capacity of a system to act appropriately in an uncertain environment."[14] Though sometimes imperfect, human intelligence generally handles diverse, uncertain environments well, embodying natural intelligence. Artificial general intelligence (AGI) similarly aims to manage such environments universally.[15]

To replicate human intelligence, it is assumed that it can be digitized purely through computation. If human thoughts are expressed formally and logically, a computer could theoretically replicate the human mind. This means a computer could autonomously recognize and understand objects, achieving self-awareness akin to human intelligence.[7]

Weak AI

Weak AI focuses on creating systems that enhance cognitive tasks without replicating human intelligence. Unlike strong AI, which aims to mimic human thought entirely, weak AI leverages specific mechanisms to perform intellectual activities efficiently.[14] Inspired by Turing's universal machine, early AI efforts sought strong AI, but human cognition's improvisational nature and storage limitations posed challenges.[16]

Weak AI accepts these limitations, emphasizing practical applications and developing problem-solving abilities through methods like bio-inspired neural networks. This approach allows for significant advancements in specific areas, such as medical diagnostics and logical reasoning. As a result, weak AI has become integral to many modern technologies, driving innovation without needing to fully replicate human intelligence.[17]

KEY COMPONENTS OF AI

Machine learning (ML)

The basic concept of machine learning is rooted in the definition of intelligence as an agent-environment model, with the goal of achieving strong AI. It's important to note that the conceptualization of artificial neural networks and machine learning is based on Kant's concept of transcendentality. According to Kant, human intellect can synthesize sensory data using certain a priori categories.[18]

Machine learning (ML) is part of weak AI; by recognizing patterns, the computer system is able to learn and make predictions.[19,7]

Machine learning-enabled decision support systems can harness vast amounts of data within healthcare systems to provide optimal learning resources for healthcare practitioners. These systems help manage the complexities of clinical variabilities and enhance diagnostic accuracy.[20]

Advances in cloud computing, data processing, and the availability of extensive data have driven the increasing adoption of AI in healthcare and dentistry. For instance, radiology has benefited from AI algorithms that assist in diagnosing conditions and suggesting potential treatment options.

AI can also be utilized in various dental fields, such as prosthodontics, orthodontics, oral surgery, and periodontics, for condition analysis and treatment planning.[21]

Deep learning (DL)

Deep learning (DL) is a subset of machine learning (ML) that involves computational models with multiple layers of data processing, allowing for learning by representing data through various levels of abstraction. Unlike traditional ML, deep neural networks (DNNs) can independently learn and organize the training database but require larger amounts of data. This eliminates the need for new feature extractors for each problem. DL employs a back propagation algorithm to train neural networks.[8]

Neural networks

In 1943, Warren McCulloch and Walter Pitts published a paper suggesting neural networks as a way to imitate human brains.[22] An artificial neural network (ANN) is a DL algorithm that simulates a biological system.It has 3 layers; An Input layer (that receives the input signals), several Hidden layers and an Output layer.[8] Deep ANNs have a large number of hidden layers and thus achieve high accuracy.[23] Other deep learning (DL) network architectures have been developed to cater to specific applications and types of learning data. For instance, convolutional neural networks (CNNs) are frequently utilized in DL for image processing tasks, such as automated segmentation and computer-aided diagnosis using medical images.[24]

Recurrent neural networks (RNNs) are another type of network architecture designed to process time-dependent information, making them suitable for applications like speech processing and video analysis.[25]

ARTIFICIAL INTELLIGENCE IN PROSTHODONTICS

Prosthodontics is a dental specialty focused on diagnosing, planning treatment, rehabilitating, and maintaining oral function, comfort, appearance, and health for patients with missing or deficient teeth and/or maxillofacial tissues using biocompatible substitutes. AI in prosthodontics primarily assists with diagnosis, treatment planning, and the fabrication of removable and fixed partial dentures, implant surgeries, and maxillofacial prostheses. It is also used to select the shade of prostheses. AI technology has now become fully integrated into prosthodontic practice.[26] Artificial intelligence (AI) technology has arrived and has been fully integrated into prosthodontic practice.

I. Removable and fixed prosthesis

With the introduction of AI-based advancements in prosthodontics, digital impression-taking and intraoral scanning methods now support the fabrication of fixed and removable prostheses with remarkable accuracy. Additionally, 3D face tracking systems can create dental prostheses as an alternative to conventional methods. As clinical environments constantly evolve, it is crucial to maintain a skeptical approach to AI's outputs.[27]

II. Implantology

The application of AI in implantology presents the opportunity to enhance and develop future prosthetics. Implantology can address many limitations of fixed and removable prostheses. Implants offer several benefits, such as increased resistance to dental diseases, preservation of the residual ridge, and improved support in distal extension cases.[28]

Implants are widely used in dentistry to replace the missing tooth or for the entire mouth rehabilitation. Acceptance of implant prosthesis has been increased in recent years due to better aesthetics and stability.

In a study by Lee J and Jeong S, convolutional neural networks (CNNs) were used to analyze implants with the help of panoramic and periapical radiographs. The results indicated that the deep CNN model can classify implant systems with accuracy comparable to or even greater than that of human experts.[29]

III. Maxillofacial prosthesis

"Maxillofacial prosthodontics" is a sub specialty of prosthodontics focused on rehabilitating patients with congenital defects or disabilities, or those acquired due to disease or trauma. These prostheses are primarily indicated for cosmetic and psycho-social reasons, but they are also essential for restoring normal oral functions such as swallowing, speech, and chewing.

In 1953, Ackerman defined Maxillofacial prostheses as the branch of dentistry that repairs and artificially replaces parts of the face following injuries or surgical interventions.[30]

Maxillofacial reconstruction involves implanting artificial substitutes for intraoral and extraoral structures, including the eyes, ears, nose, maxilla, mandible, and palate etc.[31]

This requires different impression materials. The problems associated with these procedures are discomfort for patients, chances of material engaging in undercuts, difficulty in breathing, soft tissues may be distorted, time consuming, and difficult procedures. Due to advancements in the field of technology, computerized three-dimensional data processing can obtain entire facial morphology measurements by using a non-contact 3D laser morphological measurement system.[32]

The success of a maxillofacial prosthesis largely depends on its retention, which enhances the patient's comfort and confidence. Methods to improve retention include adhesives, implants, eyeglasses, and their combinations. Advances in adhesive techniques and materials for maxillofacial prostheses have been significant.[33] Over the past two decades, osseointegrated implants have been utilized to improve retention in the craniofacial regions. Available systems on the market include bar and clip systems, magnets, mushroom, and ball retention methods.[34] Additionally, these prostheses can now be manufactured using digital technologies.[35]

The creation of maxillofacial prostheses using CAD/CAM technology begins with imaging techniques that capture the patient's soft and hard tissues. This data is then converted into a rapid prototyping (RP) model using specialized software. The RP models are subsequently used to create wax or acrylic resin reproductions. Finally, a silicone elastomer prosthesis can be fabricated from these casts. This method is more time-efficient compared to traditional approaches.[36]

IV. CAD-CAM (Computer Aided Designing & Computer Aided Manufacturing)

Additive manufacturing, subtractive manufacturing, 3D printing are commonly used CAD-CAM technology for fabrication of prostheses in Prosthodontics.

CAD-CAM system has got 3 components

1. Digital impressions: Collection of data of prepared teeth and adjacent tissues from dentist and later transform into visual impressions. These are later transferred to the laboratory.
2. Designing the final prosthesis and preparing for milling.
3. Milling phase: After the design of the final prosthesis, fabrication of the prosthesis is done by milling suitable restorative material.[32]

1. Digital impressions/scanners: Conventional impression techniques are the ideal ways of recording prepared teeth and adjacent dental tissues. Regardless of advancements in material sciences, there are many drawbacks of impression materials. Till recently we do not have one common ideal impression material available for all kinds of procedures. With the advancements in the field of technology, intraoral scanners were developed to overcome the drawbacks of the conventional impression.[37]

2. Designing final prosthesis: After receiving the scanned impression of prepared tooth from the dentist in the laboratory, the data are processed by design software. Final 3-dimensional image can be designed which exactly looks like provisional restoration. The designed final prosthesis can be transferred to dentist for approval, if required the final design can be modified. After designing the final prosthesis, the data is transferred to the special milling device.[38]

3. Milling phase: After steps 1 and 2 where design is completed, data is transferred to the centralized milling/production centre. Suitable restorative material can be milled by using additive technique, subtractive technique or 3D printing technique.[39]

CONCLUSION

As with any technological advancement, there is a range of opinions among professionals about the role of AI in healthcare. Nevertheless, the future of AI in healthcare looks promising, especially in its ability to decentralize treatment processes and enhance the accuracy of remote care. AI elevates diagnostics by integrating predictive analytics with human expertise, resulting in more precise disease diagnoses.

In prosthodontics, AI is increasingly influential across various areas, including removable, fixed, maxillofacial, and implant prosthodontics. AI enhances the functionality and acceptance of prosthodontic treatments while also minimizing human error. The impact of AI is particularly significant in prosthodontic implant applications. Researchers are actively utilizing AI to develop innovative systems that advance both dental care and overall health.

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