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Artificial Intelligence in Clinical Practice- A Narrative Review

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ABSTRACT:
Artificial intelligence (AI) is revolutionizing in dental practice by improving diagnostic accuracy, treatment planning, and patient care. AI, which includes machine learning (ML), deep learning (DL), neural networks (NN), and data science has enhanced various dental disciplines like periodontics, implantology, endodontics, orthodontics, prosthodontics, and oral maxillofacial surgery. In periodontics, AI-driven its advancement in bone-level assessments and periodontal disease detection. Implantology has benefited from AI's ability to optimize implant design and assist in robotic surgery. Endodontics utilizes AI for root canal detection, vertical root fracture identification, and predicting treatment outcomes. Orthodontics leverages AI for facial analysis, tooth segmentation, and orthodontic case assessments. In prosthodontics, AI enhanced in removable partial denture design and automated crown preparation. AI also aids in diagnosing maxillofacial tumors, improves radiographic image quality, and facilitates remote monitoring in pedodontics. Despite challenges such as data quality, ethical concerns, and integration issues, the continued advancement of AI is set to transform dental care by making treatment more personalized, efficient, and precise. AI is poised to significantly reshape the future of dentistry, offering more personalized, efficient, and accurate patient care.

KEY WORDS: Artificial Intelligence (AI), Dental Practice, Diagnostic Accuracy, Treatment Planning, Personalized Care, Technological Advancement

I. INTRODUCTION

In the rapidly evolving field of healthcare, technology integration has significantly enhanced diagnostics, treatments, and patient care across various medical domains. A notable advancement is the implementation of artificial intelligence (AI) in dental practice. While AI developments started in 1943, the terminology "artificial intelligence" was introduced by John McCarthy during a conference at Dartmouth in 1956. AI's ability to emulate human intelligence enables it to perform complex predictions and decisionmaking in healthcare. In dentistry, AI is transforming diagnosis, treatment planning, and patient care management, heralding a new era of precision and efficiency. This essay explores the profound impact of AI on dental practice and its role in reshaping the future of oral healthcare.

Artificial intelligence(AI) is defined as ‘a field of science and engineering concerned with the computational understanding of what is commonly called intelligent behaviour, and with the creation of artifacts that exhibit such behaviour’ [1]. AI's core components include machine learning (ML), neural networks (NN), deep learning (DL), data science, and big data, all of which play pivotal roles in dental applications. ML uses algorithms to predict outcomes based on data, allowing machines to learn autonomously and make decisions without human input. NN, which mimic the functioning of the human brain, process signals and data, while DL utilizes multiple computational layers to construct a neural network capable of automatically recognizing patterns, thereby enhancing feature detection (Figure 1). Data science focuses on analyzing and extracting insights from large datasets, and big data enables real-time access to continuously growing information, supporting decision-making in dental care[2].

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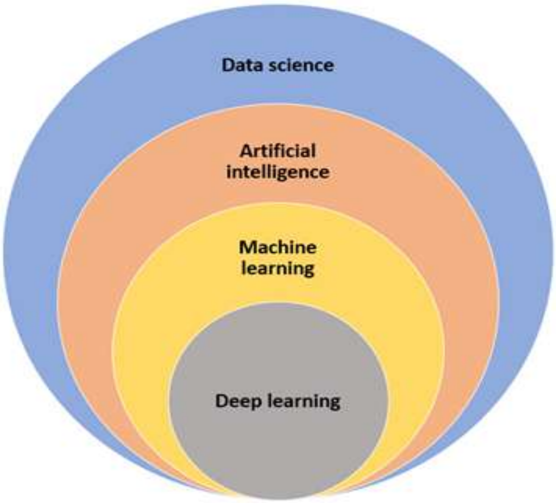

Figure 1: Relationship Between Data Science, Machine Learning, Deep Learning, and Artificial Intelligence

Advanced AI systems such as Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), and Recurrent Neural Networks (RNN) further enhance the capabilities of AI in dentistry. Artificial Neural Networks (ANN) are feed-forward networks that process information layer by layer without revisiting nodes, similar to the human brain's neuron structure. They recognize patterns in raw data and improve independently with each new input. ANNs consist of multiple interconnected layers that handle data input, processing, and output, aiding in understanding complex concepts. Unlike traditional programming, ANNs use distributed information storage, which enhances fault tolerance.Convolutional Neural Networks(CNN) which excel in image and video recognition; recommendation systems, and image analysis. They identify features automatically without human supervision but struggle with variations in data, such as partially hidden or rotated objects. Training CNNs is computationally demanding, requiring multiple GPUs.Recurrent Neural Networks(RNN) designed process bothhistorical and current data, retain information, and handle various input-output relationships, including many-to-many, one-to-many, and many-to-one mappings. They have memory, dual data processing capabilities and excel at understanding sequences but face challenges due to slow, complex, and time-consuming training. Additionally, Generative Adversarial Networks (GANs), introduced in 2014, is a DL. algorithm designed for unsupervised learning. It consists of two neural networks: generator and discriminator. The generator aims to produce data indistinguishable from the original input, while the discriminator tries to differentiate between the generated and original data. GANs have evolved to include 3D-GAN, which can generate 3D objects from 3D spaces or 2D images[3] (Figure 2).

This article aims to explore the profound impact of AI on dental practice, highlighting its role in reshaping the future of oral healthcare. The ongoing integration of AI into dentistry marks a new era of innovation, where technology plays an increasingly central role in improving the quality of care.

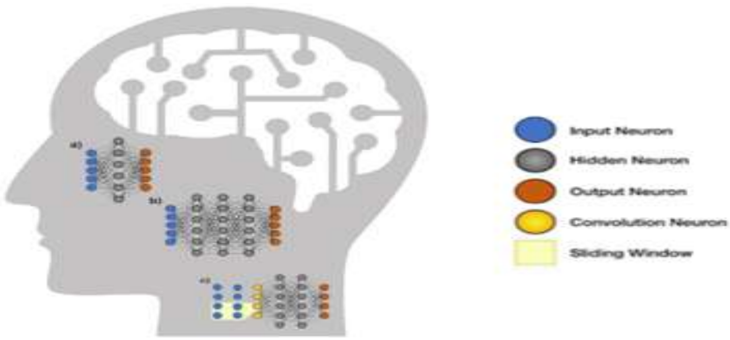

Figure 2: Schematic representation of the architecture of neural networks.

Machine learning employs artificial neural networks as learning structures. They are made up of many tiny, layer-organized communication units called neurons. a A shallow neural network consists of an input layer, an output layer, and a few hidden layers. b. An input layer, several hidden layers, and an output layer are the components of deep neural networks. c. Convolutional neural networks scan a small input neighborhood using filters.

II. REVIEW

AI in General Dental Practice AI is transforming general dental practice by automating complex tasks, improving diagnostics, and streamlining treatment processes, leading to more efficient and accurate patient care. [4]

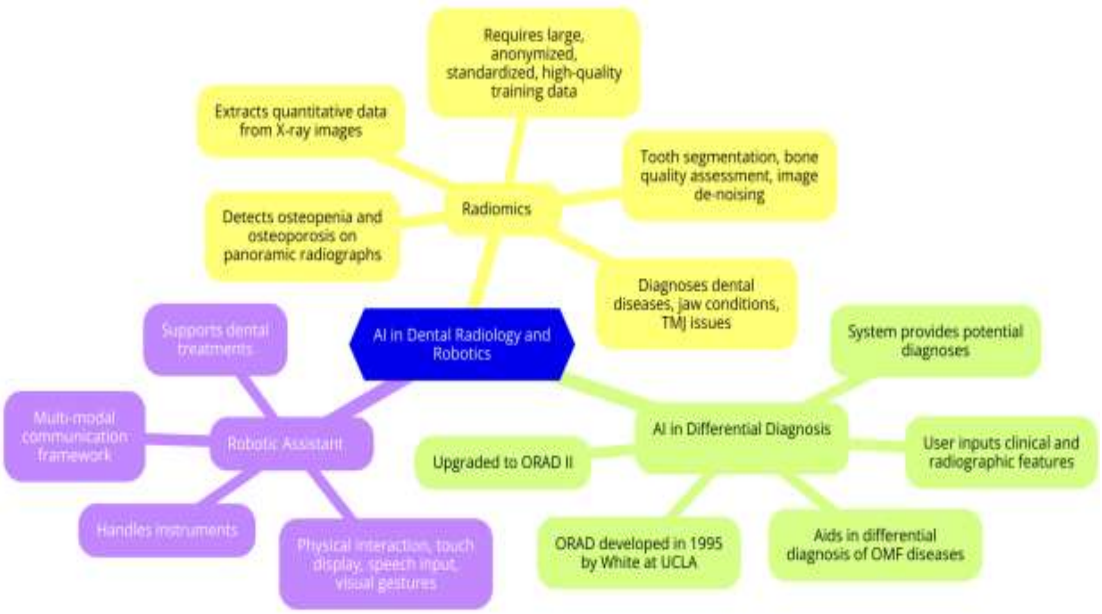

Figure 3: AI in Dental Radiology And Robotics

AI in periodontics

Artificial intelligence (AI) is playing an increasingly vital role in various aspects of periodontal disease detection, classification, and implantology.[5]Machine learning (ML) algorithms trained on dental images and patient records are used to recognize patterns in periodontal tissues, such as Aberin and Goma's CNN system, which achieved 75.5% accuracy in identifying periodontal disorders from dental plaque microscopy images. Similarly, Feres et al. (2018) [6] used a support vector classifier with 40 bacterial species to differentiate between generalized chronic periodontitis, generalized aggressive periodontitis, and healthy individuals. AI has also proven useful in risk assessment, with Patel et al. (2022) [7] demonstrating that neural networks trained with the Levenberg-Marquardt algorithm were most effective when using the Periodontal Risk Scoring System (PRSS), which had a 70% prediction rate followed by PreViser at 55%, PRA and Sonicare at 35%, and Cigna at 25%.

AI-driven imaging analysis has transformed the way bone level assessments are conducted, providing an advanced method to swiftly process radiographs and intraoral scans. This technology identifies subtle changes in bone density that may be difficult for human clinicians to detect. For example**,** Krois et al [8] utilized a Convolutional Neural Network (CNN) approach to evaluate radiographic images from 2001, achieving promising results with sensitivity, specificity, and accuracy values of 0.81**.**

AI-driven innovations extend to other areas such as in the detection of halitosis, an electronic nose, combining mammalian olfaction with AI, can identify specific smell patterns in exhaled volatile compounds. Nakhleh et al. (2017) [9]demonstrated the use of an AI-driven system with 20 nanomaterial sensors to detect 17 distinct systemic diseases from exhaled air, achieving 86% precision**.** This highlights the potential of AI in diagnosing conditions through non-invasive methods. In periodontal surgery, the Yomi Robot was used to provide haptic guidanceduring microsurgical procedures like osteotomy and root-end resection, chosen based on clinical and radiographic findings of periapical lesions. The robot offered auditory, visual, and physical guidance**,** utilizing cone-beam CT scans to enhance precision, reduce human error, and improve surgical outcomes. Additionally, AI plays a crucial role in postoperative care**,** where AI-driven mobile apps and wearable devices assist patients in their recovery by providing real-time feedback, guiding care routines, monitoring symptoms, and alerting periodontists to complications like infection or delayed healing. This integration of AI throughout the treatment process ensures better precision, monitoring, and overall patient care. Additionally, robotic devices like Robututor are revolutionizing patient education by demonstrating tooth-cleaning techniques in a more engaging manner

AI in implantology

AI and augmented reality (AR) technologies are transforming dental implant procedures by enhancing efficiency and accuracy. According to Mangano et al [10] ,these technologies provide a swift, precise method for static-guided implant placement in partially dentate individuals, potentially replacing conventional software in treatment planning.[11] Machine learning (ML) models such as logistic regression and support vector machines (SVM) are highly effective in detecting implant types from panoramic radiographs, especially when implants were placed in other clinics (Benakatti et al., 2021)[12]. Additionally, AI algorithms, like support vector regression, combined with finite element analysis (FEA), optimize implant design by reducing strain at the implant-bone interface, offering a reliable alternative to traditional FEA methods (Li et al., 2019) [13].

Robo assisted implant surgery

Robo-assisted implant surgery [14] is categorized into three main types based on the level of automation: Passive Robots**,** Semi-active Robots**,** and Active Robots**.** Passive robots, such as Yomiand DentRobot, require operator guidance for tasks like maneuvering the robotic arm into and out of the mouth, preparing the implant site, and placing the implant. Semi-active robots, like Remebot, can autonomously handle implant site preparation and insertion but still need operator assistance for the arm's movement during entry and exit. In contrast, active robots, exemplified by YekeBot**,** are fully autonomous, capable of independently entering and exiting the mouth, preparing the implant site, and completing the implant placement without human intervention.[15] This classification highlights varying levels of automation in robot-assisted dental implant procedures

AI in endodontics

AI has significantly advanced various aspects of endodontic care, from root canal detection to predicting treatment outcomes (Figure 4) For detecting vertical root fractures (VRFs), Kositbowornchai et al [16] andJohari et al used Probabilistic Neural Networks (PNNs) on dental radiographs, and Fukuda et al [16]applied CNNs on OPGs. Similarly, Vicory et al developed an algorithm to detect microfractures in CBCT scans.Sherwood et al[17] utilized deep learning (U-Nets) for classifying and predicting C-shaped canals, while Wang et al [18] employed DentalNet and PulpNet for automatic segmentation of tooth and root canal anatomy in CBCT scans, demonstrating AI's precision and efficiency

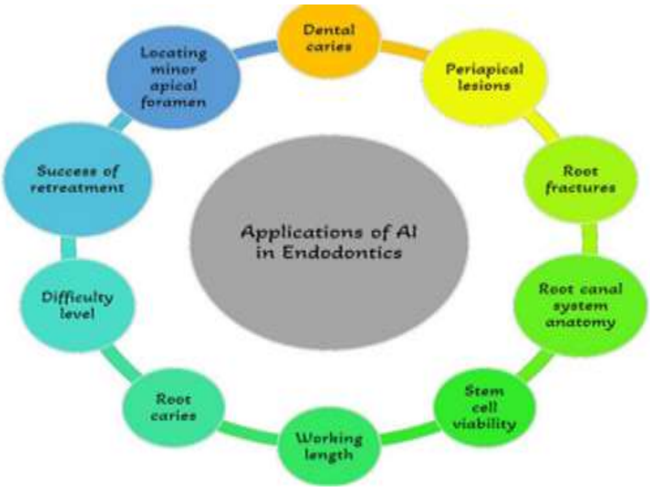

Figure 4 : Application Of AI in Endodontics

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In caries detection, GhaznaviBidgoli et al [19] used a CNN to identify dental diseases from OPGs, while Oztekin et al [20]employed machine learning models on OPGs of 562 subjects, demonstrating AI's accuracy in detecting dental caries, highlighting its precision and automation capabilities. AI has also enhanced automated pulpal diagnosis**,** withTumbelaka et al [16] usingArtificial Neural Networks (ANN) to distinguish healthy pulp from pulpitis and pulpal necrosis, and Zheng et al leveraging CNNs like VGG19, Inception V3**,** and ResNet18 to diagnose carious lesions and pulpal inflammation. However, AI should complement clinical and radiographic exams for comprehensive evaluation

AI is also transformingworking length (WL) determination**,** with Saghiri et al [21] using aPerceptron mode**l** on periapical radiographs to locate the minor apical foramen, enhancing WL determination accuracy and Qiao et al employing a neural network with multifrequency impedance for improved WL measurement accuracy and robustness. These studies highlight AI's potential to revolutionize WL determination in endodontics.

AI's role extends to predicting treatment outcomes, where Hasan et al [16] used (You-Only-Look-Once version) YOLOv5s and YOLOv5x for precise detection of root canal obturation in distorted periapical X-rays, effectively categorizing obturationand complications. Herbst et al [16] applied ML techniques, including SVM, LogR(Logistic Regression), Decision Trees, XGBoost and Gradient Boosting, to predict endodontic failure and optimal root filling length.

AI is also useful for case difficulty assessments**,** as shown by Qu et al whereXGBoostoutperformed LogR and SVR(Support Vector Regression) in assessing microsurgery case difficulty. Mallishery et al, developed an ANN-based system to evaluate and assist with referral decisions using 500 subjects, showcasing AI's potential in creating standardized, efficient treatment plans in endodontics.[22]

AI in orthodontics

Automated dental and facial analyses are rapidly evolving with the integration of AI technologies. Im et al [23]introduced a dynamic-graph CNN for tooth segmentation using 3D intraoral scanner images, which outperformed other software in accuracy and computational efficiency. Accurate tooth segmentation and landmark recognition are essential for automated dental analysis, with ongoing advancements promising further clinical applications (Figure 5).

In facial analysis, Rao et al [24**]** utilized an active shape model algorithm on facial photographs for automatic landmark identification, achieving 50% accuracy, while Rousseau et al [25]employed CNNs to assess patients' vertical dimensions, achieving remarkable precision with a confidence interval limit of agreement below 10%.

For decision-making in extractions, ANN are widely used for predicting extraction diagnoses and Jung et al [26] developed an AI model using neural networks with 12 cephalometric parameters and 6 indices, achieving a 93% performance rate in extraction decisions. The YOLOv3 algorithm has also excelled in automated landmarking in cephalometrics, with Parket al [27] demonstrating its superiority over the Single-Shot Multibox Detector (SSD) in identifying 80 landmarks in lateral cephalometric radiographs. Additionally, the LAMDA (Lingual Archwire Manufacturing and Design Aid) system shapes nickel-titanium archwires by heating at 600°F and shape it under 6 minutes, outperforming manual bending by specialists in accuracy. LAMDA's advantages include simplicity, low cost, versatility, reduced labor, prevention of archwire fatigue fractures, and improved treatment efficiency. Regarding skeletal age assessment, accuracy rates for determining cervical vertebral maturation stages exceed 90%, with Inception-ResNet-v2 achieving the highest accuracy at 94.1%. Grad-CAMs reveal that Inception-ResNet-v2 analyzes several cervical vertebrae, whereas other algorithms mainly concentrate on the third cervical vertebra for determining skeletal age. [28]

Dental Monitoring(DM) system consists of a patient mobile application, a Doctor Dashboard, and a movement-tracking algorithm that evaluates patient photographs. It aims to decrease in-office appointments, recognize aligner misalignments, and personalise treatment plans. DM benefits include minimized chairside time, improved patient adherence, prompt emergency detection, reduced relapse, remote aligner monitoring, and improved oral hygiene [29].

Finally, AI and ML algorithms have shown over 90% accuracy in identifying orthognathic surgery diagnoses, with Jeong et al [30]achieving 89% accuracy using a CNN for classifying surgical cases from facial photos, and Knoops et alemploying a 3D morphable model for automatic diagnosis, risk categorization, and treatment simulation, achieving 95.5% sensitivity and 95.2% specificity.

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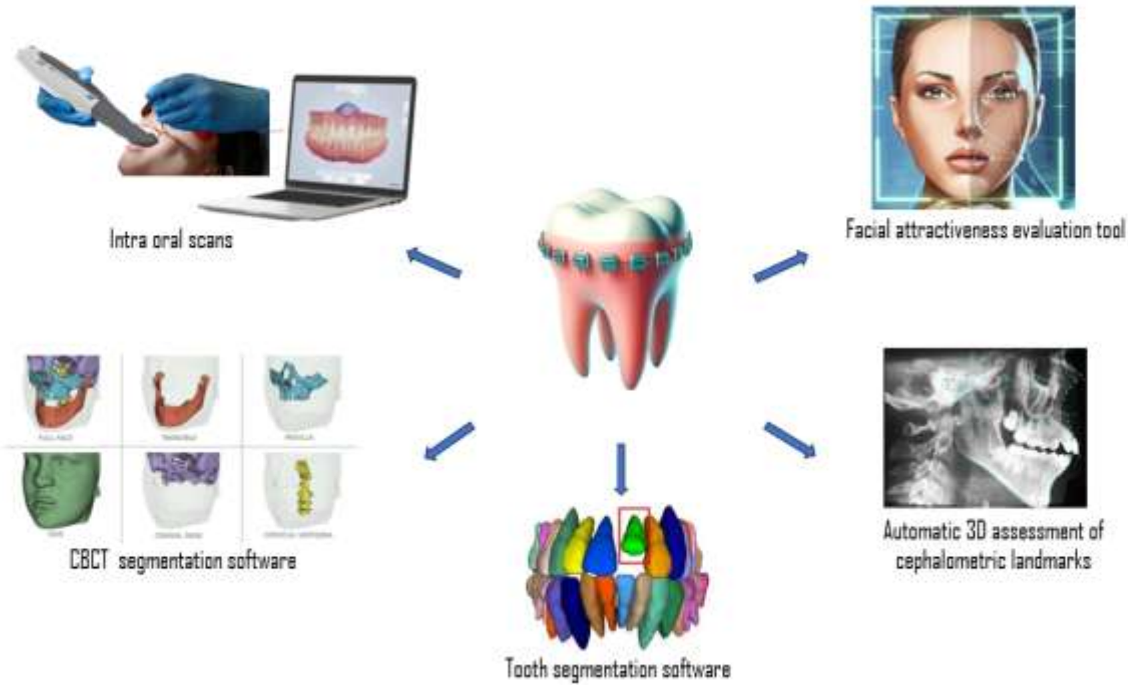

Figure 5: AI Applications in Orthodontics: From Data Collection to AI Tools and Training Cycle

AI in prosthodontics

AI has significantly advanced various areas of prosthodontics, improving efficiency, accuracy, and personalization in treatments.[31]

AI enhances the fabrication of RPDs through 3D printing, offering efficient and cost-effective solutions. By using AI models and CNNs, dental arches are classified, and patient data is analyzed to create personalized designs. AI suggests optimal framework designs, classifies dental arches with high accuracy, and analyzes stress on adjacent teeth. It also assists inexperienced dentists in selecting suitable prosthetic options.

AI improves tooth preparation accuracy and optimizes crown designs by automating tasks like marginal line extraction. Zhang et al [32] achieved 97.43% precision using a CNN model called Sparse-Octree. AI enhances occlusal morphology, defines emergence profiles, and improves the aesthetics and function of FPDs, ensuring accurate margins and promoting healthy periodontal tissues.[33]

The integration of AI with CAD/CAM technologies enhances prosthetic rehabilitation by improving crown margin detection and generating accurate crown morphology. AI minimizes cementation errors, reduces production time, and enhances the quality of prostheses while decreasing the need for laboratory work.

Shade reproduction and color matching are crucial in aesthetic dentistry. Traditional backpropagation neural networks (BPNNs) have low accuracy, but Li et al [34] introduced a genetic algorithm (GA) to optimize BPNN's initial weights, improving accuracy and stability in shade matching.

Robotic systems like the LaserBotmicrorobot provide precise 3D laser control for tooth preparation. Recent advances reduced preparation time to 17 minutes. Otani et al [35] found this robotic system as accurate but less precise than conventional freehand preparation for porcelain-laminated veneers.

AI is transforming maxillofacial prosthodontics with CNN-powered prosthetic eyes and smart glasses. In tissue engineering, AI aids in developing artificial skin grafts, enhancing functions like oxygenation and infection prevention. AI in artificial olfaction mimics the human sense of smell using electronic noses.

AI in oral maxillofacial surgery

AI is revolutionizing the diagnosis and treatment of maxillofacial conditions (Figure 8). Commercial applications like dentalXr and Dentomo assist in diagnosing cysts and tumors, with models such as Abdolali's segmenting radicular and dentigerous cysts. Rana's work measures keratocyst volumes, while AI models demonstrate an 86% accuracy in detecting lymph

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nodes related to head and neck carcinoma in a review by Santer et al [37].AI and deep learning (DL) improve X-ray image clarity by reducing noise, motion artifacts, and metallic distortions, especially in dental CT and CBCT images, resulting in clearer diagnostics.CNNs are effective in analyzing complex dental images. Orhan K et al [38] demonstrated CNNs' high accuracy in detecting third molar impaction angles, depth and relationships with anatomical structures.

AI enhances computer-aided planning with 3D imaging, streamlining cephalometric analysis, surgical simulations, and splint creation. The integration of AI with 3D imaging and printing improves visualization and treatment outcomes for orthognathicsurgeries.[39]

AI-powered applications help patients adhere to medical regimens and track health indicators using biosensors. AI assistants like BotMD provide round-the-clock medical support, enhancing patient- healthcare provider communication and clinical decision-making.

Robots improve surgical precision by analyzing lesions, reconstructing 3D images, and planning operations. In orthognathic surgery, robots like KUKA assist in bone segment repositioning with enhanced stability and success compared to manual techniques under computer-aided navigation.[40]

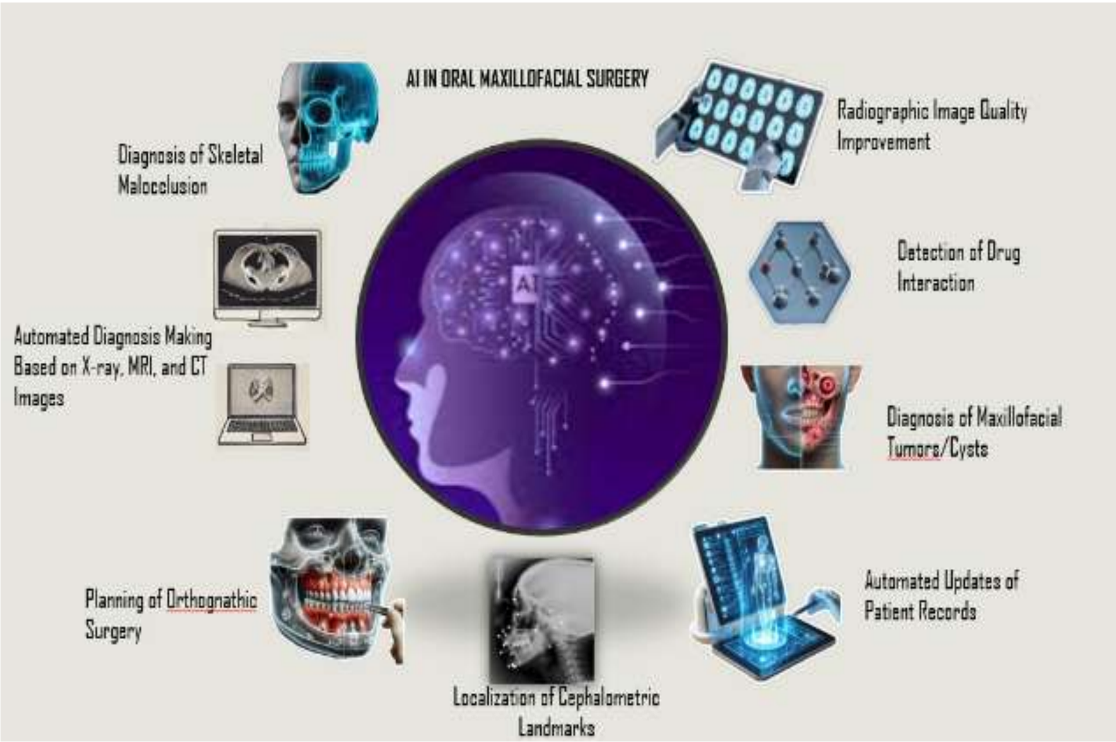

Figure 6: Artificial intelligence (AI) Uses In clinicalasspects of Oral And Maxiallofacial Surgery

AI in pedodontic practice

Patients or guardians can autonomously scan and document their teeth using AI-driven remote monitoring (AIRM) via smartphones.[41] This approach enables clinicians to oversee oral health remotely. AIRM utilizes deep learning (DL) to track tooth movement and identify key features from patient images. DL methods, such as CNNs, are used to accurately detect sound teeth and early dental caries via digital cameras. Research shows DL techniques can identify teeth affected by plaque, caries, and molar–incisor hypomineralization, improving early disease detection and clinical decision-making.

DL models like ResNet-18, SqueezeNet, Inception-ResNet-v2 effectively classify mesiodens. AlexNet, VGG16-TL, and Inceptionv3-TL excel in detecting supernumerary teeth. A PyTorch-implemented U-Net CNN model diagnoses taurodontism with panoramic radiography. YOLOv4 demonstrates exceptional speed and accuracy in identification of tooth and its number. CNN algorithms detect erupting molars for tailored treatment planswhile YOLO excels in real-time object analysis and robust performance. [42]

Machine learning ML) models, including XGBoost and random forest, predict and diagnose early childhood caries (ECC) and evaluate risk factors like salivary cystatin S levels. ML supports early prevention and diagnosis of ECC.Digitalorthopantomography provides precise age estimations for children aged 4 to 15 years. ANN predict dental maturity and chronological age. ML using SOS-ResNext50 radiomorphometric characteristics outperformed existing methods.

III. CONCLUSION

Artificial intelligence has the capability to revolutionize dental practice by enhancing diagnostic precision and optimizing treatment planning. However, challenges such as the quality and availability of data, the interpretability of AI models, integration with existing systems, and ethical concerns must be addressed. Current AI applications are often task-specific, and broader implementation in complex decision-making is still in development. Despite these limitations, AI is poised to play an increasingly important role in dentistry, offering more personalized and effective patient care as technology and integration improve.

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