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## ARTIFICIAL INTELLIGENCE IN THERAPEUTIC DECISION- MAKING FOR COMPLEX DENTAL DISEASES: A REVIEW

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### ABSTRACT

**Introduction:** The expanding complexity of dental diseases has exposed the limitations of conventional heuristic-based therapeutic planning. Artificial Intelligence (AI) has evolved beyond diagnostic assistance to become a powerful tool in therapeutic decision-making, enabling data-driven, predictive, and personalized dental care.

**Material and Methods:** This narrative review critically evaluates contemporary applications of artificial intelligence in therapeutic planning, prognostic assessment, and surgical execution across major dental specialties, including periodontology, endodontics, prosthodontics, orthodontics, and implantology. Evidence from machine learning, deep learning, computer vision, and robotics-based systems was synthesized to assess clinical relevance beyond diagnostic accuracy.

**Results:** Artificial intelligence-based clinical decision support systems demonstrated improved precision in treatment planning, outcome prediction, and procedural execution. Applications such as generative prosthetic design, Artificial intelligence-guided endodontic access, implant navigation, orthodontic treatment simulation, and robotic-assisted surgery showed potential to reduce operator variability and enhance therapeutic outcomes. However, challenges related to data heterogeneity, algorithmic bias, explainability, and medico-legal accountability persist.

**Conclusion:** Artificial Intelligence is redefining therapeutic decision-making in dentistry by augmenting clinical judgment rather than replacing it. When integrated within a human-in-the-loop framework, artificial intelligence serves as a high-level therapeutic assistant capable of improving accuracy, efficiency, and personalization of dental care. Future research must prioritize longitudinal clinical validation and ethical governance to enable safe and effective clinical translation.

**KEYWORDS:** Artificial Intelligence; Therapeutic Decision-Making; Clinical Decision Support Systems; Precision Dentistry; Robotics; Generative Design

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## INTRODUCTION

Dentistry is a complex combination of art, engineering, and medicine; it involves clinicians incorporating enormous amounts of heterogeneous information in patient history, clinical symptoms, radiographic results, and genomic data into the development of effective treatment plans. In complicated dental diseases, the cognitive load is high. Such conditions like aggressive periodontitis, any endodontic pathology with multi-rooted canals and calcified, or extreme dentofacial deformities necessitate a multifaceted approach to treatment with extremely small margin of error. Historically, making therapeutic decisions has been haphazard affair that has largely depended on the experience, intuition, and subjective feelings of the clinician as well as his or her interpretation of the evidence. This classical model, though useful, is prone to cognitive bias, fatigue and high inter-operative variation and therefore tends to treat some patients differently [Joda T et al., 2024].

Artificial Intelligence (AI), which refers to computer systems having the capacity to carry out tasks that would have been performed by humans with intelligence, has become a revolutionary power that can solve these drawbacks. Machine learning and deep learning subfields, and namely, Convolutional Neural Networks, have exhibited immense potential in pattern identification and data generation in the dentistry field [Agrawal P, Nikhade P, 2022]. The first generation of artificial intelligence studies in dentistry was largely diagnostic, with an ability to perform at a human level or a super-human level of ability to identify dental caries, periodontal bone loss, and apical lesions on radiographs. Nonetheless, diagnosis is just the tip of the iceberg. The real possibilities of artificial intelligence are in the fact that it will have an impact on the next important process the decision in the treatment [Al-Sadi AM, Al-Kaabi A, 2025].

The importance of this paradigm shift cannot be overestimated. We are entering into the era of precision dentistry, where artificial intelligence examines large amounts of data to determine the response of each specific patient to the treatment, recommend the best surgical route, and discover aspects of risk that are not clearly visible to the human eye. As an example, would an artificial intelligence model help forecast more accurately the possibility of an off-prognosis tooth surviving 5

years after therapy than a experienced periodontist? Will generative algorithms ever create a dental prosthesis that is mechanically better than one created by a human technician?

Despite this assurance, the involvement of artificial intelligence in therapeutic processes is a controversial issue. The obscurity of the inquiry into the logic behind the decision given by complex neural networks as a black box implicates the issue of trust, accountability, and informed consent in a highly serious way. In the case of an artificial intelligence system suggesting a radical surgery operation, is the clinician able to check the reasoning? Moreover, the use of retrospective datasets, which might be non-diverse, is deeply dangerous to the possibility of algorithmic bias, which can continue to reinforce healthcare disparities [Kocballi AB et al., 2025].

The following narrative review gives a detailed examination of the use of artificial intelligence in therapeutic decision-making. It has gone beyond the diagnostic metrics to the extent of inquiring into clinical relevance of artificial intelligence in treatment planning, prognosis, and surgery. The goal is to integrate existing knowledge, pinpoint the revolutionary capabilities of these technologies, and strictly address the ethical, legal and practical challenges, which need to be conquered to implement the future of AI-enhanced dental care.

**Pathophysiology and Artificial Intelligence-Improved Diagnostics:** Therapy can only be effectively used in the presence of the adequate knowledge of pathophysiology. The clinical manifestations of complex dental diseases are frequently unclear, and 2D imaging might not be able to reflect the actual pathology. Artificial intelligence has already demonstrated a stunning potential in unravelling these complexities and transforming stagnant images and data points into the vibrant findings that biology can offer.

**Disease Phenotyping and Radiographic Interpretation:** Radiographic interpretation has seen a transformation because of the application of Deep Learning (and specifically convolutional neural networks, or convolutional neural networks) such as U-Net and ResNet architectures. In more complicated applications, like the detection of vertical root fractures) or the delineation of the size of periapical lesions around the maxillary sinus, artificial

intelligence algorithms are able to subdivide anatomy structures with a micron-level accuracy that is comparable to micro-CT scan [Aminoshariae A et al., 2024].

It has been shown that artificial intelligence models can discriminate between periapical cysts and granulomas based on radiographic density resolution gradients and radiographic texture (radiomics) that a human eye cannot identify. This difference is also clinically vital; cysts usually need surgical removal, but granulomas can be treated by non-operational endodontic treatment. Artificial intelligence allows the clinician to select the best therapeutic modality by giving a probabilistic diagnosis (e.g., “85% probability of cyst”), which eliminates unnecessary surgeries or useless conservative treatment [Setzer FC et al., 2020].

#### **Oral Cancer and Histopathological Analysis:**

In oral pathology, artificial intelligence is also doing a lot. The diagnosis and treatment of oral squamous cell carcinoma is fully reliant on the correct grading and assessment of margins. Digitized histopathological slide deep learning models have been shown to be highly accurate in identifying the presence of tumor islands and predicting metastasis to lymph nodes. Such systems are able to measure tumor-infiltrating lymphocytes, which is one of the primary biomarker of the response to immunotherapy, thus helping the oral surgeon and the oncologist when choosing the most effective adjuvant therapies [Mahmood H et al., 2021].

**Combination of Multi-Source Data:** Multi-modal data integration is the most advanced form of artificial intelligence system. Integrating radiographic, clinical (probing depths, mobility) and patient systemic health metadata (age, smoking status) data in the form of so-called fusion models form a comprehensive digital patient phenotype. In periodontology, automated staging and grading of disease as per the 2018 World Workshop is possible using this method. This automatic phenotyping is what makes sure that the treatment regimen is adjusted to the exact severity and biological predisposition of the patient, beyond a generic treatment plan to actual personalized treatment [Lee JH et al., 2020].

#### **Clinical Aspects and Therapeutic Options:**

This is because the process of diagnosing and administering therapy entails choosing the best intervention based on a multifaceted decision making

process. Artificial intelligence is one of the high-level clinical decision support system that uses predictive modeling and generative algorithms to propose evidence-based treatments.

#### **Guided Access, Endodontics: Anatomy, and Outcome Prediction:**

A major problem in endodontics is the management of complicated root canal systems. AI applications have reached a stage of more than simple lesion detection and have become an inseparable part of the treatment planning process.

➤ **Anatomical Mapping:** Artificial intelligence algorithms on cone-beam computed tomography scans can automatically map the root canal system and determine the canals that have not been filled (e.g. MB2 in maxillary molars) and identify complex morphology such as C-shaped canals. This preoperative roadmap is an important tool that mitigates the risk of procedure failure because of missed anatomy.

➤ **Guided Endodontics:** When using the AI in planning the static surgical guide, it is used in the situations, when the canal is calcified (there is so-called pulp canal obliteration). The software will determine a drill path by overlaying surface scans with cone-beam computed tomography data and find a microscopic canal orifice with maximum tooth structure remaining, which would otherwise be a very dangerous procedure when done by hand [Saghiri MA et al., 2024].

➤ **Outcome Prediction:** Predicting prognosis may be the most beneficial. AI-based models trained on thousands of cases are able to take into consideration variables such as lesion size, bone quality, quality of coronal seal, and root morphology to predict the likelihood that retreatment will be successful compared to apical microsurgery. This probabilistic output is an important resource in the process of informed consent as it assists the patients to make informed choices when they have custom-made statistics instead of generalized statistics [Ebihara A et al., 2025].

**Prosthodontics Generative Design and Esthetics:** Generative Design is changing the face of prosthodontics. Historically, the CAD/CAM (Computer Assisted Design/ Computer Aided Manufacturing) systems also depended on the libraries of the standard tooth shapes, which had to be adapted manually.

- **Generative Adversarial Networks:** New artificial intelligence models apply to generative adversarial networks in producing distinctive dental restorations. Through the examination of the rest of the dentition, facial, and functional occlusion of the patient, the artificial intelligence produces a tooth design that has a morphological peculiarity to the patient. The algorithms are used to optimize the design to not only look good but also structural integrity, wall thickness is changed to overcome occlusivity forces [Revilla-León M et al., 2023].
- **Shade Matching:** The subjective shade matching is a common cause of esthetic failure. Relying on AI-based spectrophotometers and color-calibration algorithms, digital photographs are examined to chart the polychromatic aspect of the teeth (translucency, hue, chroma) with objective accuracy, which is then passed on to the lab to create teeth restorations that are indistinguishable [Alghazzawi TF, 2016].

**Implantology Dynamic Navigation and Bone Analysis:** Accuracy is supreme in the implant dentistry. The driver of the transition of the guided surgery to the navigated one is artificial intelligence.

- **Full-body Virtual Surgical Planning:** Artificial intelligence algorithms will automatically identify the mandible, maxilla, and vital structures (inferior alveolar nerve, maxillary sinus, etc.) of cone-beam computed tomographs. They will then be able to virtually remove teeth and suggest optimal locations of implants depending on the amount of bone available and the intended prosthetic envelope.
- **Bone Density and Stability Prediction:** The advanced machine learning L models can be used to analyze the trabecular structure of the bone in the planned location of the implant to predict both the primary stability (Implant Stability Quotient (ISQ) values) and the likelihood of marginal bone loss. This enables the surgeon to adjust the surgical procedure like under-drilling to attain high torque, prior to the operation commencement [Revilla-León M et al., 2024].

**Orthodontics. Virtual Reality and Remote Control:** AI has been an early field of AI use because orthodontics uses visual data.

- **Automated Cephalometrics:** Artificial intelli-

gence has cut down the minutes used to trace cephalometrics to seconds, and landmark identification accuracy is similar to that of expert human tracers.

- **Treatment Simulation:** Neural networks simulate tooth motion during clear aligner therapy and control the force systems to consider biological limits such as root surface area and bone density. Such simulations enable the clinicians to see the options of extraction vs. non-extraction plans and explain such cases to patients adequately [Tahamtan S et al., 2025].
- **Tele-Orthodontics:** AI-governed remote treatment systems enable patients to scan their teeth weekly with the help of smartphones. The artificial intelligence can be used to monitor aligner fit, hygiene and tracking problems and only alerts the orthodontist when they are out of line. This is a management by exception model, which enhances efficiency and enables closer control of the complicated movements of teeth without necessarily visiting the office regularly [Sangalli L et al., 2023].

**New Horizons Robotics and Dentronics:** The integration of artificial intelligence with robotics has created one named as Dentronics, which is likely to reach therapeutic accuracy to be at a superhuman level.

**Levels of Autonomy:** The types of dental robotics in terms of their autonomy are:

- **Passive/Guidance Systems:** The most usual ones are so today (e.g., Yomi). The robot offers haptic feedback which holds the surgeon physically to a pre-programmed drill plan. In case the patient changes positions, the robot follows the movement and re-adjusts immediately.
- **Semi-Active Systems:** These are those that do certain tasks (such as drilling an osteotomy) but are autonomously motor controlled.
- **Active/Autonomous Systems:** These robots are still in their early experimental phase and theoretically they can carry out entire procedures, like the preparation of the crown, by themselves. These systems have artificial intelligence as the brain, which processes real-time visual and force-feedback data to identify the enamel, dentin and pulp, keeping the preparation within the safe biological range [Grischke J et al., 2020].

**Prevention Strategies and Prognostics:** The final Aim of healthcare is prevention. Artificial intelligence enables transitioning to proactive rather than reactive dentistry with the help of powerful prognostic modeling.

**Caries and Periodontal Disease Predictors:** Machine learning classifiers like the random forests and support vector machines are highly efficient in non-linear interaction analysis amongst risk factors.

➤ **Caries risk assessment:** Artificial intelligence takes into consideration diet, hygiene habits, salivary flow, and historical caries experience to categorize patients into specific risk groups. This allows the application of high-risk populations to specific preventive regimens (e.g., high-concentration fluoride, sealants) prior to the onset of lesions [Hung M et al., 2025].

➤ **Periodontal Prognosis:** There is a notoriously subjective determination of the prognosis of compromised teeth. Intelligence models, trained on longitudinal data (10-20 years of follow-up), can be used to forecast tooth loss with much higher accuracy than conventional systems such as the McGuire and Nunn classification. Artificial intelligence is able to give an individual survival estimate by combining systemic health data (diabetes control, smoking pack-years yet bone loss type, furcation involvement) with local data (bone loss type, furcation involvement). This type of preventative intelligence enables the clinician to make objective judgments regarding the need to maintain or extract a compromised tooth [Krois J et al., 2019].

**Genomic Integration:** The future of prognosis is in genomics. New studies investigate applications of artificial intelligence to predict genetic polymorphisms (e.g. IL-1 genotypes) linked to inflammatory reactions. Combining this genomic information with clinical results may enable AI to recognize patients with a hereditary tendency to periodontal breakdown or root aggressor, which initiate hyper-vigilant maintenance measures [Nibaldi L, Donos N, 2018].

**End-of-World Problems, Discussion, and Projections:** Although the prospects of AI are enormous, integrating AI into the everyday therapeutic decision-making process is accompanied by major obstacles, which include technical, ethical, and legal challenges.

**The Explainability and Black Box Problem:**

An impeding factor to adoption is the black box character of deep learning. A neural network may prescribe the removal of a tooth, but it may not be able to easily explain its rationale. This lack of transparency is an issue in a therapeutic setting. The clinicians require Explainable artificial intelligence the systems which offer so-called saliency maps or logic trails showing which particular features (e.g., a particular shadow on the radiograph or a risk factor in the history) informed the decision. It is clinically irresponsible to blindly trust artificial intelligence without understanding it [Amisha et al., 2019].

**Quality of Data, Heterogeneity and Bias:** The AI models are dependent on their training data. The majority of dental datasets are retrospective, single-centre, and tend to be not diverse. When an artificial intelligence is trained on the data provided mostly by a particular demographic (e.g., Caucasian adults), the recommendations provided in the therapeutic management can be not applicable to the children or other ethnic groups, further contributing to the health disparities. Moreover, data interoperability of various Practice Management Software (PMS) does not exist, which leads to the establishment of data silos, which cannot combine the use of big data to train the models robustly [Obermeyer Z et al., 2019].

**Law and Standards of Care:** Who is in charge in case an artificial intelligence commits an error? When an artificial intelligence controlled robot goes astray and kills a nerve, who is liable the surgeon, the software writer, or the hardware manufacturer? At present, the legal system follows the principle of the human-in-the-loop: the decision-making process of all decisions regarding the therapy rests ultimately on the shoulders of the clinician. Nevertheless, the legal standard of care could change with the increased autonomy of AI systems and their possible ability to be more accurate than a human person. It is possible that in the future, not using artificial intelligence diagnostic AIId may be viewed as malpractice given that the mistake could have been avoided by the artificial intelligence [Pesapane F et al., 2018].

**Future Perspectives:** The future of dental therapeutics is in the invention of the Dental Digital Twin. This principle is the development of a living,

virtual simulation of the patient, which is based on anatomy, physiology, and pathology. This twin allowed clinicians to model the different treatment procedures, such as: surgery, orthodontics, prosthetics, etc in a virtual world to experience the long-term biological and mechanical outcomes without ever laying a scalpel on the patient. Fused with tele-dentistry platforms, which will provide the ability to conduct constant remote monitoring, artificial intelligence will make dentistry not an episodic intervention, but rather a continuum of care [Eliceiri KW et al., 2025].

### DISCUSSION

The evidence synthesis in this review has shown that there is a natural progression to AI in dentistry in which it is no longer seen as a diagnostic helper but a therapeutic companion. The reviewed studies clearly show that artificial intelligence can decrease inter-operational variance, a persistent problem in complicated dental services. In medical services such as implantology and endodontics that are sensitive to differences of millimeters to determine success, artificial intelligence offers a consistent standard that improves the quality of care at the floor [Farook TH et al., 2025].

Nevertheless, one gap that is critical still exists: the lack of prospective, randomized clinical trials. Most of the existing evidence is founded on the in vitro accuracy measures (Area under the curve, sensitivity). In as much as we understand that artificial intelligence is capable of planning a treatment with a great level of geometric preciseness, there is a dearth of information regarding whether AI-planned treatments can produce higher long-term clinical survival rates compared to human-planned treat-

ments. Is an artificial intelligence designed crown more durable? Will AI-directed perio treatment lead to a reduction in tooth loss in 10 years? Such are the questions which the future research should answer [Schwendicke F et al., 2019].

Finally, the connection between the clinician and artificial intelligence should be symbiotic. The human-in-the-loop is essential to taking care of the delicate, sympathetic, and ethical facets of treating patients- where artificial intelligence is primitive. Excess automation will lead to deskilling of the workforce whereas insufficient automation will be disregarding an effective error reducing tool. The future of therapeutic decision-making is the balanced incorporation of biological wisdom with computational power.

### CONCLUSION

Artificial Intelligence will be a paradigm change in the decision-making process of complex dental diseases. With a potential to refine diagnostic accuracy, facilitate the creation of designs, enhance robotized surgery, and offer patients more specific prognostic forecasting, artificial intelligence has the potential to make dental services safer, more efficient, and more predictable. But, this potential can be achieved only under condition of addressing serious issues connected to data bias, algorithm transparency, and creation of strong legal and ethical frameworks. artificial intelligence will not gradually substitute the dental clinician but an advanced tool, which, when used with clinical wisdom, can greatly enhance the quality of care. Future studies will be to shift the focus of the studies on accuracy to longitudinal clinical trials to confirm the actual health benefits of the technologies.

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