UDK: 616.716.4-001.5:531.3

Okklyuziya tahlilida sun’iy intellekt texnologiyalarini qo‘llash va stomatologik menejment tizimi samaradorligini optimallashtirish

Safarov M.T.[1], Odilova M.U.[2], Xabilov D.N.[3], Qosimova K.A.[4], Olimjonova N.O.[5], Dadabayeva M.U.[6] Azimov R.I.[7]

Annotatsiya

Ushbu sharhning maqsadi okklyuziya tahlilida sun’iy intellekt (SI)ni qo‘llash imkoniyatlarini baholash hamda uning stomatologik menejment samaradorligiga ta’sirini aniqlashdan iborat. Tahlil so‘nggi klinik tadqiqotlar, raqamli stomatologiya hisobotlari va ekspertlar konsensus hujjatlari asosida amalga oshirildi. Natijalar shuni ko‘rsatadiki, mashinaviy o‘qitish algoritmlari va raqamli okklyuzion tahlil vositalarini o‘z ichiga olgan SI tizimlari okklyuzion kontaktlarni aniqlash, kuch taqsimotini baholash hamda davolash rejasini tuzishda aniqlikni sezilarli darajada oshiradi.

An’anaviy diagnostik yondashuvlar bilan solishtirganda, SI asosidagi texnologiyalar yuqori barqarorlikni, inson omiliga bog‘liq xatolarning kamayishini va natijalarning takrorlanuvchanligini ta’minlaydi. Bundan tashqari, SI tizimlarini stomatologik menejmentga integratsiya qilish bemor oqimini optimallashtirish, resurslardan samarali foydalanish hamda ma’lumotlarga asoslangan klinik qaror qabul qilish jarayonini takomillashtirishga xizmat qiladi. Ushbu sharh zamonaviy texnologik yutuqlarni yoritadi, mavjud cheklovlarni aniqlaydi va stomatologik amaliyotda SI ni joriy etish bo‘yicha dalillarga asoslangan tavsiyalarni taqdim etadi.

Kalit so‘zlar: sun’iy intellekt, okklyuziya tahlili, raqamli stomatologiya, mashinaviy o‘qitish, stomatologik menejment, klinik qaror qabul qilish, okklyuzion kuch taqsimoti

KLINIK TADQIQOTLAR VA INNOVATSION TIBBIYOT
VOLUME-02. ISSUE-03

The Application of Artificial Intelligence Technologies in Occlusal Analysis and Optimization of Dental Management Efficiency

Safarov M.T.[1], Odilova M.U.[2], Khabilov D.N.[3], Kosimova K.A.[4], Olimjonova N.O.[5], Dadabayeva M.U.[6] Azimov R.I.[7]

Abstract

The purpose of this review is to evaluate the application of artificial intelligence (AI) in occlusal analysis and to assess its impact on the efficiency of dental management. A comprehensive analysis was performed based on recent clinical studies, digital dentistry reports, and expert consensus publications. The findings indicate that AI-driven systems, including machine learning algorithms and digital occlusal analysis tools, significantly improve the accuracy of occlusal contact detection, force distribution assessment, and treatment planning. Compared to conventional diagnostic approaches, AI-based technologies demonstrate higher consistency, reduced human error, and enhanced reproducibility of results. Furthermore, the integration of AI into dental management systems contributes to optimized patient flow, improved resource allocation, and data-driven clinical decision-making. This review outlines current technological advancements, identifies existing limitations, and provides evidence-based recommendations for the implementation of AI in modern dental practice.

Keywords: artificial intelligence, occlusal analysis, digital dentistry, machine learning, dental management, clinical decision-making, occlusal force distribution.

СРАВНИТЕЛЬНАЯ ОЦЕНКА МЕТОДОВ РЕГИСТРАЦИИ ЦЕНТРАЛЬНОГО СООТНОШЕНИЯ ПРИ ИЗГОТОВЛЕНИИ ПОЛНОГО СЪЕМНОГО ПРОТЕЗА: НАУЧНЫЙ ОБЗОР

Сафаров М.Т.[1], Одилова М.У.[2], Хабилов Д.Н.[3], Косимова К.А.[4], Олимжонова Н.О.[5], Дадабаева М.У.[6]Азимов Р.И.[7]

Аннотация

Цель данного обзора — оценить применение искусственного интеллекта (ИИ) в анализе окклюзии и определить его влияние на эффективность стоматологического менеджмента. Анализ проведён на основе современных клинических исследований, данных цифровой стоматологии и экспертных консенсусных публикаций. Результаты показывают, что системы на базе ИИ, включая алгоритмы машинного обучения и цифровые инструменты окклюзионного анализа, повышают точность выявления окклюзионных контактов, оценки распределения нагрузки и планирования лечения. По сравнению с традиционными методами диагностики технологии ИИ обеспечивают более высокую воспроизводимость результатов, снижение человеческого фактора и улучшение качества клинических решений. Интеграция ИИ в систему стоматологического менеджмента способствует оптимизации потоков пациентов, рациональному использованию ресурсов и принятию управленческих решений на основе данных.

Ключевые слова: искусственный интеллект, анализ окклюзии, цифровая стоматология, машинное обучение, стоматологический менеджмент, клинические решения, распределение окклюзионной нагрузки.

1. Introduction

Occlusal analysis represents a fundamental component of comprehensive dental examination and treatment planning. Proper identification of occlusal relationships, including central occlusion, intercuspal position, and dynamic contacts, is essential for maintaining functional harmony of the stomatognathic system. Disturbances in occlusion may contribute to temporomandibular joint (TMJ) disorders, abnormal tooth wear, periodontal overload, muscle dysfunction, and failure of prosthetic or restorative constructions. Therefore, accurate and objective occlusal assessment is critical for achieving long-term clinical success.

Traditionally, occlusal evaluation has been performed using articulating paper, shimstock foil, wax records, and mechanical articulators. While these methods remain widely used, they are largely subjective and depend heavily on clinician experience. Interpretation of contact intensity, force distribution, and timing may vary between practitioners, reducing reproducibility and potentially affecting treatment outcomes. Moreover, conventional techniques provide limited quantitative data and may not fully reflect dynamic occlusal interactions during mastication.

The rapid development of digital dentistry has introduced advanced diagnostic technologies such as intraoral scanners, digital articulators, computerized occlusal analysis systems, and 3D jaw motion tracking devices. These systems generate large volumes of high-resolution digital data, including three-dimensional occlusal maps and force distribution patterns. However, effective interpretation of such complex datasets requires advanced analytical tools capable of identifying clinically relevant patterns and correlations.

Artificial intelligence (AI), particularly machine learning (ML) and deep learning (DL) algorithms, offers powerful solutions for automated data processing and decision support in dentistry. AI systems can analyze digital impressions, occlusal contact distributions, and functional movement trajectories with high precision. By recognizing patterns in large datasets, AI models can assist in identifying occlusal discrepancies, predicting functional imbalances, and optimizing prosthodontic or orthodontic treatment planning.

The integration of AI technologies into occlusal diagnostics has the potential to enhance diagnostic accuracy, reduce clinician-dependent variability, and standardize assessment protocols. Furthermore, AI-driven systems can improve clinical workflow efficiency by accelerating data analysis, supporting evidence-based decision-making, and facilitating personalized treatment strategies. As digital dentistry continues to evolve, the application of artificial intelligence in occlusal analysis represents a promising direction for improving both diagnostic quality and overall dental management efficiency.

2. Theoretical The Application of Artificial Intelligence Technologies in Occlusal Analysis and Optimization of Dental Management Efficiency

The application of artificial intelligence (AI) technologies in occlusal analysis is grounded in the evolution of digital dentistry, computational modeling theory, biomechanical science, and healthcare efficiency frameworks. Its theoretical foundations derive from the interaction between systems theory, statistical learning models, predictive analytics, and clinical decision-support paradigms. Understanding these foundations is essential for constructing an integrated digital occlusal management system that aligns diagnostic precision with clinical efficiency and long-term treatment outcomes.

The development of AI-driven occlusal analysis reflects broader transformations in dental practice. Traditional occlusal assessment emphasized visual interpretation, articulating paper markings, and clinician experience. Diagnosis was largely qualitative, incremental, and dependent on subjective interpretation. While clinically valuable, such approaches lacked reproducibility and quantitative force analysis.

The emergence of digital dentistry marked a turning point. Intraoral scanners, dynamic occlusal force sensors, and CAD/CAM systems introduced measurable, data-rich environments. Under this paradigm, occlusal analysis began shifting from static contact visualization toward dynamic biomechanical assessment. Digital records enabled objective documentation of contact timing, force magnitude, and distribution patterns.

However, early digital systems remained descriptive rather than predictive. They provided numerical data but required manual interpretation. As computational capacity increased, artificial intelligence introduced a new theoretical layer: predictive modeling. AI systems do not merely display occlusal data; they learn patterns, detect nonlinear relationships, and generate probabilistic predictions regarding overload risk, premature contacts, and post-treatment stability.

From a systems theory perspective, occlusion can be conceptualized as a dynamic biomechanical network. Teeth function as structural nodes, musculature generates force vectors, and temporomandibular joints regulate movement trajectories. Any localized disturbance may propagate across the system. AI models, particularly deep learning architectures, are theoretically capable of capturing these complex interdependencies through multidimensional pattern recognition.

Statistical learning theory provides the formal foundation for AI-based occlusal diagnostics. Supervised learning models estimate functional relationships:

f(X)→Yf(X) \rightarrow Yf(X)→Y

where XXX represents multimodal clinical input (3D geometry, force-time data, patient variables), and YYY denotes predicted outcomes (contact classification, overload probability, adjustment map). The objective is minimization of expected prediction error within probabilistic frameworks.

Predictive modeling extends beyond diagnosis toward optimization theory. Occlusal adjustment may be formulated as a constrained optimization problem in which morphological modifications aim to minimize imbalance and excessive load:

min⁡M F(M)\min_{M} \; F(M)MminF(M)

where MMM denotes modification of occlusal morphology and F(M)F(M)F(M) represents predicted force imbalance or biomechanical stress. This theoretical framing transforms occlusal management from reactive correction to forward-looking simulation-based planning.

The theoretical evolution of AI in dentistry parallels developments in decision-support systems within medicine. Rather than replacing clinicians, AI operates as an augmentation tool, enhancing cognitive capacity through rapid data processing and pattern detection. Human–AI collaboration models emphasize interpretability, explainability, and clinician oversight to maintain accountability and patient safety.

Healthcare efficiency theory further expands the conceptual basis of AI-driven occlusal management. Dental workflows consist of sequential stages—diagnosis, digital design, fabrication, insertion, and adjustment. Inefficiencies often arise from repeated occlusal corrections and prosthetic remakes. By reducing diagnostic uncertainty and enabling predictive design optimization, AI contributes to measurable improvements in time utilization, cost control, and treatment predictability.

Institutional and technological integration also shape the theoretical architecture. AI-driven occlusal analysis must operate within interconnected digital ecosystems, linking scanning devices, CAD software, practice management systems, and laboratory workflows. The concept of digital interoperability becomes central to achieving methodological coherence.

Moreover, adaptive learning theory underpins the continuous improvement potential of AI systems. Clinical outcomes—patient comfort, restoration survival, follow-up adjustments—serve as feedback inputs for model recalibration. This creates an iterative loop:

Data → Model → Clinical Application → Outcome → Model Update

Such feedback mechanisms align with modern adaptive governance principles in healthcare systems, where decision-making evolves in response to new evidence.

Ethical and regulatory theory also informs the theoretical framework. AI systems must incorporate uncertainty estimation, transparency, and traceability. Explainable AI principles address concerns related to black-box decision-making and strengthen clinician trust.

Synthesizing these perspectives, the theoretical foundations of AI-driven occlusal analysis can be conceptualized around five interrelated principles:

1. **Biomechanical systems integration** – modeling occlusion as a dynamic, interconnected force network.
2. **Data-driven prediction** – replacing heuristic interpretation with probabilistic learning models.
3. **Optimization-based planning** – shifting from reactive correction to simulated pre-adjustment design.
4. **Workflow efficiency alignment** – integrating diagnostic precision with resource optimization.
5. **Adaptive clinical feedback** – continuous model refinement through outcome-based learning.

Together, these principles form the conceptual basis for developing an AI-enabled occlusal management system that integrates diagnostic accuracy, predictive modeling, digital workflow integration, and healthcare efficiency within a unified clinical framework.

3.Methodological The Application of Artificial Intelligence Technologies in Occlusal Analysis and Optimization of Dental Management Efficiency

Strategic integration of artificial intelligence (AI) technologies in occlusal analysis requires a coherent methodological architecture that connects multimodal data acquisition, computational modeling, clinical validation, workflow integration, and outcome-based evaluation. While theoretical foundations define the principles of predictive diagnostics and digital precision dentistry, methodological approaches operationalize these principles into clinically applicable decision-support systems.

One of the core methodological pillars of AI-driven occlusal management is multimodal data integration. Effective AI systems combine dynamic occlusal force recordings, three-dimensional intraoral scans, digital bite registrations, and structured clinical metadata into unified analytical frameworks. This integration ensures that occlusal contact detection is not limited to static geometry but incorporates temporal and biomechanical dimensions of mandibular movement.

The methodological logic of AI-based occlusal analysis includes:

• Acquisition of high-resolution 3D intraoral scans and dynamic force-time data;
• Spatial-temporal registration between sensor-derived contacts and digital tooth surfaces;
• Feature extraction from force curves and geometric mesh representations;
• Model training using supervised or semi-supervised machine learning algorithms;
• Validation against expert-annotated clinical ground truth;
• Iterative refinement through outcome-based feedback loops.

This structured approach enhances diagnostic objectivity and reduces inter-operator variability in occlusal assessment.

Machine learning and deep learning algorithms constitute the analytical core of the methodological framework. Convolutional neural networks (CNNs) and mesh-based architectures enable automated detection of occlusal contacts and premature interference patterns. Temporal neural networks process force distribution sequences to predict overload risk and asymmetry indices. Regression-based models estimate force magnitude and contact timing, while classification models identify occlusal scheme types.

Generative and optimization algorithms extend the methodology beyond diagnosis toward treatment planning. AI-driven CAD/CAM systems simulate post-adjustment occlusal states and propose minimal corrective modifications to restorative morphology. This optimization logic reduces chairside adjustments and prosthetic remakes, thereby increasing clinical efficiency.

Programmatically, the AI methodological architecture follows a continuous digital cycle:

Data Acquisition → Preprocessing & Registration → Feature Engineering → Model Training → Clinical Inference → Decision Support → Outcome Monitoring → Model Updating

Such a closed-loop structure ensures that predictive models evolve through real-world feedback, reinforcing both accuracy and reliability.

Clinical validation is an essential methodological component. Prospective comparative studies evaluate AI-assisted workflows against conventional occlusal assessment in terms of:

• Chairside adjustment time;
• Number of postoperative visits;
• Prosthetic remake rates;
• Patient-reported comfort;
• Biomechanical stability indicators.

Robust statistical evaluation, including mixed-effects modeling and survival analysis for prosthetic outcomes, strengthens the evidence base for AI deployment in routine practice.

Monitoring and evaluation systems play a critical role in closing the methodological loop. Digital dashboards integrated into CAD/CAM and practice management software provide real-time visualization of force distribution, predicted risk zones, and adjustment maps. Continuous data capture enables longitudinal performance tracking and adaptive algorithm recalibration.

Digitalization further supports methodological integration by reducing information asymmetry between clinicians and laboratories. Automated data pipelines streamline communication, improve reproducibility of restorative design, and enhance accountability through traceable decision logs.

Risk management is also embedded in the methodological architecture. AI models must incorporate uncertainty estimation and confidence scoring to prevent over-reliance on algorithmic outputs. Scenario-based simulation allows clinicians to test alternative occlusal adjustments before irreversible interventions are performed.

In sum, methodological approaches to AI-driven occlusal analysis integrate multimodal data acquisition, computational modeling, predictive analytics, CAD/CAM optimization, clinical validation, and continuous monitoring into a unified operational architecture. Such integration transforms occlusal management from a predominantly subjective procedure into a data-driven, efficiency-oriented, and outcome-optimized clinical system.

4. Discussion

The analysis of theoretical, technological, and clinical dimensions of artificial intelligence integration in occlusal analysis reveals several important scientific and practical implications.

First, AI-assisted occlusal management should be understood as an integrated digital clinical system rather than a standalone diagnostic tool. The literature consistently demonstrates that isolated technologies—such as intraoral scanners or force sensors—cannot independently ensure improved treatment outcomes. Their impact depends on systematic integration within a coherent digital workflow architecture that connects data acquisition, predictive modeling, CAD/CAM design, clinical decision support, and outcome monitoring.

Second, the transition from traditional occlusal assessment to AI-driven systems reflects a broader paradigm shift in dentistry. Conventional approaches emphasized clinician experience and qualitative interpretation. Early digital systems improved visualization but remained descriptive. Contemporary AI models introduce predictive and optimization-based logic, enabling simulation of occlusal outcomes before irreversible clinical intervention. This transition represents movement from reactive adjustment toward anticipatory, data-driven planning.

Third, the evidence suggests that technological sophistication alone does not guarantee clinical effectiveness. The success of AI deployment depends heavily on data quality, annotation reliability, institutional readiness, and clinician training. Similar to other healthcare digital reforms, premature adoption without sufficient validation may lead to overreliance on algorithmic outputs or superficial implementation without measurable efficiency gains.

Fourth, AI integration has implications beyond diagnostics. It reshapes workflow efficiency, interprofessional communication, and cost structures within dental practice. Reduction in chairside adjustment time, decreased prosthetic remake rates, and improved reproducibility of restorative designs contribute to measurable improvements in clinical management efficiency. However, these gains must be empirically validated through prospective comparative studies and long-term outcome monitoring.

Fifth, ethical and regulatory considerations remain central to sustainable implementation. The use of predictive models in clinical decision-making requires transparency, explainability, and clearly defined professional accountability. AI systems must function as decision-support instruments rather than autonomous authorities, preserving clinician oversight and patient-centered care principles.

The discussion also highlights a broader academic implication: the need for a unified conceptual framework that synthesizes biomechanical modeling, statistical learning theory, digital workflow integration, and healthcare efficiency principles into a single operational architecture. Such a framework bridges engineering innovation and clinical applicability, reducing the gap between technological potential and practical implementation.

In rapidly digitalizing dental systems, the integration of AI into occlusal management may serve as a model for broader transformation of restorative and prosthetic workflows. However, sustainable adoption will require robust validation, institutional alignment, and interdisciplinary collaboration between clinicians, engineers, and health system administrators.

This study examined the theoretical and methodological foundations of applying artificial intelligence technologies in occlusal analysis and dental management optimization. By synthesizing concepts from systems theory, statistical learning, biomechanical modeling, and digital workflow integration, the analysis demonstrates that effective AI-driven occlusal management requires systemic integration rather than isolated technological adoption.

The study identifies five core principles underpinning AI-enabled occlusal systems:

1. Biomechanical integration of spatial, temporal, and force-related data.
2. Predictive modeling based on probabilistic learning frameworks.
3. Optimization-driven treatment planning using simulation and algorithmic adjustment.
4. Workflow efficiency alignment across scanning, design, fabrication, and clinical insertion stages.
5. Adaptive feedback mechanisms enabling continuous model refinement through clinical outcomes.

International experience in digital dentistry confirms that successful implementation depends on data infrastructure, interdisciplinary expertise, regulatory compliance, and clinician engagement. While AI demonstrates strong potential to enhance diagnostic accuracy and reduce procedural inefficiencies, long-term sustainability requires harmonization of technical, ethical, and institutional frameworks.

The findings contribute to academic discourse by proposing an integrated conceptual model for AI-driven occlusal management that unites predictive analytics, digital dentistry, and healthcare efficiency theory. Future research should focus on large-scale clinical trials, cost-effectiveness evaluation, longitudinal prosthetic survival analysis, and development of standardized validation benchmarks for AI-based occlusal systems.

In conclusion, artificial intelligence has the potential to transform occlusal analysis from a subjective, corrective practice into a predictive, optimization-based, and efficiency-oriented clinical discipline. Its full impact, however, will depend on systematic integration, rigorous validation, and responsible clinical governance.

References

1. Schwendicke, F., Samek, W., & Krois, J. (2020). Artificial intelligence in dentistry: Chances and challenges. Journal of Dental Research, 99(7), 769–774. https://doi.org/10.1177/0022034520915714

2. Schwendicke, F., Golla, T., Dreher, M., & Krois, J. (2019). Convolutional neural networks for dental image diagnostics: A systematic review. Journal of Dentistry, 91, 103226. https://doi.org/10.1016/j.jdent.2019.103226

3. Krois, J., Ekert, T., Meinhold, L., et al. (2019). Deep learning for the radiographic detection of periodontal bone loss. Scientific Reports, 9, 8495. https://doi.org/10.1038/s41598-019-44839-3

4. Revilla-León, M., & Özcan, M. (2019). Additive manufacturing technologies used for processing polymers in dentistry. Journal of Prosthodontics, 28(2), 146–158. https://doi.org/10.1111/jopr.12801

5. Mangano, F., Gandolfi, A., Luongo, G., & Logozzo, S. (2017). Intraoral scanners in dentistry: A review of the current literature. BMC Oral Health, 17, 149. https://doi.org/10.1186/s12903-017-0442-x

6. Joda, T., Ferrari, M., Gallucci, G. O., Wittneben, J. G., & Brägger, U. (2017). Digital technology in fixed implant prosthodontics. Periodontology 2000, 73(1), 178–192.

7. Miyazaki, T., Hotta, Y., Kunii, J., Kuriyama, S., & Tamaki, Y. (2009). A review of dental CAD/CAM: Current status and future perspectives. Journal of Prosthodontic Research, 53(1), 1–7.

8. Kerstein, R. B. (2015). Combining technologies: A computerized occlusal analysis system synchronized with a computerized electromyography system. Cranio, 33(3), 189–198.

9. Sierpinska, T., & Golebiewska, M. (2020). Digital occlusal analysis in prosthetic dentistry. Advances in Clinical and Experimental Medicine, 29(2), 255–260.

10. Dawood, A., Marti Marti, B., Sauret-Jackson, V., & Darwood, A. (2015). 3D printing in dentistry. British Dental Journal, 219(11), 521–529.

11. Javaid, M., & Haleem, A. (2020). Artificial intelligence applications in dentistry. Dental Journal, 8(2), 44.

12. Khanagar, S. B., Al-Ehaideb, A., Maganur, P. C., et al. (2021). Developments, application, and performance of artificial intelligence in dentistry – A systematic review. Journal of Dental Sciences, 16(1), 508–522.

13. Hung, K., Montalvao, C., Tanaka, R., et al. (2020). The use and performance of artificial intelligence applications in dentistry: A systematic review. Journal of Dentistry, 103, 103434.

14. Lee, J. H., Kim, D. H., Jeong, S. N., & Choi, S. H. (2018). Detection and diagnosis of dental caries using a deep learning-based convolutional neural network. Journal of Dentistry, 77, 106–111.

15. Patzelt, S. B. M., Emmanouilidi, A., Stampf, S., Strub, J. R., & Att, W. (2014). Accuracy of full-arch scans using intraoral scanners. Clinical Oral Investigations, 18, 1687–1694.

16. Rekow, D. (2017). Digital dentistry: The new state of the art—Is it disruptive or destructive? Dental Materials, 33(7), 739–741.

17. Mörmann, W. H. (2006). The evolution of the CEREC system. Journal of the American Dental Association, 137(Suppl), 7S–13S.