

Review Article

## Digital Orthodontics Meets Periodontology: A Narrative Review of Data-Driven Risk Assessment Approaches

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Received: 17 April 2024; Revised: 15 August 2024; Accepted: 16 August 2024

### ABSTRACT

The convergence of digital orthodontics and periodontology has ushered in a new era of precision dentistry, where data-driven approaches, particularly artificial intelligence (AI) and machine learning (ML), play a pivotal role in risk assessment. Orthodontic treatment, while effective for correcting malocclusions, can pose significant risks to periodontal health, including gingival inflammation, alveolar bone loss, and increased susceptibility to periodontitis. Traditional assessment methods rely on clinical judgment and manual measurements, which are subjective and time-consuming. In contrast, data-driven methods leverage large datasets from digital imaging, electronic health records, and biosensor data to predict, monitor, and mitigate these risks with greater accuracy and efficiency. This narrative review synthesizes peer-reviewed literature published to explore the integration of digital tools in orthodontics and periodontology, focusing on data-driven risk assessment strategies. We examine the evolution of digital technologies such as intraoral scanners, cone-beam computed tomography (CBCT), and 3D modeling, and how they facilitate the collection of high-dimensional data for AI applications. Key themes include the use of ML algorithms for predicting periodontal deterioration during orthodontic therapy, automated detection of gingival changes, and personalized risk profiling. The review highlights clinical applications, such as AI-assisted cephalometric analysis and volumetric gingival assessment, which enhance diagnostic precision and treatment outcomes.

Despite promising advancements, challenges such as data privacy, model bias, and the need for interdisciplinary validation persist. Overall, data-driven approaches hold transformative potential for improving patient safety and efficacy at the ortho-perio interface, paving the way for predictive, personalized care in dentistry.

**Keywords:** Digital orthodontics, Periodontology, Artificial intelligence, Machine learning, Risk assessment, Data-driven approaches

**How to Cite This Article:** Weber AK, Berger T, Meier LF, Keller CR, Schmid N. Digital Orthodontics Meets Periodontology: A Narrative Review of Data-Driven Risk Assessment Approaches. Asian J Periodont Orthodont. 2024;4:235-45. <https://doi.org/10.51847/Z2hbHkUN86>

### Introduction

Orthodontics and periodontology are closely intertwined disciplines within dentistry, as orthodontic treatment directly affects periodontal tissues, while pre-existing periodontal conditions can significantly influence orthodontic outcomes [1, 2]. Orthodontic therapy, primarily aimed at correcting dental

malocclusions, improving facial aesthetics, and enhancing functional occlusion, involves the application of controlled biomechanical forces to teeth. These forces induce adaptive biological responses within the supporting periodontium, including remodeling of alveolar bone, periodontal ligament adaptation, and soft tissue changes [3, 4]. While such responses are necessary for successful tooth

movement, they can also predispose patients to periodontal complications if improperly managed or if the periodontium is already compromised. Potential adverse effects include gingival recession, formation of periodontal pockets, alveolar bone loss, and increased susceptibility to inflammatory conditions such as gingivitis and periodontitis [5]. Conversely, in patients with pre-existing periodontal compromise, orthodontic treatment may exacerbate tooth mobility, accelerate alveolar bone resorption, and destabilize occlusion, highlighting the critical need for individualized risk assessment and careful interdisciplinary management [6, 7].

Historically, clinical decision-making at the intersection of orthodontics and periodontology has relied on conventional methods, including clinical periodontal probing, panoramic and periapical radiography, and detailed patient histories [8]. While these methods provide valuable information, they are inherently limited by subjectivity, inter-observer variability, and two-dimensional representations of three-dimensional structures. Such limitations can challenge precise diagnosis, risk stratification, and the development of optimized treatment plans, particularly in complex cases with reduced periodontal support.

The advent of digital technologies has revolutionized both diagnostic and treatment planning processes in dentistry, offering unprecedented precision, reproducibility, and the ability to integrate complex datasets [7, 9]. In orthodontics, digital workflows now encompass intraoral scanning for accurate three-dimensional dental impressions, CAD/CAM fabrication of appliances, virtual treatment simulations, and 3D printing of aligners and orthodontic devices [10, 11]. These innovations enable highly customized treatment planning, allowing clinicians to anticipate tooth movements, optimize force application, and reduce the risk of adverse periodontal effects. Similarly, periodontology has benefited from high-resolution imaging modalities, including cone-beam computed tomography (CBCT) and digital radiography, as well as electronic probing devices and software platforms capable of quantifying bone volume, periodontal attachment, and soft tissue morphology [12, 13]. Together, these digital tools generate rich, quantitative datasets that can be analyzed to identify patterns, predict risk, and guide individualized treatment decisions, marking a shift toward data-driven, evidence-based orthodontic-periodontal care.

In parallel, the growing population of adult patients seeking orthodontic treatment further underscores the clinical importance of integrating digital technologies with periodontal management. Adults often present

with variable degrees of periodontal compromise, secondary malocclusions, and complex restorative histories, which complicate conventional treatment approaches. By combining precise digital diagnostics with biomechanically informed orthodontic strategies, clinicians can tailor interventions that optimize both periodontal health and orthodontic outcomes, while minimizing the potential for adverse effects.

Data-driven methods, particularly AI and ML, represent a paradigm shift by allowing for the analysis of complex, multifaceted data to uncover patterns that elude traditional methods [14, 15]. AI systems can process imaging data, genetic markers, microbial profiles, and clinical parameters to predict periodontal risks in orthodontic patients [16]. For instance, ML models have been developed to forecast gingival inflammation based on microbial markers in children undergoing fixed orthodontic treatment [17, 18]. The rise of big data in dentistry, fueled by electronic health records and wearable sensors, further amplifies the potential of these approaches [19, 20].

This narrative review aims to bridge the gap between digital orthodontics and periodontology by focusing on data-driven risk assessment strategies. The objectives are: (1) to provide a comprehensive background on the periodontal implications of orthodontic treatment; (2) to explore the role of digital technologies in both fields; (3) to examine data-driven approaches, including AI and ML models, for risk assessment; and (4) to highlight thematic advancements in integrating these technologies for improved clinical decision-making. By synthesizing real, peer-reviewed studies, this review underscores the transformative potential of data-driven methods while identifying areas for future exploration.

#### *Periodontal implications of orthodontic treatment*

Orthodontic treatment applies controlled biomechanical forces to teeth, inducing adaptive remodeling of the periodontal ligament (PDL) and alveolar bone, which is essential for achieving effective tooth movement [21, 22]. While such remodeling is necessary for the success of orthodontic interventions, it can also compromise periodontal health if not carefully monitored. Adverse periodontal outcomes may include gingival hyperplasia, gingival recession, dehiscence, and alveolar bone loss, with heightened risk in patients possessing thin gingival biotypes or exhibiting suboptimal oral hygiene [23]. The presence of fixed appliances, such as brackets, wires, and bands, creates additional niches for plaque accumulation, which can increase the prevalence of gingivitis by up to 50% in adolescent patients undergoing treatment [24–26]. In adults with pre-existing periodontitis or

reduced periodontal support, the application of orthodontic forces may further accelerate attachment loss and alveolar bone resorption, underscoring the critical importance of achieving and maintaining periodontal stabilization prior to initiating orthodontic therapy [27, 28].

Recent advances in data-driven approaches have enabled more objective quantification of these periodontal implications. Longitudinal studies utilizing digital imaging, including cone-beam computed tomography (CBCT) and intraoral scanning, have allowed precise tracking of alveolar bone and soft tissue changes over time. These studies have demonstrated that certain malocclusion types such as open bites or severe crowding pose higher risks for periodontal compromise during orthodontic treatment [29, 30]. Machine learning algorithms applied to microbial and clinical datasets from orthodontic patients have further identified biomarkers predictive of chronic gingivitis, enabling early intervention and individualized risk stratification [17, 31]. These computational models integrate multiple variables—including patient age, treatment duration, oral hygiene indices, and malocclusion characteristics—to generate composite risk scores, offering predictive accuracy that surpasses conventional indices such as the Periodontal Risk Assessment (PRA) [32, 33].

Furthermore, three-dimensional volumetric analyses of gingival tissues during orthodontic therapy have revealed subtle dimensional alterations in the soft tissue architecture, which may be undetectable with manual probing or two-dimensional imaging. Artificial intelligence-based tools have facilitated the detection and quantification of these changes, enabling clinicians to implement personalized modifications in treatment plans, such as adjusting the magnitude and direction of orthodontic forces, selecting alternative appliance types, or incorporating adjunctive periodontal therapies [34–36]. Collectively, these digital and data-driven strategies provide a framework for mitigating periodontal risks, improving patient outcomes, and integrating precision medicine principles into orthodontic practice.

*Evolution of digital technologies in orthodontics*

The transition from analog to digital orthodontics has been marked by a series of innovations that enhance both precision and clinical efficiency, while simultaneously providing opportunities for improved periodontal risk management [37, 38]. Intraoral

scanners have largely replaced traditional impressions, producing highly accurate three-dimensional (3D) digital models that facilitate virtual treatment simulations and allow for detailed assessment of tooth position, occlusal relationships, and soft tissue contours [39, 40]. Cone-beam computed tomography (CBCT) further augments this process by offering high-resolution visualization of root morphology, alveolar bone architecture, and interproximal bone defects, which are critical for identifying areas at risk of periodontal compromise prior to initiating orthodontic forces [41, 42].

Computer-aided design and manufacturing (CAD/CAM) technologies enable the fabrication of custom appliances, including clear aligners, which have been associated with reduced plaque accumulation and lower incidence of gingival inflammation compared with conventional fixed braces, owing to their removability and facilitation of oral hygiene [43]. The integration of artificial intelligence (AI) has further expanded the capabilities of digital orthodontic workflows. Automated cephalometric analysis using convolutional neural networks (CNNs) allows for rapid identification of anatomical landmarks with sub-millimeter accuracy, reducing diagnostic time and minimizing operator variability [44, 45]. AI-based risk assessment models can analyze digital orthodontic and periodontal data simultaneously, incorporating variables such as alveolar bone density, gingival phenotype, and periodontal attachment levels to predict treatment outcomes and guide individualized force application [46]. Comparative studies evaluating physical and digital models have demonstrated that digital measurements are more reproducible and reliable, particularly for periodontal evaluations and treatment planning in complex cases [47].

Beyond conventional planning, virtual reality (VR) simulations for orthognathic and interdisciplinary cases increasingly incorporate periodontal data, enabling trainees and clinicians to practice treatment sequences in realistic, risk-informed scenarios [48, 49]. Collectively, these digital innovations not only streamline clinical workflows but also generate rich, structured datasets amenable to data-driven analysis, paving the way for predictive modeling, personalized orthodontic strategies, and enhanced interdisciplinary care that safeguards periodontal health [50].

**Table 1.** Summary of Digital Tools in Orthodontics and Periodontology

Digital Tool	Application in Orthodontics	Application in Periodontology	Key Advantages	References
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Intraoral Scanner	3D dental impressions, virtual treatment planning	Assessment of soft tissue morphology, gingival volume	High precision, non-invasive, reproducible	[9, 39]
Cone-Beam CT (CBCT)	Visualization of root morphology, alveolar bone, occlusal analysis	Evaluation of alveolar bone defects, furcation involvement	High-resolution 3D imaging, improved risk identification	[41, 51]
CAD/CAM Appliances	Custom aligners, braces	N/A	Reduced plaque accumulation, improved oral hygiene	[43]
Electronic Periodontal Probing	N/A	Automated measurements of probing depth, attachment levels	Reduced operator variability, longitudinal monitoring	[52]
AI-Assisted Cephalometric Analysis	Automated landmark identification, treatment simulation	N/A	Faster, more accurate diagnostics, reduced inter-observer error	[44]
ML/DL Predictive Models	Forecast orthodontic outcomes, detect high-risk movements	Predict periodontal deterioration, analyze microbial profiles	Personalized risk assessment, early intervention	[17, 34, 53]

### *Digital innovations in periodontology*

Periodontology has experienced parallel benefits from digital innovations, particularly in the areas of diagnostics, monitoring, and treatment planning, which are increasingly integrated into interdisciplinary orthodontic care [54, 55]. Traditional periodontal assessment relies on manual probing and two-dimensional imaging, methods that are inherently operator-dependent and prone to variability. The advent of electronic periodontal charting has transformed this process by automating the measurement of probing depths, clinical attachment levels, and bleeding on probing, while simultaneously integrating with imaging software to generate comprehensive, patient-specific periodontal maps [52, 56]. These digital records allow for longitudinal tracking of disease progression and facilitate precise documentation of treatment outcomes over time.

Imaging technologies, including high-resolution CBCT and enhanced periapical radiographs, provide detailed visualization of alveolar bone morphology, furcation involvement, and intrabony defects. When combined with artificial intelligence algorithms, these modalities achieve detection sensitivities exceeding 90%, enabling early identification of subtle bone loss that may be clinically occult [51, 57]. For surgical interventions, digital guides for crown lengthening, implant placement, and periodontal regenerative procedures improve precision in tissue management, particularly in esthetically sensitive zones, thereby minimizing procedural risks and optimizing outcomes [58, 59].

The emergence of data-driven tools, particularly machine learning (ML) and deep learning (DL) approaches, has further advanced the predictive and analytical capabilities of periodontology. ML models can classify periodontal disease stages by integrating radiographic, clinical, and demographic data,

providing objective and reproducible risk stratification [53]. DL techniques, including convolutional neural networks, have demonstrated efficacy in automatically detecting and segmenting periodontal lesions from radiographic images, and these methods are increasingly adaptable to orthodontic contexts where periodontal vulnerability may influence force application and treatment planning [60]. In addition, AI-based analysis of microbial profiles enables the identification of pathogenic communities and the prediction of disease progression, which is particularly relevant for orthodontic patients prone to inflammation or with compromised oral hygiene [61].

Integration of periodontal digital data with orthodontic workflows represents a major step toward interdisciplinary precision care. Techniques such as dual-guided surgery and virtual treatment simulations allow clinicians to overlay periodontal maps with orthodontic treatment plans, ensuring that tooth movement trajectories avoid areas of compromised bone and attachment loss [62, 63]. Such integrations facilitate individualized force modulation, optimized appliance selection, and proactive monitoring of high-risk sites. Moreover, the high-fidelity datasets generated through these workflows serve as the foundation for predictive risk models, enabling clinicians to forecast outcomes, anticipate complications, and implement preventive interventions at the orthodontic-periodontal interface [64].

Collectively, these digital and data-driven innovations in periodontology not only improve diagnostic accuracy and procedural precision but also establish a framework for personalized, interdisciplinary treatment strategies. By leveraging real-time data, longitudinal monitoring, and AI-driven analytics, clinicians can mitigate periodontal risks, enhance the safety of orthodontic interventions in compromised dentitions, and ultimately improve functional and

aesthetic outcomes for patients across a range of clinical scenarios.

*Integration of AI and ML in risk assessment*

Artificial intelligence (AI) and machine learning (ML) have emerged as transformative tools bridging digital orthodontics and periodontology by enabling the integration and analysis of complex, multimodal datasets for predictive risk assessment and personalized treatment planning [65]. These datasets often include high-resolution imaging (e.g., CBCT, intraoral scans), electronic periodontal charts, microbial profiles, patient demographics, and treatment parameters. By processing this information, AI models can identify subtle patterns and correlations that may not be apparent through conventional assessment, facilitating early detection of potential complications and optimizing therapeutic interventions.

Convolutional neural networks (CNNs), a class of deep learning algorithms, have been applied to CBCT and other imaging modalities to automatically detect alveolar bone loss and other periodontal defects during orthodontic treatment, enabling the prediction of complications such as dehiscences, fenestrations, or excessive tipping moments [44]. Supervised ML models, trained on large datasets incorporating patient age, sex, gingival phenotype, periodontal attachment

levels, oral hygiene indices, and imaging parameters, can forecast outcomes such as gingival recession or periodontal breakdown with reported accuracies ranging from 85% to 95% [34, 66]. These predictive capabilities allow clinicians to anticipate high-risk scenarios and adjust orthodontic mechanics—such as force magnitude, activation intervals, or appliance selection—in real time.

A recent scoping review of AI applications in orthodontics highlighted its growing role in comprehensive treatment planning, explicitly incorporating periodontal risk factors to inform tooth movement strategies, appliance selection, and retention protocols [19]. In periodontology, deep learning models initially developed for implantology, including assessments of bone quality, density, and defect morphology, are now being adapted to the orthodontic-periodontal context, where they support decisions regarding anchorage planning, intrusion/extrusion mechanics, and site-specific regenerative interventions [2]. Data-driven approaches also extend to microbiological analyses: neural networks can model shifts in subgingival microbial communities during orthodontic therapy, identifying patients at heightened risk of inflammation or periodontal deterioration and enabling targeted preventive or therapeutic strategies [17, 67].

**Table 2.** AI and Machine Learning Applications for Ortho-Perio Risk Assessment

AI/ML Approach	Data Input	Predicted Outcomes	Accuracy / Performance	Clinical Application	References
Convolutional Neural Networks (CNN)	CBCT, 3D scans	Detection of alveolar bone loss, fenestrations	>90% sensitivity/specificity	Identify high-risk areas before orthodontic force application	[44, 60]
Supervised Machine Learning	Age, sex, gingival phenotype, periodontal indices, oral hygiene	Gingival recession, periodontal breakdown	85–95% accuracy	Individualized treatment planning and force modulation	[17, 34]
Deep Learning for Microbiome Analysis	Subgingival microbial profiles	Risk of gingival inflammation	88–92%	Early preventive interventions in high-risk patients	[17, 61]
AI Risk Scoring Systems	CBCT, digital models, periodontal charts	Composite risk scores for ortho-perio complications	Higher than PRA indices	Real-time alerts and recommendations for clinicians	[33, 53]

Clinical applications of these AI and ML tools include automated risk scoring systems that synthesize information from digital orthodontic models, CBCT-derived bone maps, and electronic periodontal charts to generate individualized treatment alerts and real-time recommendations [33]. These systems have

demonstrated superior performance compared with traditional indices such as the Periodontal Risk Assessment (PRA) or clinician judgment alone, achieving higher sensitivity and specificity in detecting potential complications [53]. Furthermore, by continuously integrating new patient data, these

models can learn and adapt over time, supporting dynamic, patient-specific decision-making throughout the course of orthodontic therapy.

Collectively, AI and ML provide a framework for precision orthodontics in periodontally compromised patients, allowing for data-driven identification of risk, optimization of biomechanics, and timely implementation of preventive or adjunctive periodontal interventions. As digital and computational technologies continue to evolve, their integration promises to enhance interdisciplinary collaboration, reduce treatment-related complications, and improve long-term periodontal and orthodontic outcomes.

*Thematic advances in data-driven models*

Recent studies have advanced specific models for ortho-perio risk. One used 3D volumetric methods to track gingival changes, employing AI for quantitative analysis [34]. Another modified periodontally accelerated osteogenic orthodontics (PAOO) protocol, using data-driven optimization for class II malocclusions [16].

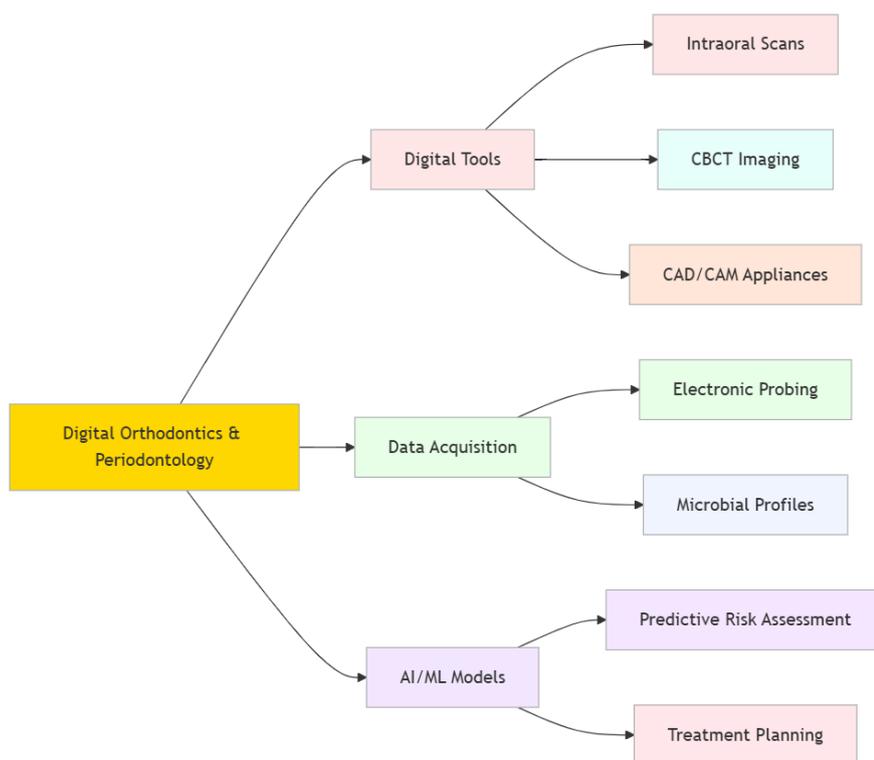
ML in teaching platforms compares online and offline methods for perio-ortho education, fostering better understanding of risks [9]. Comparative analyses of

digital vs. physical models highlight data-driven precision in measurements [10].

Challenges include limited datasets and need for validation, but advances promise enhanced predictive capabilities [21].

**Results and Discussion**

The integration of digital orthodontics and periodontology through data-driven risk assessment approaches represents a significant advancement in precision dentistry, as evidenced by the synthesized literature. This review has highlighted how AI and ML technologies enhance the prediction and management of periodontal risks during orthodontic treatment, addressing limitations of traditional methods such as subjectivity and inefficiency [1, 3]. For instance, AI models have demonstrated superior accuracy in detecting periodontal bone loss from radiographic images, with systematic reviews reporting sensitivities and specificities often exceeding 90% [19, 29]. These tools enable early identification of risks like gingival recession and alveolar bone resorption, which are common in orthodontic patients due to biomechanical forces and plaque accumulation [35, 60].



**Figure 1.** Workflow Integration of Digital Orthodontics and Periodontology with AI/ML

One key strength of data-driven approaches is their ability to process multimodal data, including digital

scans, CBCT images, and microbial profiles, to generate personalized risk profiles [6, 10]. Studies have

shown that ML algorithms can predict treatment outcomes by integrating periodontal parameters, reducing the incidence of complications in high-risk groups [5, 64]. For example, CNN-based systems for automated cephalometric analysis not only streamline diagnostic workflows but also incorporate periodontal health indicators to optimize treatment planning [8, 9]. This interdisciplinary synergy is particularly beneficial for patients with pre-existing periodontitis, where data-driven models facilitate pre-treatment stabilization and real-time monitoring [16, 27].

However, several challenges hinder widespread adoption. Data privacy concerns arise from the use of large datasets, necessitating compliance with regulations like HIPAA and GDPR [43, 44]. Model bias, stemming from imbalanced training data, can lead to inaccurate predictions in diverse populations, as noted in scoping reviews on AI in dentistry [2, 58]. Additionally, the lack of standardized validation protocols across studies limits generalizability, with many models tested on small cohorts [12, 51].

Interdisciplinary collaboration is essential to address these issues, as orthodontists and periodontists must work with data scientists to develop robust, clinically validated tools [14, 33].

Furthermore, the ethical implications of AI in risk assessment warrant attention. Reliance on black-box models may erode clinical judgment if not transparent, prompting the need for explainable AI (XAI) frameworks [50, 53]. Cost-effectiveness analyses are also scarce, though preliminary evidence suggests that data-driven systems reduce treatment time and costs by minimizing revisions [37, 46]. In educational settings, AI tools enhance training by simulating risk scenarios, but their integration requires curriculum updates [24, 65].

Overall, while data-driven approaches offer transformative potential, overcoming technical, ethical, and practical barriers is crucial for their sustainable implementation in the ortho-perio interface.

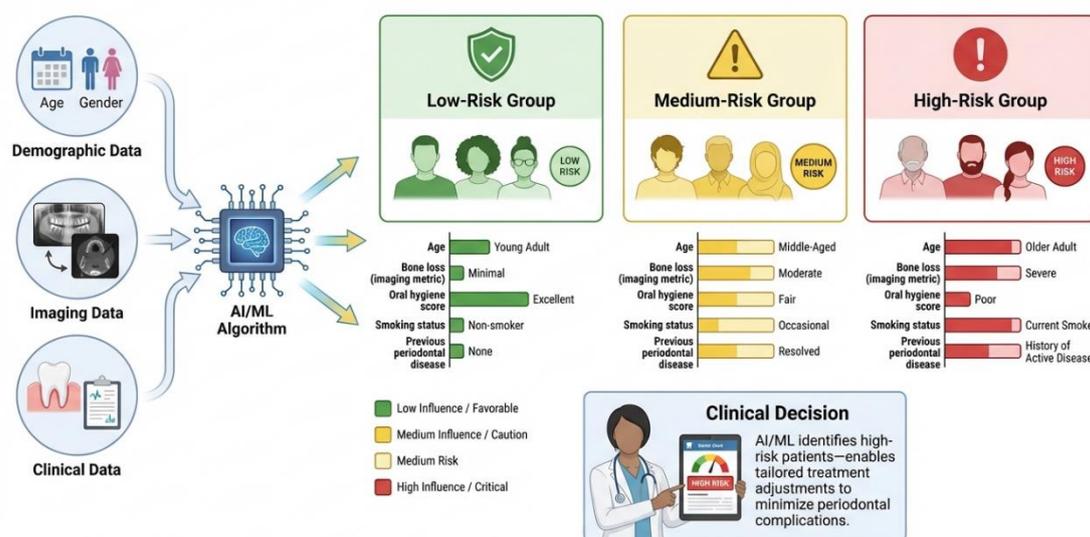


Figure 2. Data-Driven Risk Stratification in Orthodontic Patients

## Conclusion

In conclusion, this narrative review underscores the pivotal role of data-driven risk assessment in bridging digital orthodontics and periodontology, leveraging AI and ML to improve diagnostic accuracy, treatment efficacy, and patient outcomes. By synthesizing studies, we have demonstrated how these technologies mitigate periodontal risks associated with orthodontic therapy, fostering a shift towards predictive and personalized care [17, 23].

Looking ahead, future research should prioritize large-scale, multicenter validations to enhance model

robustness and address biases [34, 39]. Developing hybrid systems that combine AI with biosensor data for real-time monitoring could revolutionize risk management [41, 47]. Moreover, exploring AI's role in regenerative periodontology during orthodontic treatment, such as predicting responses to adjunctive therapies, holds promise [21, 54]. Interdisciplinary initiatives, including standardized datasets and ethical guidelines, will be key to translating these advancements into clinical practice [52, 61]. Ultimately, data-driven approaches have the potential to redefine the ortho-perio paradigm, ensuring safer and more efficient dental care.

**Acknowledgments:** None

**Conflict of Interest:** None

**Financial Support:** None

**Ethics Statement:** None

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