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PROSTHETIC AND IMPLANT DENTISTRY
Official Publication of Indian Prosthodontic Society
Kerala State Branch

REVOLUTIONIZING PROSTHODONTICS THROUGH ARTIFICIAL INTELLIGENCE – A REVIEW

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https://doi.org/10.55231/jpid.2025.v08.i03.02

Abstract

Artificial intelligence (AI) is transforming prosthodontics by enhancing efficiency, accuracy, and patient satisfaction. This review explores the latest advancements and innovative applications of AI across various subspecialties, including fixed, removable, implant, and maxillofacial prosthodontics. AI is revolutionizing multiple aspects of prosthodontic care, from diagnosis and decision-making to treatment planning and outcome prediction. Its applications extend to tooth shade selection, restoration design, precise tooth preparation, optimization of casting and manufacturing, implant design, robotics, and predicting facial changes in patients with removable prostheses. Additionally, AI plays a crucial role in assessing treatment outcomes for temporomandibular disorders, further contributing to improved oral health care. Despite its potential to enhance precision and streamline dental procedures, widespread implementation is hindered by the limited availability of extensive datasets. Overcoming this challenge will be essential for maximizing AI's impact on prosthodontic practice.

Keywords: artificial intelligence, machine learning, deep learning, robotics, CAD/CAM

Introduction

Prosthodontics is rapidly evolving with advancements in technology, materials, and digital innovations, with artificial intelligence (AI) and robotics significantly enhancing clinical practice, education, and research. AI, first conceptualized in 1943 and formally named by John McCarthy in 1956, refers to machine programs capable of logical reasoning and cognitive tasks. With advancements in computing, big data, and machine learning (ML), AI has become an essential tool in various medical fields, including dentistry[1]. A specialized branch of ML, deep learning (DL), utilizes convolutional neural networks (CNNs) to analyze complex datasets, making it particularly useful in dentistry for improving image analysis, optimizing workflows, and enhancing treatment precision by processing vast amounts of clinical, imaging, and proteomic data[2]. In Prosthodontics, AI-powered CAD/CAM software enables precise tooth realignment for denture fabrication, ensures superior aesthetics and function, enhances color-matching techniques

for seamless restorations, and improves implant planning by integrating intraoral scans with CAD programs for more accurate implant placement and prosthetic design. AI is time-saving and revolutionizes dental care by minimizing costs, providing customized, proactive treatment, and integrating healthcare services to enhance overall patient welfare[3].

Relevence of AI

Traditionally, prosthodontic restoration has heavily depended on the expertise of dentists and technicians, requiring labor-intensive manual techniques that leave room for human error. While modern advancements have mitigated these errors to some extent, the integration of AI has the potential to transform the entire prosthodontic workflow, from diagnosis to treatment planning and execution. AI offers various attributes that enhance precision, efficiency, and predictability in prosthodontic restoration.[4]

These attributes include:

• Autonomous operation: Automation of tasks ranging from laborious manpower to the recruitment process with the help of AI can ease the complexities of tedious manual tasks. This can contribute to focusing on more important and complex tasks.

• Increased performance: Automation helps with minimum effort, maximum efficiency, increased performance, and time management.

• Smart decision making: Artificial intelligence is a technology that uses machines to imitate intelligent human behavior. Machine learning focuses on applying algorithms derived from former cases, which help decision-making and ensure accuracy.

• Addressing intricate challenges: Navigating intricate issues demands a blend of critical thinking and innovative solutions. Healthcare demands solutions to such complex challenges, which might involve diagnosis, correlating clinical findings, or treatment planning.[5]

Scope of AI in Dentistry

Artificial intelligence is transforming dentistry by improving diagnosis, treatment planning, and patient care. Machine learning algorithms analyze dental images to detect caries, periodontal disease, and oral pathologies with high accuracy. In orthodontics, prosthodontics, and implantology, AI optimizes treatment planning, enhances digital smile design, and improves the precision of CAD/CAM restorations. AI also aids in endodontics by identifying root canal morphology and periapical infections, ensuring better treatment outcomes.

Beyond clinical applications, AI enhances patient management and education. AI-powered chatbots assist with scheduling and post-operative care, while tele-dentistry enables remote diagnosis. In research and training, AI analyzes large datasets to improve treatment protocols and supports simulations for dental students. Despite challenges like data privacy concerns, AI is making dentistry more efficient, precise, and patient-focused[6].

Role of AI in Prosthodontics

Prosthetic dentistry is the art and science of dentistry that deals with the diagnosis, treatment planning, rehabilitation and preservation of the oral structures function, comfort, aesthetics and health of patients with clinical problems associated with missing or deficient teeth and oral and maxillofacial tissues. Prosthodontics mainly focuses on the treatment and fabrication of removable and fixed dental prosthesis, preparation of finishing margins alongside the tooth for better extension and fitting of the prosthesis, implant procedure and construction of a maxillofacial prosthesis. Maintenance of proper maxillomandibular relations, selection of tooth shade for better aesthetics. AI can be very advantageous in various methods of treatment protocol[7].

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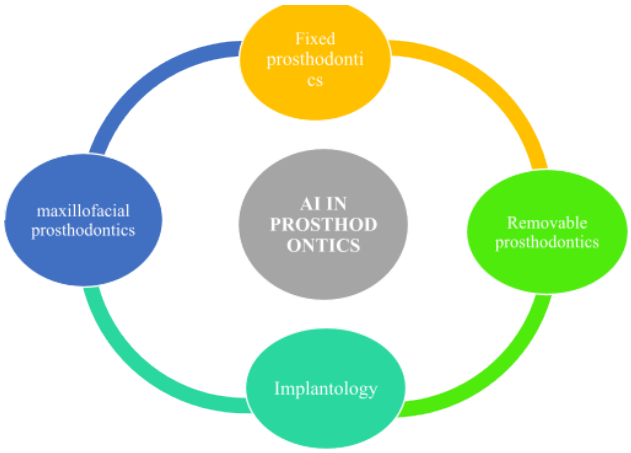
The main areas of focus for AI in prosthodontics are:



Discussion

Diagnosis and Treatment Planning

The application of artificial intelligence for accurate diagnosis in Prosthodontics is based on AI-based imaging analysis. Intra oral scanners and CBCT scans generate large amounts of digital data, AI algorithms can extract valuable information and assist in diagnosis. Machine learning (ML) makes these functions possible by teaching computers rules based on data and identifying inherent statistical patterns and structures in the data and thus help in analyzing any anomalies in the tooth structure.

AI-assisted treatment planning algorithms play a vital role in simplifying and optimizing the treatment planning process. These algorithms create personalized treatment regimens by analyzing patient data, such as clinical records, diagnostic pictures, and patient-specific characteristics, using artificial intelligence approaches. AI algorithms can identify patterns and correlations in a big dataset to establish the best course of action for each patient by utilizing machine learning and data mining. To create individualized treatment plans and optimize treatment outcomes, factors such as patient's current state of oral health, aesthetic preferences, functional requirements, and anatomical concerns are considered.[8]

Prosthodontic Specific AI Implications

Fixed Prosthodontics

1. The Digital Smile Design

Artificial intelligence (AI) is increasingly being integrated into the domain of smile design, bringing forward numerous benefits and advancements. The AI algorithms possess the capability to meticulously analyze various aspects of facial features, including symmetry, lip line, tooth shape, and size, to generate optimal smile designs. This technological advancement significantly enhances both the precision and efficiency of the design process, thereby enabling dental practitioners to deliver treatments that are not only aesthetically pleasing but also functionally effective. One of the AI-based systems, such as the Visagi Smile concept, leverages Machine Learning techniques to establish a relationship between facial perception and personality traits in the context of smile design. This approach facilitates the creation of highly personalized treatment plans that take into account the unique characteristics of each patient, ultimately leading to more tailored and satisfactory outcomes.[1]

2. The Tooth Shade Selection

The shade guides for tooth shade selection in clinical prosthodontics are currently available in countless types and capabilities. Along the classical Vita Classical Shade Guide, the shade-matching spectrophotometers, intraoral electronic devices like Vita Easyshade (Vita Zahnfabrik, Bad Säckingen, Germany), the ShadeEye NCC Chroma Meter (Shofu Dental, Menlo, CA, USA), the iTero Element (Align Technology, Inc., San Jose, CA, United States), computer-aided shade selection software,

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colorimetric systems, hybrid devices, and mobile applications are some of the past and current options for an accurate assessment of tooth color and shade[9].

3. The Mapping of the Preparation Finishing Line

The use of AI in mapping the preparation finishing line in fixed prosthodontics promises significant precision and efficiency in the last decade. AI algorithms, particularly those based on ML and DL, have been developed to accurately detect and map the preparation finishing line of dental preparations. These algorithms analyze digital impressions or intraoral scans to identify the exact margins of the preparation, ensuring a precise fit for the dental crowns and bridges.[10]

4. The Automated Tooth Preparation

Recently, Perceptive, a company based in Boston (MA, USA), introduced an AI-driven robotic system designed for dental procedures, including the preparation of teeth for dental crowns. This innovative robot utilizes advanced optical coherence tomography (OCT) and AI programming to create detailed 3D maps of the teeth, which are then analyzed by AI to plan the tooth preparation. The system can complete a procedure that typically takes several hours in just about 15 min. Further benefits consist of increased precision and accuracy compared to that matched by the human hands, resulting in better fitting crowns and bridges[11].

5. Prosthesis Design and Fabrication

The fabrication and delivery of the finest removable and fixed prostheses is the primary expectation of prosthodontics. CAD and CAM systems combined with a three-dimensional digital workflow have revolutionized the practice of dentistry. An initial intra-oral scan is sent to the CAD/CAM software, which designs, manufactures, prints, or mills the prosthesis. CAD/CAM is useful to manufacture inlays, onlay, crowns, and bridges. This saves time, resources, and energy for both prosthodontics and patients. This also reduces the chances of human error in the final prosthesis.[12]

AI-Driven Workflow in Modern Dental Practice

In modern dental practice, AI co-piloting enhances the dentist's role by acting as an intelligent assistant. While the dentist remains the primary decision-maker, AI supports the process by analyzing vast amounts of data and extracting insights from comprehensive knowledge bases. This collaboration leads to more informed decision-making by providing evidence-based recommendations, predicting treatment outcomes, identifying potential risks, and personalizing care strategies. As a result, AI integration optimizes clinical efficiency and improves patient care.[13]

Removable Prosthodontics

1. Predicting facial changes before treatment

AI models have been employed to forecast facial alterations in edentulous individuals who are going to undergo complete denture treatment. Following the delivery of the prosthesis, the model successfully anticipated alterations in the facial soft tissue[14].

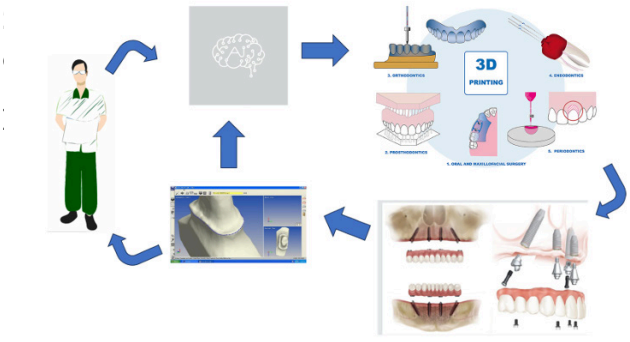

Figure 1. Workflow of dental practice with A.I. co-piloting

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Backpropagation Neural Network (BPNN) to create an AI model that effectively forecasted the surface roughness and microhardness of four denture tooth materials when subjected to four distinct liquids. Predicting surface roughness and microhardness based on particular characteristics can help in choosing suitable denture materials and fostering their performance[15].

Designing of Removable partial dentures

AI has been employed in the design of Removable Partial Dentures (RPDs), beginning with the identification of the position of the missing teeth, categorization of the prosthetic condition of the remaining teeth, and analysis of the occlusion. AI applications translate two dimensional RPD design diagrams into a structured tree format utilizing CAD/CAM technology to generate three dimensional RPD frameworks[16].

Designing Removable Partial Dentures (RPDs) is a complex task guided by a set of established rules. To streamline this process, a novel logic-based RPD design software called AiDental was developed. The AiDental RPD Designer utilizes algorithm-based software with basic AI functionality, acting as a decision-making tool for RPD design. Its algorithms incorporate the principles of RPD design, allowing the software to process user input and automatically generate accurate RPD frameworks.[17]

Implantology

Assist in diagnosis and Treatment Planning

AI algorithms, trained on vast datasets of images, possess the capability to analyze vast amounts of patient data, including radiographic images, three-dimensional scans, and clinical records, and also accurately identify and classify dental pathologies, bone structures, and anatomical landmarks. This capability is crucial for the precise placement of dental implants, ensuring optimal integration with the patient's existing bone structure. For instance, AI systems can analyze CBCT scans to detect the quality and quantity of bone, which is essential for determining the feasibility of implant placement and planning the surgical approach.

Detection/Recognizing Implant Type/ Brand

Different implant brands have various abutments and prosthetic components, making it challenging to identify them when complications arise, especially if the original clinician is unavailable. Accurate identification requires information about the implant manufacturer, diameter, length, platform, and abutment type. AI-based implant brand detection offers a promising solution to this problem. Studies, such as a multi-center study by Park et al. involving 156,965 radiographs, have shown high accuracy in identifying dental implant systems (DIS). However, differences in datasets, CNN models, and implant brands lead to varying results[18]. To improve accuracy, it is essential to expand datasets and develop regional-based deep learning models while maintaining ethical standards[19].

Development of New Implant Designs

AI models have been used to enhance dental implant design by predicting how implants manage stress at the bone connection. For example, Li et al. developed an AI model that reduced stress at the implant-bone interface by 36.6% compared to traditional FEA methods. Roy et al. combined neural networks and genetic algorithms to optimize implant geometry, while Zaw et al. applied AI to measure the elasticity of the bone-implant interface. Although these studies show promise, more research involving in vitro, animal, and clinical studies is needed to improve practical applications[20].

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Prediction of Treatment Outcomes in Implantology

AI algorithms have been used to predict the risk of dental implant failure, helping dentists identify high-risk patients and adjust treatment plans.[21] Huang et al. developed three models—a clinical model, a radiographic model, and a combined model—with the combined model showing the best performance in predicting implant failure within five years. Similarly, Zhang et al. developed a model using dental X-rays, achieving 87% accuracy by analyzing bone loss around implants. While these models are promising, more long-term studies are needed to ensure their reliability in practice[22].

Robotic Implant Surgery

The integration of robotics and AI in dentistry, known as "dentronics," aims to enhance precision in dental implant placement. Accurate surgical placement is essential to avoid complications during both surgical and prosthetic phases. In 2017, the FDA approved a robotic surgical assistant for dental implant placement.[11] The dentist plans the implant position using CBCT scans, and the robotic arm performs the surgery while the dentist monitors and can adjust angulation in real-time. In the same year, a successful case in China involved a robot placing two implants in a patient without dentist intervention. AI can further advance dentronics by analyzing large patient datasets to improve diagnosis and treatment planning.[23]

Detection of fractured implants

AI has shown great potential in detecting fractured dental implants. Dong-Woon Lee et al study evaluated VGGNet-19, GoogLeNet Inception-v3, and automated DCNN (Deep Convolutional Neural Network) architectures, all of which demonstrated acceptable accuracy in identifying and classifying fractured implants. Among them, automated DCNN performed the best, using periapical radiographic images. Further clinical validation is needed.[24]

Maxillofacial Prosthodontics

Coloration Techniques for Maxillofacial Prostheses

The pigmentation of maxillofacial prostheses is vital in attaining a lifelike and authentic appearance for those in need of facial repair. Commercially available computerized colour matching system (e-skin) has enabled good colour matching. Creating a skin colour-matching technique based on real-time Deep earning (DL) might improve the accessibility and affordability of colouring support for maxillofacial prostheses.[25]

Skin tissue engineering

Skin tissue engineering is a contemporary medical practice that aims to create bioprinter biomaterial-based synthetic skin grafts. This cutting-edge approach to wound regeneration attempts to create skin replacements that work as bioactive dressings, improving the wound's functionality.[14]

AI-Enhanced Techniques in Obturator Fabrication

Recent research shows progress in using AI to design and fabricate obturators, aiming to improve accuracy, reduce fabrication time, and enhance the quality of life for maxillofacial patients. Ali I.E. et al. evaluated four pre-trained CNN models (VGG16, Inception-ResNet-V2, DenseNet-201, and Xception) to recognize seven prosthodontic scenarios related to the maxilla, including conditions like cleft palate and various types of maxillectomy. All models achieved over 90% accuracy, with Xception and DenseNet-201 performing slightly better, reaching up to 95% accuracy. These results demonstrate the potential

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of AI in dental image analysis, automated diagnosis, and prosthesis design.[26]

Advancements in eye Prosthesis Fabrication Using AI

"Smart reading glasses," which are voice-activated gadgets that can be attached to any pair of glasses, are designed primarily to help blind and visually challenged people. It can quickly read text from a book, smartphone screen, or any other surface, identify faces, work more effectively, and help its user lead an independent life. "Bionic eye," created in the United States, utilizes artificial intelligence to help patients who have lost their sight see without surgery[5].

The Role of AI in TMJ Disorder Management

Diagnosis and treatment planning

Within the domain of prosthetic rehabilitation for temporomandibular joint (TMJ) disorders, the utilization of Artificial Intelligence (AI) techniques offers multifaceted benefits. In the diagnostic phase, AI, particularly machine learning algorithms, proves instrumental in assimilating and interpreting extensive patient data, facilitating a nuanced and early detection of TMJ disorders. This data-driven approach enhances the accuracy of diagnosis and sets the foundation for targeted interventions.

Prosthetic Rehabilitation

In the arena of prosthetic rehabilitation, AI contributes significantly to the customization of devices. Machine learning algorithms delve into patient-specific data, discerning unique anatomical features and functional requirements. This tailored approach ensures the design and fabrication of prosthetic devices that align precisely with individual needs, fostering enhanced comfort and functionality.[28]

Robots for treating TMJ disorders

The Waseda Asahi Oral-Rehabilitation Robot No. 1 (WAO1) is an oral rehabilitation robot developed by Waseda University in Japan. It consists of a headrest-equipped body, two robotic arms with six degrees of freedom, a control box, a computer, and an automated massage system. The robot massages the patient's face, including facial tissues, masticatory muscles (masseter and temporalis), and oral structures like the parotid gland and duct. Controlled by a computer, it helps treat conditions such as dry mouth and temporomandibular joint (TMJ) disorders.[11]

Limitations of AI

Similar to any other technology, AI has its own set of limitations and boundaries. AI technology has not been completely understood owing to its complexity, and it has the ability to autonomously change its behaviour.[7]

Any fault in the accumulation, assessment, or assortment of data can lead to substantial errors in AI programs. Hence, the information and data provided to AI must be correct, authentic, and accurate at any given time. Therefore, AI models and software require regular updates and upgrades. AI processes large amounts of data quickly, requiring high computational power. This can be a potential barrier to AI productivity because quantum computing is expensive and unavailable for common use. Interpreting AI results can pose challenges because of the generalization of similar techniques across various conditions. Prosthodontics involves rehabilitation of the patient using prosthetic materials; therefore, any miscalculation can lead to unfavourable and disapproving outcomes or

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results.[9]

Ethical and legal considerations challenge the growth of AI. Factors such as privacy, data protection, informed consent, autonomy, social gaps, justice, empathy, and safety must be considered before using full-scale AI in medical healthcare systems.[18]

Conclusion

It can be concluded that the use of artificial intelligence are of immense use in dentistry, in general but for prosthodontics it has a broader role to play. AI is of greater application in removable, fixed, maxillofacial, and implant prosthodontics for its precision and accuracy. The functionality and acceptance of prosthodontic treatment are enhanced with the use of AI and invading human errors. It is also revealed that in prosthodontic implant applications benefit the most from its success of prosthesis. In addition, researchers were found to use AI to create systems for dentistry and improve overall health.

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