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Current Updates In Artificial Intelligence In Prosthodontics: A Narrative Review

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Abstract:
Background:
Artificial intelligence (AI) is revolutionizing prosthodontics with technologies such as machine learning (ML), neural networks, and computer vision. This review discusses AI's history, applications, and potential across prosthodontics, including challenges like ethical issues and data privacy. AI can streamline workflows, enhance diagnostics, and improve treatment planning and outcomes in areas like removable and fixed prosthodontics, maxillofacial prosthetics, and implantology.
Search methodology:
A comprehensive literature search was conducted across electronic databases, including PubMed, Scopus, and Google Scholar. The search focused on articles published in English within the last 10 years (2013–2023), using key terms such as "artificial intelligence," "machine learning," "deep learning," and "prosthodontics," combined with specific terms like "dental implants," "digital dentistry," and "CAD/CAM." Relevant peer-reviewed articles, clinical studies, and review papers were included, while editorials, conference abstracts, and non-peer-reviewed content were excluded. The literature was manually screened for relevance based on titles and abstracts, and reference lists of selected studies were also reviewed to identify additional relevant publications
Conclusion:
AI has shown significant potential to enhance accuracy, efficiency, and personalization in prosthodontics. While current applications are promising, further research is needed to validate AI-driven technologies in clinical practice and explore their integration into routine prosthodontic care.
Keywords: *Artificial intelligence, prosthodontics, machine learning, neural networks, removable prosthodontics, fixed prosthodontics, CAD/CAM, maxillofacial prosthesis, implantology*

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I. Introduction

Prosthodontics, a dental specialty focused on tooth restoration and replacement, is increasingly benefiting from AI. The technology helps improve clinical outcomes, assists in complex treatment planning, and reduces human error. AI's integration into prosthodontics spans removable and fixed prosthodontics, maxillofacial prosthetics, and implantology, marking a significant shift toward more data-driven, efficient patient care.

History of Artificial Intelligence in Medicine:

The evolution of artificial intelligence (AI) traces back to the mid-20th century, with several pivotal developments shaping its trajectory in medicine and prosthodontics [1,2].

1. **Early Concepts (Pre-1940s):** Philosophers like Leibniz and mathematicians like Alan Turing conceptualized intelligent machines. Turing's 1936 paper on the "universal machine" laid the foundation for modern computation. In 1950, he introduced the **Turing Test**, which proposed a way to evaluate whether a machine could exhibit human-like intelligence.
2. **Birth of AI (1950s):** AI as a formal discipline emerged in the 1950s. In 1956, John McCarthy coined the term "artificial intelligence" at the **Dartmouth Conference**, now seen as the birth of AI. Early programs, such as **Logic Theorist** (1955) and **ELIZA** (1964), demonstrated AI’s ability to mimic human reasoning and conversational abilities.
3. **First Medical AI Systems (1960s):** In the 1960s, AI began its medical journey with **Dendral**, an expert system used for chemical analysis. The medical counterpart, **MYCIN**, emerged in the 1970s, diagnosing bacterial infections and recommending treatment. These early expert systems paved the way for AI applications in clinical decision-making.

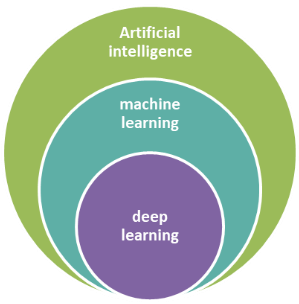
4. **AI Winter (1970s-1980s):** Due to limitations in computational power and unmet expectations, AI progress slowed in the 1970s, leading to reduced funding—a period known as the "AI Winter." Despite this, notable advancements like the **MYCIN** system demonstrated AI's potential in diagnosing infectious diseases and guiding antibiotic therapies.
5. **Renewed Interest (1980s-1990s):** AI regained momentum in the 1980s with the rise of **expert systems** and advancements in **machine learning (ML)**. Systems like **Internist-I** and **PIP (Present Illness Program)** became decision-support tools in medical diagnostics. Improved computing power, especially neural networks, supported more complex AI models, expanding their use in healthcare.
6. **Modern AI (2000s-Present):** The 2000s witnessed rapid advances in AI, primarily driven by **deep learning** and neural networks. **Convolutional Neural Networks (CNNs)** and breakthroughs in **natural language processing (NLP)** and **robotics** have enabled AI to excel in diagnostic imaging, predictive analytics, and robotic surgeries.

In dentistry, AI systems such as **IBM Watson Health** have been utilized to interpret electronic health records (EHRs) and make personalized treatment recommendations. Robotic systems, such as the **Da Vinci Surgical System**, and AI-assisted diagnostic tools in radiology have similarly transformed clinical workflows and improved outcomes.

Types of AI: AI can be categorized by its capabilities:
1. **Narrow AI**: Specialized in specific tasks (e.g., Siri, Alexa).
2. **General AI**: Hypothetical, capable of reasoning like humans.
3. **Super AI**: A theoretical concept surpassing human intelligence.

Machine Learning[1,2] is a subset of AI that involves the use of algorithms and statistical models to enable computers to learn from and make predictions or decisions based on data, without being explicitly programmed for each specific task.ML algorithms learn from data to make predictions or decisions. Common algorithms include linear regression, decision trees, support vector machines (SVMs), and k-nearest neighbours (k-NN).
- Training Data: ML models are trained using historical data, where they learn patterns and relationships within the data.
- Supervised Learning: Involves training a model on labeled data, where the output is known. Examples include spam detection in emails or predicting house prices based on features.
- Unsupervised Learning: Involves training a model on unlabeled data, where the system tries to find patterns or groupings without explicit labels. Examples include clustering customers into segments or dimensionality reduction.
- Reinforcement Learning: A type of ML where an agent learns to make decisions by receiving rewards or penalties based on its actions. It's used in areas like game playing and robotics.

Deep Learning[1,2] is a specialized subset of machine learning that uses neural networks with many layers (hence "deep") to model and understand complex patterns and representations in data. It is particularly effective in handling large amounts of unstructured data such as images, text, and audio.
Key Concepts include :
- Neural Networks: DL models are built on artificial neural networks, which are inspired by the structure and function of the human brain. They consist of layers of interconnected nodes (neurons) that process data.
- Deep Neural Networks (DNNs): These networks have multiple hidden layers between the input and output layers. The depth of the network allows it to learn hierarchical features from data.
- Convolutional Neural Networks (CNNs): Specialized for image processing, CNNs use convolutional layers to detect features such as edges, textures, and patterns in images.
- Recurrent Neural Networks (RNNs): Designed for sequential data, RNNs process data in sequences, making them suitable for tasks like language modeling and time series prediction.
- Transformers: A type of neural network architecture that has revolutionized natural language processing by improving tasks like machine translation and text generation.



Deep learning models, such as CNNs, are used for tasks like facial recognition, object detection, and medical image analysis.[3]

II. AI in Prosthodontics

Introduction of digital dentistry into complete dentures begin with data acquisition. There are two methods to digitise data – direct and indirect.

A. AI in Radiology

One of the significant advancements in AI for prosthodontics is its application in **radiology** for detecting dental caries[3,4]. **Convolutional Neural Networks (CNNs)**, a deep learning architecture, have proven highly effective in identifying caries from radiographic images.

How CNNs are Trained for Caries Detection:

1. **Data Collection:** The first step in training a CNN model for caries detection involves gathering a large dataset of annotated radiographs. These radiographs are labeled to indicate the presence or absence of caries. Thousands of these images are used to create a comprehensive dataset that the CNN will learn from.
2. **Model Training:** During training, the CNN learns to identify patterns in pixel-level data from the radiographs. The model processes images through multiple layers of convolutional filters, detecting features like changes in tooth density or shadowing, which may indicate caries.

The model is trained using deep learning techniques, where the CNN adjusts its weights through backpropagation, continuously improving its ability to recognize caries based on the labeled examples. As it processes more data, the CNN becomes increasingly accurate in detecting caries at various stages of development, from early lesions to more advanced cases.

3. **Detection:** Once trained, the CNN model can automatically analyze new radiographs to detect caries. The system highlights potential areas of concern for dental practitioners, identifying the location, size, and severity of carious lesions. Studies have demonstrated that CNN models can match or even surpass the diagnostic accuracy of human dentists, particularly for early-stage caries, which may be challenging to identify visually.

To determine cavities, fractures and bone loss etc., digital radiographs, CBCT scans among other imaging modalities can be analysed by the use of AI tools such as **Second Opinion by Pearl[5,6], Videa caries assit[7]**. They also help in greater effectiveness in interpreting images and might help in cutting out mistakes that a human would make in diagnosis.

For instance, **Overjet AI[8]** can generate highlighted alerts on radiographs or other x-rays thus changing the focus of concern of the dentist. This not only helps in faster diagnosis but also helps in excluding any other complications that are being missed.

Diagnocat[9] and Denti.AI can be used to identify periapical radiolucencies in radiographic images and demarcate Vertical Root Fractures on panoramic radiographs and CBCT images. **EndoVisionAI** specifically designed accurate assessment of root morphology and pathology.

B. AI in Removable Prosthodontics:

AI is enhancing the design and production of removable prostheses. Through **CAD/CAM** technology, AI-driven systems can analyze intraoral scans and patient data to create highly customized and accurate prosthetic designs. These systems reduce manual errors and improve prosthetic fit and function. **Exocad**: offers multiple designs for removable partial dentures (RPDs) based on factors like stress on adjacent teeth and implants, optimizing the prosthetic framework for better patient outcomes.

C. AI in Fixed Prosthodontics:

In fixed prosthodontics, AI integrates with **CAD/CAM systems** to automate the design and milling of restorations like crowns and bridges. AI models can accurately interpret digital impressions and radiographs, suggesting optimal materials and designs while predicting the long-term durability of the prosthetics. **AI Automate and AI dentbird** by **3Shape Dental System[10]** is notable for its precision in evaluating crown preparation margins and reducing occlusal and positional errors, improving the success rate of fixed restorations.

D. AI in Maxillofacial Prosthodontics:

Maxillofacial prosthodontics benefits from AI's role in designing prostheses for patients with facial defects due to trauma or congenital conditions. AI-driven **3D printing** and facial recognition technologies are helping clinicians create highly customized prosthetics. For the disabled in society, those who cannot see or those with normal vision, the **Smart bionic prosthetic eyes[11]** can read, see texts, recognize faces and record audio.

RaPiD is a design assistant that combines anthropological data and patient preferences to suggest the most appropriate prosthesis, ensuring both functional and aesthetic outcomes.

E. AI in Implantology:

AI enhances implantology by improving implant placement planning through **CBCT data analysis**, predicting the best implant site based on bone density and anatomical structures. Additionally, AI systems can forecast implant longevity and anticipate complications[12]. **3Shape Dental System, Exocad, Diagnocat** are some of the available tools assisting in implant planning and placement, analysing digital records and providing real-time adjustments during surgery, improving the precision and safety of procedures.

AI models are also being trained for recognizing implant brands and models when treating patients with undocumented implants. **Identi** and **DentID** are AI-powered tools that analyze radiographs to identify implant make, aiding in treatment planning and maintenance[13-15].

F. AI-enabled Virtual Reality (VR) and Augmented Reality (AR)

Virtual and Augmented reality both with the support of AI are revolutionizing dentistry as they allow interaction and even improve patient understanding of the procedures to be performed. While using the VR headsets or AR devices, the patients can visualize, and physically engage in simulated dental procedures, thereby decreasing their anxiety levels and aiding informed decision-making. It also provides significant leap in education and training of students with virtual and augmented models.

III. Challenges And Ethical Concerns

The use of AI in the medical field poses several challenges and ethical issues. One key challenge is the **lack of clinical validation and regulation**. Many AI tools are still experimental, requiring extensive validation through clinical trials to ensure accuracy, safety, and consistency in real-world medical environments. Integrating AI into existing healthcare systems is another challenge, as medical professionals must learn to use AI effectively while maintaining high standards of patient care.

Ethically, **data privacy and security** are major concerns. AI systems rely on large datasets, often involving sensitive patient information. Ensuring this data is securely stored and processed is critical to avoid breaches of patient confidentiality. Moreover, the **ownership and control of data** can be ambiguous, raising legal and ethical questions about who has access to and control over patient information.

Bias in AI algorithms is another pressing issue. AI systems can inherit biases from the data they are trained on, potentially leading to unequal or substandard care for underrepresented groups. Additionally, the **lack of transparency** in AI decision-making can make it difficult for healthcare providers to understand and trust AI recommendations. Finally, issues of **accountability and liability** need to be addressed through clear regulatory frameworks, particularly in cases where AI errors result in misdiagnosis or harm to patients.

IV. Conclusion

AI is poised to revolutionize prosthodontics by enhancing precision, improving clinical outcomes, and streamlining workflows. From removable and fixed prosthetics to maxillofacial reconstructions and implantology, AI's applications are diverse and growing. However, challenges such as data privacy, ethical considerations, and the need for clinical validation remain significant. As AI technology continues to evolve, it holds the potential to become an indispensable tool in prosthodontic care, ultimately improving the quality of life for patients worldwide.

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