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ARTIFICIAL INTELLIGENCE AS A DECISION-SUPPORT TOOL FOR MATERIAL SELECTION IN PROSTHODONTICS: AN ANALYTICAL REVIEW OF THE LITERATURE

Introduction. Background. The rapid development of digital dentistry and artificial intelligence (AI) is expanding the range of technologies available for diagnosis, treatment planning, prosthetic design, and outcome prediction. Material selection remains a clinically important component of prosthodontic treatment because the choice of restorative material must account for mechanical, functional, biological, and esthetic requirements.

Aim. To analyze recent literature on the application of AI in prosthodontics, with particular attention to its potential role in supporting restorative material selection, integrating clinical and digital parameters, predicting prosthetic outcomes, and personalizing treatment planning.

Materials and methods. A narrative analytical review was developed from literature published during seven completed calendar years (January 2019–December 2025). Relevant publications were identified in PubMed/MEDLINE, Scopus, Web of Science, and NCBI resources using combinations of terms related to artificial intelligence, machine learning, prosthodontics, dental materials, CAD/CAM, crowns, dental prostheses, occlusion, and treatment outcomes. Publications were thematically analyzed according to AI application, type of prosthodontic task, data source, clinical purpose, reported outcomes, and limitations.

Results. The reviewed literature demonstrates that AI is increasingly applied in prosthodontic diagnostics, treatment planning, automated crown design, finish-line detection, occlusal assessment, prediction of prosthetic outcomes, and digital workflows. AI-assisted CAD systems have shown potential to improve design efficiency and, in selected studies, achieve clinically acceptable crown fit. However, the evidence remains heterogeneous with substantial differences in datasets, algorithms, validation procedures, and outcome measures. Direct evidence supporting independently validated AI systems for individualized restorative material selection remains limited. Current evidence therefore supports the use of AI primarily as a clinical decision-support tool rather than as an autonomous system for material selection.

Conclusions. AI has considerable potential to support individualized material selection and prosthodontic treatment planning by integrating multiple clinical and digital parameters. At the same time, current evidence does not support treating AI as an autonomous replacement for professional clinical judgment. Direct validation of AI systems specifically designed to select restorative materials remains limited, and many predictive models require stronger external validation and prospective clinical evaluation. The most appropriate current framework is therefore a human-in-the-loop decision-support model in which AI augments, rather than replaces, clinical expertise.

Key words: artificial intelligence, prosthodontics, dental materials, machine learning, CAD/CAM, clinical decision support, dental crowns, personalized prosthetic treatment.

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ШТУЧНИЙ ІНТЕЛЕКТ ЯК ІНСТРУМЕНТ ПІДТРИМКИ ВИБОРУ МАТЕРІАЛІВ В ОРТОПЕДИЧНІЙ СТОМАТОЛОГІЇ: АНАЛІТИЧНИЙ ОГЛЯД ЛІТЕРАТУРИ

Вступ. Актуальність. Стрімкий розвиток цифрової стоматології та штучного інтелекту (ШІ) розширює спектр технологій, доступних для діагностики, планування лікування, проектування ортопедичних конструкцій та прогнозування результатів. Вибір матеріалу залишається важливим компонентом ортопедичного лікування, оскільки вибір ортопедичного матеріалу має враховувати механічні, функціональні, біологічні та естетичні вимоги.

Мета. Проаналізувати сучасну літературу щодо застосування ШІ в ортопедичній стоматології, з особливою увагою до його потенційної ролі у підтримці вибору ортопедичних матеріалів, інтеграції клінічних і цифрових параметрів, прогнозуванні результатів ортопедичного лікування та персоналізації планування лікування.

Матеріали та методи. Проведено наративний аналітичний огляд літератури, опублікованої протягом семи завершених календарних років (січень 2019 – грудень 2025 рр.). Релевантні публікації були визначені в PubMed/MEDLINE, Scopus, Web of Science та ресурсах NCBI з використанням комбінацій термінів, пов'язаних зі штучним інтелектом, машинним навчанням, ортопедичною стоматологією, стоматологічними матеріалами, CAD/CAM, коронками, ортопедичними конструкціями, оклюзією та результатами лікування. Публікації тематично аналізували за напрямом застосування ШІ, типом ортопедичної задачі, джерелом даних, клінічною метою, отриманими результатами та обмеженнями.

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Результати. Проаналізована література демонструє, що ШІ дедалі ширше застосовується в діагностиці в ортопедичній стоматології, плануванні лікування, автоматизованому проєктуванні коронок, визначенні лінії препарування, оцінюванні оклюзії, прогнозуванні результатів ортопедичного лікування та цифрових робочих процесах. Системи CAD із підтримкою ШІ продемонстрували потенціал для підвищення ефективності проєктування та, у вибраних дослідженнях, забезпечення клінічно прийнятної точності прилягання коронок. Водночас доказова база залишається неоднорідною через суттєві відмінності в наборах даних, алгоритмах, процедурах валідації та показниках результативності. Прямі докази на користь незалежно валідованих систем ШІ для індивідуалізованого вибору ортопедичних матеріалів залишаються обмеженими. Отже, сучасні дані переважно підтримують використання ШІ як інструменту підтримки клінічних рішень, а не як автономної системи вибору матеріалу.

Висновки. ШІ має значний потенціал для підтримки індивідуалізованого вибору матеріалів та планування ортопедичного лікування шляхом інтеграції численних клінічних і цифрових параметрів. Водночас сучасні дані не підтримують розгляд ШІ як автономної заміни професійного клінічного рішення. Пряма валідація систем ШІ, спеціально розроблених для вибору ортопедичних матеріалів, залишається обмеженою, а багато прогностичних моделей потребують ґрунтовнішої зовнішньої валідації та проспективної клінічної оцінки. Отже, найбільш доцільною сучасною моделлю є підхід «людина в контурі» (human-in-the-loop), за якого ШІ доповнює, а не замінює клінічну експертизу.

Ключові слова: штучний інтелект, ортопедична стоматологія, стоматологічні матеріали, машинне навчання, CAD/CAM, підтримка клінічних рішень, зубні коронки, персоналізоване ортопедичне лікування.

Problem Statement. Material selection is a clinically important stage of prosthodontic treatment because restorative materials differ in mechanical behavior, optical properties, processing requirements, and clinical indications. Contemporary digital prosthodontics offers a broad range of ceramic, hybrid, composite, and metal-based options. The increasing number of possible treatment configurations makes material selection a multifactorial decision rather than a simple choice based on a single material property.

Traditional decision-making relies on the clinician's experience, scientific evidence, material characteristics, laboratory capabilities, and patient-specific considerations. Recent developments in AI have introduced computational approaches capable of processing large and heterogeneous datasets and identifying patterns that may support diagnosis, treatment planning, prosthetic design, and outcome prediction [1–4].

The relevance of AI to material selection is therefore not limited to identifying the strongest or most esthetic material. A clinically meaningful decision may require simultaneous consideration of restoration location, occlusal conditions, prosthetic design, available space, patient-related factors, digital morphology, and anticipated functional demands. Current literature, however, contains substantially more evidence for AI-assisted design and diagnostics than for validated autonomous material-selection systems. This distinction is important when defining the clinical role of AI [2–4].

Materials and Methods. Study design. The present work was designed as a narrative analytical review rather than a systematic review or meta-analysis. The methodology was structured to provide a transparent description of the literature search and thematic analysis while avoiding quantitative pooling of heterogeneous studies.

Search period and information sources. The review focused on publications issued during seven completed calendar years, from January 2019 through December 2025. Literature was searched using PubMed/MEDLINE, Scopus, and Web of Science. NCBI resources were additionally used for bibliographic verification and access to indexed full-text records. PubMed/MEDLINE was treated as the principal biomedical database; NCBI was not considered a separate bibliographic database. Searches were supplemented by reference-list checking of relevant reviews and primary studies.

Database platforms: PubMed (<https://pubmed.ncbi.nlm.nih.gov/>); Scopus (<https://www.scopus.com/>); Web of Science (<https://www.webofscience.com/>); NCBI (<https://www.ncbi.nlm.nih.gov/>).

Search terms. The search strategy combined controlled vocabulary and free-text terms. The principal concepts were: (“Artificial Intelligence”[MeSH] OR “Machine Learning”[MeSH] OR “deep learning” OR “neural network*”) AND (“Prosthodontics”[MeSH] OR prosthodont* OR “dental prosthesis” OR crown* OR “fixed dental prosthesis”) AND (“dental material*” OR zirconia OR “lithium disilicate” OR CAD/CAM OR “computer-aided design” OR “material selection” OR “treatment planning” OR “clinical decision support”). Additional searches used combinations of “artificial intelligence” with “prosthodontics”, “dental crown”, “occlusion”, “implant prosthodontics”, “prosthetic complication*”, and “CAD/CAM”.

Eligibility criteria. Inclusion criteria were: (1) peer-reviewed publications in English; (2) publication within January 2019–December 2025; (3) studies or reviews addressing AI, machine learning, deep learning, or neural-network applications relevant to prosthodontics; and (4) relevance to diagnosis, treatment planning, prosthetic design, material-related decision-making, occlusion, prediction of complications, or digital prosthodontic workflows.

Exclusion criteria were: (1) publications unrelated to prosthodontics or dental prostheses; (2) conference abstracts, advertisements, non-peer-reviewed materials, and opinion pieces without substantive scientific data; (3) studies in which AI was used exclusively for a non-prosthodontic purpose; and (4) publications for which the bibliographic record could not be verified.

Data extraction and thematic analysis. The literature was analyzed qualitatively. For each relevant publication, attention was directed to: type of AI technology; prosthodontic application; source and type of input data; clinical or laboratory task; reported performance or outcome; validation approach; and stated limitations. The findings were organized into eight thematic categories: (1) AI as clinical decision support; (2) personalized restorative material selection; (3) occlusal and functional analysis; (4) prediction of prosthetic complications; (5) AI-assisted CAD/CAM and crown design; (6) implant-supported prosthodontics; (7) workflow and economic implications; and (8) ethical, legal, and clinical limitations.

Because the included literature differed substantially in study design, AI architecture, datasets, endpoints, and validation methods, no meta-analysis or pooled statistical estimate was performed. The review therefore emphasizes the direction and clinical relevance of reported findings rather than quantitative comparison across studies.

Results and Discussion. 1. AI as a clinical decision-support technology. The literature indicates that AI is increasingly being investigated as an adjunct to clinical reasoning in prosthodontics. Early systematic evidence identified applications in prosthodontic diagnosis, treatment planning, and outcome-related prediction, while also emphasizing the limited number of clinically validated systems [1]. More recent reviews demonstrate a broader range of applications, including automated diagnostics, prosthetic design, predictive analysis, and integration with digital workflows [2–4].

Importantly, the current evidence does not justify describing AI as an autonomous clinical consultant. The strongest evidence concerns specific computational tasks, whereas individualized material selection requires integration of clinical judgment, patient preferences, biological considerations, functional demands, and the limitations of available materials. AI can therefore be conceptualized as a decision-support layer that organizes and interprets information rather than replacing the clinician.

A systematic mapping review published in 2024 identified 70 reports describing artificial neural-network prediction models in prosthodontics after screening 597 records. The authors reported applications in both implant and non-implant prosthodontics and emphasized heterogeneity in data, architectures, evaluation metrics, and model development [4]. This heterogeneity remains an important consideration when transferring AI research findings into routine clinical practice.

2. Personalized selection of restorative materials. The concept of AI-supported material selection arises from the multifactorial nature of prosthodontic treatment. Zirconia, lithium-disilicate ceramics, resin-based and hybrid materials, and other restorative options possess different combinations of strength, fracture behavior, translucency, processing requirements, and clinical indications. Consequently, the clinically appropriate material cannot be determined from a single mechanical or esthetic parameter.

Current literature supports the broader principle that AI can integrate multiple variables relevant to prosthodontic treatment. Reviews of AI in prosthodontics describe applications in treatment planning, prosthetic design, and prediction of treatment outcomes [2, 3, 5]. However, direct evidence for independently validated AI systems whose primary endpoint is the individualized selection of a restorative material remains comparatively limited. Therefore, statements that AI “selects the best material” should be interpreted as a prospective or decision-support capability rather than an established autonomous clinical function.

A more realistic clinical model would allow the system to process restoration location, prosthetic design, occlusal conditions, available restorative space, digital morphology, material properties, and patient-related factors, and

then present several evidence-based options with associated advantages and potential risks. The clinician would remain responsible for the final selection.

This distinction also reduces the risk of overinterpretation of AI performance. A prediction model can identify statistical associations in a dataset without demonstrating that the resulting recommendation improves patient outcomes. External validation and prospective clinical testing are therefore essential before AI-based material-selection systems can be considered reliable clinical tools.

3. Occlusal and functional analysis. Occlusal conditions are relevant to prosthetic prognosis because restorative performance is influenced by the functional environment in which a restoration operates. Digital occlusal technologies can provide quantitative information that complements conventional clinical examination. For example, T-Scan-based assessment has been used to characterize occlusal contacts and force-related parameters in dental research [13].

The integration of quantitative occlusal information with machine-learning approaches is potentially relevant to individualized treatment planning. An AI system could theoretically combine occlusal measurements with restoration type, tooth position, material characteristics, and prosthetic geometry. Nevertheless, the available evidence is currently stronger for AI-assisted assessment and prediction than for a clinically validated workflow that converts occlusal data directly into a material recommendation. This distinction should be maintained in clinical interpretation.

Patients with parafunctional activity represent a particularly relevant population because functional loading may influence restoration design and material requirements. AI-supported analysis may assist in identifying complex interactions among variables, but such systems require clinically representative datasets and validation across different patient populations before routine implementation.

4. Prediction of prosthetic complications. Prediction of prosthetic complications is one of the most developed areas of AI research relevant to personalized treatment. AI and machine-learning models have been investigated for prediction and classification tasks involving prosthetic outcomes, crown-related parameters, implant complications, and treatment performance [2, 4, 14].

The evidence is especially informative when the outcome is clearly defined. For example, recent literature on implant prediction models demonstrates that prediction systems can incorporate patient-, implant-, and treatment-related variables; however, systematic appraisal has also shown that external validation remains uncommon and methodological quality may be variable [14]. These limitations are directly relevant to the interpretation of AI-based prognostic tools in prosthodontics.

For restorative materials, potential prediction targets include marginal or internal fit, fracture-related outcomes, debonding, chipping, and other mechanical complications. The clinical value of such models would be greatest if risk estimates could be generated before fabrication, thereby allowing the clinician to compare alternative restorative strategies. At present, however, the evidence base remains

heterogeneous, and predicted risk should not be treated as a substitute for clinical assessment.

The appropriate role of AI is therefore to provide an additional layer of quantitative risk information. The final decision should incorporate the quality of the underlying evidence, applicability of the dataset to the individual patient, and clinician assessment.

5. AI-assisted CAD/CAM and digital prosthetic design. The strongest recent evidence concerns the integration of AI with CAD/CAM workflows. AI-equipped CAD systems have been evaluated for automated crown design, design efficiency, finish-line detection, and restoration fit [6–10].

Nagata et al. compared conventional CAD with an AI-equipped CAD system for crown design and reported significantly shorter design times with the AI-assisted system. In their in vitro study, the AI-based workflow also produced more uniform crown designs across operators [9]. These findings support the practical value of AI for reducing repetitive design tasks, but the study was performed under controlled laboratory conditions and therefore cannot by itself establish clinical superiority.

A 2025 clinical study evaluated crowns designed using generative AI and conventional CAD. The authors reported clinically acceptable fit and broadly comparable marginal accuracy when preparation margins were well defined, while also identifying differences in specific regions and emphasizing the need for inspection of automatically generated designs [10]. This is particularly relevant to clinical implementation because automated generation does not eliminate the need for professional verification.

AI-assisted detection of crown finish lines is another important digital application. A 2024 study evaluated automated and semi-automated approaches for finish-line detection using a large set of digital jaw scans [7]. Such technologies may improve workflow efficiency, but automated recognition should still be understood as a technical aid within a clinician- or technician-controlled workflow.

The broader evidence therefore supports a model in which AI and CAD/CAM are integrated rather than separated: digital data provide the input, AI performs selected analytical or generative functions, CAD/CAM translates the selected design into a prosthetic construction, and the clinician or dental technician performs verification and final approval.

6. Implant-supported prosthodontics. Implant-supported prosthodontics presents a particularly complex decision environment because restoration design is influenced by implant position, prosthetic geometry, occlusal loading, available restorative space, and biological factors. AI has been investigated across implant dentistry for image analysis, prediction modeling, and treatment-related decision support [4, 5, 14].

A 2025 systematic review of prediction models for dental implant complications and survival identified multiple models addressing peri-implant complications, marginal bone loss, implant loss, and related outcomes. Although several models demonstrated good discrimination, only a small proportion had undergone external validation, and the authors emphasized methodological and

reporting limitations [14]. This evidence illustrates both the potential and the current limitations of predictive modeling in implant-related prosthodontics.

For material selection in implant-supported restorations, AI may eventually assist in integrating implant configuration, prosthetic design, functional loading, and material properties. At present, however, the literature supports this primarily as a prospective decision-support application rather than an established autonomous recommendation system.

7. Workflow efficiency and potential economic implications. AI-assisted prosthodontic workflows may influence efficiency by automating repetitive tasks, reducing design time, standardizing selected digital procedures, and facilitating communication between clinical and laboratory stages. The 2025 study by Nagata et al. provides direct evidence that AI-assisted CAD can reduce crown-design time under controlled conditions [9].

However, economic benefit should not be assumed solely from reduced design time. Implementation requires software, compatible digital infrastructure, training, maintenance, data governance, and quality-control procedures. The economic value of AI should therefore be evaluated using broader outcomes such as total workflow time, remake rates, clinician and technician workload, training requirements, and patient-related outcomes.

At present, the literature provides a stronger rationale for potential efficiency gains than for definitive claims about cost savings across prosthodontic practices. Economic conclusions should therefore remain conditional until supported by real-world comparative studies.

8. Ethical, legal, and clinical limitations. The introduction of AI into prosthodontics creates several limitations that directly affect its suitability for material-selection support. These include data quality, representativeness of training datasets, algorithmic transparency, external validation, cybersecurity, patient privacy, and allocation of clinical responsibility [2–5, 16].

The “black-box” nature of some machine-learning systems may complicate interpretation of recommendations. This is particularly important when an algorithm proposes a restorative option that differs from the clinician’s initial assessment. Explainability and traceability are therefore important requirements for clinical decision-support systems.

Another concern is dataset shift. A model developed from one population, scanner, imaging protocol, CAD environment, or material system may not perform identically in another setting. External validation should consequently be considered a prerequisite for clinical generalization.

Finally, AI should not be presented as an autonomous substitute for professional responsibility. Current evidence supports a human-in-the-loop model in which AI provides analysis, prediction, or alternative treatment scenarios, while the clinician retains responsibility for diagnosis, treatment planning, informed consent, material selection, and patient care [2, 3, 16].

Limitations of the present review. This review has several limitations. First, it is a narrative analytical review and does not follow the full protocol of a systematic

review with duplicate independent screening, formal risk-of-bias assessment, and quantitative synthesis. Second, the literature is heterogeneous, with substantial differences in AI methods, datasets, clinical tasks, and outcome measures. Third, direct evidence specifically addressing AI-driven selection of restorative materials is less extensive than evidence concerning AI-assisted design, diagnosis, and prediction. Accordingly, conclusions regarding autonomous material selection should be considered preliminary.

The seven-year publication window was selected to provide a consistent temporal criterion as requested for the review. Older publications may nevertheless remain relevant for methodological background where they are cited by the recent evidence base.

Conclusions. Artificial intelligence is increasingly integrated into prosthodontic diagnosis, treatment planning, digital design, prediction modeling, and CAD/CAM workflows. The current literature demonstrates that AI can support specific technical and analytical tasks, including automated crown design, finish-line detection, quantitative assessment, and prediction of selected prosthodontic outcomes.

The potential role of AI in restorative material selection is particularly promising because material choice is a multifactorial clinical decision. By integrating patient-related, functional, morphological, digital, and material-specific parameters, AI-based decision-support systems may help clinicians compare alternative restorative strategies in a more structured and individualized manner.

At the same time, current evidence does not support treating AI as an autonomous replacement for professional clinical judgment. Direct validation of AI systems specifically designed to select restorative materials remains limited, and many predictive models require stronger external validation and prospective clinical evaluation. The most

appropriate current framework is therefore a human-in-the-loop decision-support model in which AI augments, rather than replaces, clinical expertise.

Future research should prioritize prospective multicenter studies, standardized reporting of datasets and algorithms, external validation, explainable AI, and clinically meaningful endpoints. Particular attention should be given to models that integrate material properties with occlusal, anatomical, prosthetic, and patient-related parameters and that can demonstrate whether AI-supported recommendations actually improve clinical outcomes.

The development of such validated systems could contribute to a transition from generalized material-selection protocols toward more individualized prosthodontic decision-making while maintaining clinician oversight and responsibility.

Future Research Directions. Future investigations should focus on: (1) development of validated AI models specifically addressing restorative material selection; (2) integration of CAD/CAM morphology, occlusal data, material properties, and patient-specific variables; (3) prospective multicenter validation; (4) transparent reporting of datasets, algorithms, and performance metrics; (5) explainable AI interfaces suitable for clinical use; (6) assessment of model performance across different scanners, CAD platforms, materials, and patient populations; and (7) evaluation of clinical, economic, and patient-reported outcomes associated with AI-supported material selection.

Declaration of AI-assisted tools. During the preparation of this manuscript, an artificial intelligence-based language tool was used for language editing and improvement of clarity. The author independently reviewed and verified the scientific content, interpretation of the literature, references, and final conclusions and takes full responsibility for the content of the manuscript.

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