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Artificial Intelligence Applications in Orthodontics: Improving Diagnostic Accuracy and Treatment Outcomes

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ABSTRACT

Artificial Intelligence (AI) is reshaping orthodontics by enabling highly tailored treatments that improve accuracy and efficiency. This narrative review discusses the current uses of AI in orthodontic care, focusing on applications such as predicting tooth displacement, fabricating individualized aligners, shortening treatment duration, and supporting continuous remote monitoring. By processing extensive collections of dental images, radiographs, and 3D models, AI systems can create treatment plans that are more patient-specific, leading to improved clinical results and higher patient satisfaction. AI-guided aligners and braces apply calculated forces to teeth, thereby reducing discomfort and treatment time. Remote monitoring platforms powered by AI also allow patients to track progress at home, minimizing the frequency of clinic visits and expanding access to orthodontic care. Looking ahead, opportunities include merging AI with robotics for automated procedures, predictive orthodontics for early intervention, and integration with 3D printing to manufacture orthodontic appliances on demand. Despite its promise, challenges remain concerning privacy, algorithmic fairness, and financial barriers to implementation. Nevertheless, as AI technology develops, orthodontic treatments are expected to become more efficient, patient-focused, and effective. This review underscores the evolving role of AI in orthodontics and its capacity to advance dental health.

Keywords: Artificial intelligence, Orthodontics, Predictive modelling, Aligner design, Telemonitoring, Dental technology

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Introduction

Orthodontics, a field within dentistry, is dedicated to diagnosing, preventing, and correcting misalignments of teeth and jaws [1, 2]. Such irregularities—commonly referred to as malocclusions—not only influence facial appearance but also impair functions like chewing, speech, and oral hygiene maintenance [3]. Conventional orthodontic treatment planning has historically been a manual, expertise-driven process that involves analyzing radiographs, evaluating dental structures, and projecting tooth movement by subjective estimation. While effective, this approach often produces inconsistent results, variable treatment lengths, and differences in patient experience [4].

Traditionally, braces and aligners have been applied with standardized protocols across patients. However, since each person's dental and biological makeup is unique, responses to treatment vary widely. This uniform approach can slow progress, prolong therapy, and sometimes yield unsatisfactory results [5, 6]. Moreover, anticipating how teeth will react to applied forces adds uncertainty to conventional treatment [7].

The incorporation of AI into orthodontics is shifting this paradigm. Using machine learning (ML) and computer vision, AI tools can analyze detailed patient data—including 3D scans, X-rays, and digital photographs—at a scale beyond human ability [8]. By drawing on large datasets of past cases, AI models can better predict dental movement, calculate optimal force application, and design individualized treatment plans [9].

This new model of personalized orthodontics, powered by AI, allows for device customization (braces, aligners, expanders) based on each patient's specific anatomy. Patients may therefore achieve quicker and smoother treatments with fewer adjustments [10, 11]. AI also makes it possible to estimate treatment duration more accurately, giving patients clearer expectations. In addition, AI systems can continuously evaluate progress [12, 13]. Through advanced image recognition and predictive feedback, these tools detect deviations from expected outcomes and suggest immediate corrections, ensuring a level of adaptability rarely possible with manual methods [14].

The motivation behind studying AI applications in orthodontics lies in addressing the shortcomings of conventional techniques, which often rely on standardized protocols and subjective judgment. These limitations can extend treatment, create unpredictability, and add cost or inconvenience for patients [15]. AI offers solutions by delivering more precise tooth-movement predictions, designing patient-specific strategies, and adapting treatments in real time. The aim of this review is to evaluate how AI can be effectively incorporated into orthodontic practice to overcome these challenges and to outline pathways for future development in AI-based orthodontic care.

AI in orthodontic treatment

Artificial Intelligence is reshaping orthodontics by providing levels of precision and efficiency beyond the scope of conventional methods. Through the integration of machine learning (ML), neural networks, and computer vision, AI supports orthodontists in generating treatment plans tailored to each patient and guided by objective data [7, 16]. These technologies process large volumes of clinical information—including 3D models, radiographs, and scans of dental and jaw structures—to forecast how teeth will respond to corrective forces [17]. This enables orthodontists to customize braces or aligners, leading to quicker progress, fewer setbacks, and more predictable outcomes [18].

Data collection: Constructing a comprehensive model

The foundation of AI-guided orthodontics is the systematic collection of patient information to build a digital reconstruction of dental anatomy. Using high-definition 3D scans, intraoral photos, and X-rays, AI systems compile detailed records of tooth position and jaw alignment [17]. Such datasets allow algorithms to extract insights about spacing, occlusion, and structural relationships [19]. Advances in imaging—particularly 3D scanning—have enhanced both the precision and scope of available diagnostic data [20]. AI-supported imaging can even capture underlying bone and soft tissues, producing a holistic view of oral features [21]. These high-resolution models improve the reliability of AI-driven predictions, ensuring recommendations are closely matched to individual dental structures. **Figure 1** depicts the overall process of AI-aided orthodontic workflows, spanning initial data gathering to treatment completion.

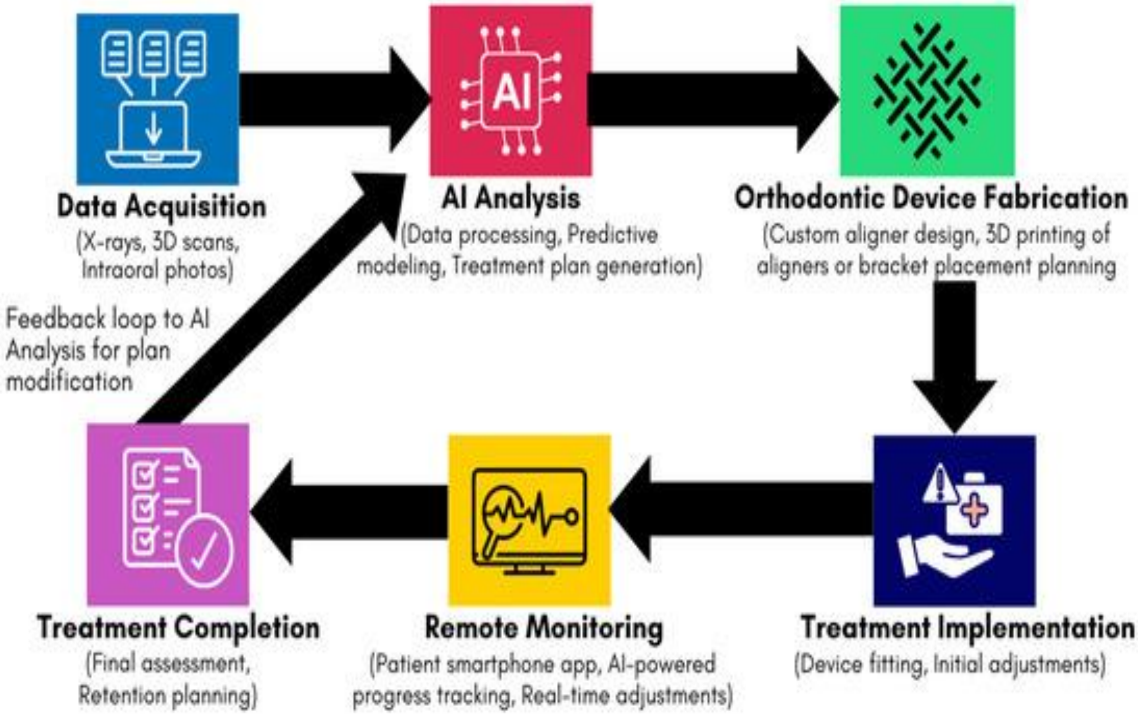

Figure 1. Diagrammatic overview of AI-assisted orthodontic treatment: data capture, computational analysis, appliance design, implementation, remote tracking, and finalization

AI-Based prediction: Modeling tooth dynamics

Once data are assembled, AI algorithms simulate dental movement under different treatment modalities. Trained on large datasets of prior orthodontic cases, ML and deep learning models learn from varied malocclusions and therapeutic strategies to anticipate how teeth respond over time [22]. These systems integrate principles of biomechanics, determining how much force and pressure should be applied for controlled movement. Predictions may include the pace of tooth migration, areas requiring additional anchorage, and expected outcomes with specific appliances [12, 23]. By offering this level of foresight, orthodontists can refine treatment strategies, minimizing trial-and-error and shortening therapy duration [18]. A growing trend involves dynamic simulations, where AI generates visual progressions of tooth movement. By testing multiple strategies virtually, orthodontists can identify the most efficient option before applying it in practice, reducing unnecessary adjustments and enhancing accuracy [24].

Personalized treatment planning: Individualized protocols

AI brings personalization to orthodontics by adapting treatment plans to each patient's unique dental profile. Instead of applying generalized methods, AI systems use clinical data to construct individualized protocols specifying device type, placement, and force application [9, 25]. For example, in clear aligner therapy, AI produces sequential sets of aligners optimized for precise movements at each stage, ensuring efficiency while reducing discomfort [26]. With braces, AI can determine ideal bracket placement, wire adjustments, and the need for auxiliaries like elastics, improving both accuracy and patient comfort [10]. Importantly, personalization is ongoing: AI algorithms can revise treatment plans as teeth move, ensuring real-time adaptability. This iterative adjustment reduces the number of office visits and prevents treatment delays [27].

Continuous monitoring and adjustment: Tracking in real time

A key benefit of AI-based orthodontics is continuous progress tracking. By comparing actual tooth movement against predictive models, AI detects deviations early and recommends corrective actions [28]. Patients can also engage directly in this monitoring. With tele-orthodontics and smartphone applications, they can submit images remotely, which AI systems analyze to generate progress reports [29]. These reports notify both clinician and patient about alignment status, which is particularly useful for clear aligner therapy, where frequent in-office visits are less essential [30]. Real-time oversight ensures that adjustments are made proactively—for instance, suggesting alterations in aligner design or bracket configuration if a tooth is not shifting as anticipated [10, 31]. In some cases, the technology can even signal when treatment is ahead of schedule, allowing earlier completion and reducing overall duration.

Applications in orthodontic care

In recent years, Artificial Intelligence has become increasingly integrated into orthodontics, offering advanced tools that support individualized treatment strategies. Using machine learning models and sophisticated algorithms, AI improves forecasting of tooth movement, enables precision fabrication of aligners, shortens treatment duration, allows real-time monitoring, and enhances visualization through 3D modeling. These applications collectively increase the effectiveness of orthodontic care and contribute to better patient outcomes [32-34].

Multiple studies have highlighted measurable benefits of AI adoption, including improvements in diagnostic accuracy, efficiency of therapy, patient satisfaction, scheduling, and predictive reliability. AI-based diagnostic platforms demonstrate greater accuracy than conventional planning approaches, with statistically significant differences ($p < 0.05$) [35]. Predictive systems achieved around 73% accuracy in estimating treatment outcomes, although challenges remain for highly complex cases [36]. A meta-analysis reported that AI-driven treatment planning reached an overall accuracy of 95.47% [15]. Regarding duration, AI support reduced treatment length by an average of 4.3 months compared to standard approaches (mean ± SD: 14.6 ± 3.2 months vs. 18.9 ± 4.5 months, $p < 0.001$) [35]. In addition, ML models estimated treatment timelines with a mean absolute error of 7.27 months [4]. Patient satisfaction levels also rose, with AI-guided treatment scoring significantly higher than traditional methods (mean ± SD: 9.2 ± 0.6 vs. 8.1 ± 0.8, $p < 0.001$) [35]. Another investigation noted that while the general public rated AI-predicted outcomes positively, orthodontists evaluated them more critically [37]. AI further reduced the number of in-office visits, showing fewer appointments on average (10.2 ± 2.1 vs. 12.8 ± 3.4, $p < 0.001$) [35]. From a predictive perspective, AI exceeded linear regression in 6 of 32 soft-tissue landmark predictions [38]. Models also displayed strong performance in forecasting post-treatment facial changes, though accuracy was lower for lip-to-teeth relationships [39]. Altogether, these findings illustrate how AI strengthens orthodontic practice by making care more precise, efficient, and patient-oriented.

Table 1 provides an overview of how AI-driven orthodontics benefits patients across age groups and malocclusion categories. Children benefit primarily from early detection, adolescents from compliance-enhancing approaches, and adults from aligner customization or surgical predictive modeling. While AI enhances efficiency, accuracy, and progress tracking, considerations such as growth in children, adherence among teenagers, and periodontal stability in older individuals must be accounted for. This structured categorization highlights AI's tailored impact in different patient contexts.

Table 1. Benefits of AI-powered personalized orthodontic treatment across different patient categories

Demographic Group	Orthodontic Requirements	Role of AI in Treatment	Key Advantages	Potential Limitations
Children (6–12 years) [36, 40]	Early management of misalignments, space preservation, growth observation	AI predicts malocclusion risks, identifies jaw anomalies, and automates cephalometric assessments	Reduces future treatment complexity, supports healthy jaw development, streamlines care	Needs ongoing growth tracking; AI must adapt to skeletal changes
Teenagers (13–18 years) [10,40]	Full-scale orthodontic correction (braces, aligners), bite adjustment, adherence monitoring	AI refines bracket/aligner placement, tracks treatment progress, and enhances remote compliance systems	Shortens treatment periods, boosts adherence via AI alerts, improves aesthetics	Varies with teen engagement; AI tracking requires active patient participation
Adults (19–40 years) [37, 41]	Cosmetic orthodontics, mild-to-moderate bite issues, aligners, relapse correction	AI designs precise aligner movements, accelerates treatment, integrates with digital smile visualization	Minimizes invasiveness, enhances efficiency, offers virtual previews for decisions	Must account for periodontal conditions and bone density variations
Older Adults (40+ years) [42, 43]	Orthodontics with periodontal concerns, pre-prosthetic	AI evaluates bone health, customizes treatment strategies,	Enables complex case management, prevents periodontal worsening,	Influenced by dental history, bone variability, and

	alignment, jaw positioning	monitors periodontal risks	supports collaborative care	coexisting conditions
Severe Skeletal Malocclusion Patients [36, 44]	Major jaw discrepancies requiring surgery, severe bite issues, asymmetry	AI forecasts surgical outcomes, plans orthodontic-surgical integration, aids virtual planning	Enhances surgical precision, improves planning, provides patient-friendly visualizations	Cannot replace surgical expertise; depends on advanced 3D imaging
Mild to Moderate Malocclusion Patients [40, 45]	Crowding, spacing, or minor bite corrections via aligners or short-term braces	AI optimizes force application in aligners, predicts faster outcomes, automates case evaluation	Reduces treatment time, improves comfort, minimizes adjustments	Varies with case complexity and patient cooperation
Orthodontic Relapse Patients [10, 46]	Post-treatment tooth shifts, retainer adjustments, minor corrective therapy	AI detects subtle shifts, optimizes retainer designs, and refines minor corrections	Prevents further misalignment, ensures stability, reduces re-treatment needs	Requires consistent monitoring and retainer compliance

Prediction of tooth movement

Among the most impactful contributions of AI to orthodontics is the precise modeling of dental movement. Traditionally, orthodontists relied on clinical expertise and biomechanical knowledge to anticipate how teeth would shift with appliances [41]. AI, however, utilizes expansive treatment datasets and computational biomechanics to simulate detailed tooth trajectories over time.

Algorithms trained on large numbers of prior cases—including varied malocclusions, dental anatomies, and appliance designs—allow AI to generate reliable forecasts of tooth movement. These systems predict both the final alignment and the step-by-step progression required [47]. Research indicates that AI can model the effects of forces applied by brackets, wires, or aligners, guiding clinicians toward the most effective appliance configurations [48, 49].

Recent evidence suggests AI outperforms manual estimation in both accuracy and efficiency. For instance, Invisalign's AI-based prediction tool demonstrated an average accuracy of 50% for tooth positioning, with buccal-lingual crown tipping reaching 56% [50]. Another investigation showed that AI-guided modeling reduced treatment length in complex scenarios, as algorithms adapt interventions dynamically based on patient progress [51].

Custom aligner fabrication

Transparent aligners, such as those in Invisalign systems, are increasingly favored for their discreet appearance and convenience. Their clinical success, however, is largely dependent on design precision [26]. Artificial intelligence contributes significantly to this process by generating aligners customized to each patient's dental anatomy. Through analysis of detailed 3D scans of teeth and jaw structures, AI models calculate the exact force distribution needed to reposition teeth effectively [17, 26, 52]. Unlike conventional approaches that often adapt prefabricated templates, AI-based aligners are created specifically for the individual, making treatment more predictable and comfortable [53]. They are engineered to deliver continuous, low-intensity pressure, ensuring smoother and more controlled dental movement [54].

Beyond accuracy, AI streamlines production. Conventional aligner fabrication is often time-consuming and requires considerable manual effort, whereas AI-driven workflows automate many stages, accelerating production and delivery [52]. This is particularly advantageous in sequential aligner treatments, as patients can receive updated sets sooner, keeping progress uninterrupted [31]. Evidence shows that AI-guided fabrication reduced the average number of aligners required per case by 20%, lowering the frequency of mid-course corrections [41]. Patients also reported less discomfort due to the improved anatomical fit, which conformed closely to natural tooth and gum shapes.

Optimization of treatment time

Another key contribution of AI is reducing the overall duration of orthodontic treatment, which traditionally lasts 18–24 months depending on severity [6]. By simulating tooth biomechanics and adjusting force application, AI ensures that every phase of treatment progresses efficiently [10, 15, 42]. Algorithms can flag when predicted movements are not occurring and recommend modifications to maintain consistent progress [55]. This real-time adaptability minimizes treatment delays, leading to faster completion compared to conventional planning [11, 32].

AI can also evaluate hybrid strategies, such as beginning with braces for major corrections before switching to aligners for fine adjustments. By simulating these combinations, clinicians can select the most time-effective plan. Clinical reports confirm AI's ability to accelerate workflows, with some studies showing analysis time reduced up to 80-fold relative to manual methods [56–59].

Enhanced patient monitoring and adjustments

Intelligent monitoring systems allow orthodontists to oversee progress continuously, especially useful for patients using aligners [42, 60]. Through smartphone applications, patients capture and upload images of their teeth, which are then assessed by AI tools [61]. Detected deviations from the predicted treatment path trigger alerts, enabling timely modifications to the plan. This approach reduces the number of in-person visits, making care more convenient for those with limited access to clinics [30, 62].

Because AI tracks real-time progress, orthodontists can intervene early if teeth are not responding as expected. Adjustments such as changing aligner geometry or repositioning brackets can be implemented before delays occur [41, 63]. Research by Sosiawan *et al.* showed that AI-assisted remote monitoring systems like *Dental Monitoring* significantly reduced clinic visits without compromising results [62]. Patients valued the flexibility and convenience, while clinicians emphasized the benefit of immediate insights that improved treatment efficiency and accuracy [10, 62].

3D Visualization for treatment planning

AI-enabled platforms also support orthodontists by generating high-resolution 3D models of teeth and jaws for comprehensive treatment design [64]. These visualizations simulate the entire therapeutic process, from baseline to expected final positions, allowing potential issues to be addressed before they arise [49]. They also enhance patient communication by clearly illustrating treatment progression and anticipated results [64].

For patients, stepwise visual demonstrations increase understanding and motivation. Studies show that when individuals are presented with 3D projections of their expected outcomes, compliance with wearing aligners and attending appointments improves [65]. One investigation reported higher satisfaction and adherence in patients who previewed AI-based 3D simulations [9, 64]. Another confirmed fewer missed visits and better aligner use when visual tools were integrated into treatment [29].

Precision and reliability of AI-Based tracing in orthodontics

Automated tracing supported by artificial intelligence has greatly accelerated cephalometric evaluations, shortening the time required for identifying landmarks and performing measurements. These platforms employ deep learning models to locate craniofacial reference points on radiographs, improving workflow in diagnosis and planning [40]. Despite these benefits, concerns remain regarding reliability, as automated systems can still misclassify points, especially in challenging images with structural overlaps, atypical anatomy, or reduced image clarity [10].

Manual versus AI-guided tracing

Traditional cephalometric tracing conducted manually by orthodontists continues to be the reference standard. Its strength lies in the clinician's interpretive ability to adapt to unusual anatomical presentations, pathologies, or distortions, even though the process is slow and labor-intensive [42].

AI-based tracing, in contrast, provides automation and speed but is not flawless. Research has shown that many systems achieve deviations of about 1–2 mm from manual tracings, yet errors remain higher for specific landmarks such as the gonion, condylion, and orbitale [66]. Studies comparing the two methods report error margins of 2–10%, varying by algorithm quality and training dataset. Well-defined points can be detected with 90–95% precision, but performance declines when the images are unclear or when craniofacial variability complicates detection [67].

Hybrid models and the need for adjustments

Because of these limitations, orthodontists often need to review and modify AI-produced tracings to ensure diagnostic accuracy. Current approaches increasingly favor hybrid models where the software performs initial landmark detection and clinicians refine the output [68]. This balance preserves speed while minimizing the risk of treatment errors. With continued improvements in adaptive learning, newer systems are capable of learning from expert input, gradually reducing error rates and improving predictive accuracy [69, 70].

Advantages of AI-supported personalized orthodontics

Incorporating AI into orthodontic practice provides numerous improvements to both patient care and clinical performance. These include shorter treatment timelines, optimized force application, and enhanced prediction of tooth movement. **Figure 2** outlines the primary benefits of AI-supported orthodontics. Among them are reduced treatment duration, fewer in-office appointments thanks to remote monitoring, improved treatment precision, and lower costs due to efficient aligner production and streamlined workflows. Patients also benefit from clearer 3D simulations and progress updates, which enhance motivation and treatment adherence.

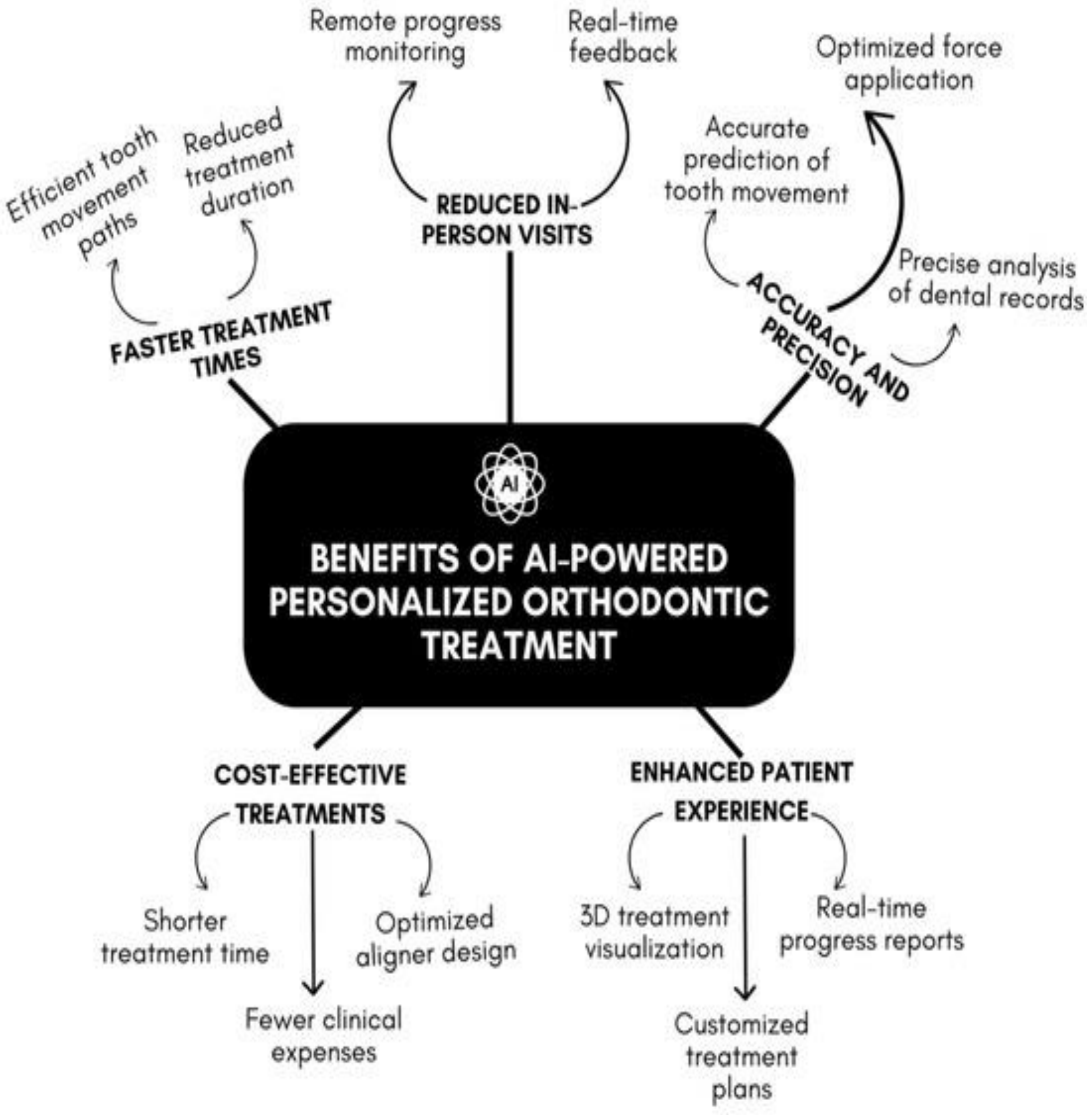

Figure 2. Summary of key benefits of AI-driven orthodontic care

Table 2 further categorizes applications of machine learning in orthodontics, highlighting the models used and their functional roles. Convolutional neural networks (CNNs) enable automatic detection of cephalometric points, recurrent neural networks (RNNs) support predictions of dental movement, generative adversarial networks (GANs) assist in custom aligner fabrication, and object detection models such as Faster R-CNN enhance bracket placement.

Table 2. Machine learning models and their applications in orthodontic care

Orthodontic AI Application	AI Model Employed	Purpose in Orthodontics	Key Benefits	Potential Challenges
Cephalometric Landmark Identification [10, 40]	Convolutional Neural Networks (CNNs), Deep Learning Systems	Automates detection of anatomical points on cephalometric radiographs for diagnosis and planning	Speeds up analysis, improves precision, reduces operator inconsistency	May struggle with low-quality images or anatomical anomalies, needing orthodontist review
3D Tooth and Jaw Analysis [69]	U-Net, Region-Based CNN (R-CNN)	Segments teeth and jaw structures in CBCT, intraoral scans, and panoramic images	Delivers accurate 3D models for diagnostics and appliance positioning	Dependent on high-quality training data; complex cases like extra teeth may be problematic
Tooth Movement Forecasting [35]	Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM) Models	Predicts tooth responses to orthodontic forces using patient-specific biomechanical inputs	Customizes treatment plans, minimizes adjustments, optimizes force delivery	Biological variations in tooth movement may affect predictions, requiring clinical verification
Automated Treatment Design [35,40]	Support Vector Machines (SVM), Gradient Boosting (e.g., XGBoost)	Generates optimized treatment strategies for braces and aligners based on individual patient data	Enhances case analysis efficiency, supports rapid evaluation of multiple scenarios	Needs orthodontist supervision; may overlook patient preferences or lifestyle factors
Precision Aligner Production [26,52]	Generative Adversarial Networks (GANs), Reinforcement Learning	Designs clear aligners with optimized force application using 3D scan data	Improves aligner accuracy, lowers production costs, shortens treatment duration	Requires 3D printing integration; force miscalculations may necessitate adjustments
Bracket Placement Optimization [60]	CNN-Based Detection (YOLO, Faster R-CNN)	Recommends precise bracket positioning for fixed orthodontic appliances	Increases placement accuracy, reduces manual errors	Complex cases may need manual tweaks; models require ongoing improvement
Caries and Periodontal Risk Detection [10,35]	Deep Learning CNNs, Transfer Learning	Identifies early caries, periodontal issues, and bone loss from scans and X-rays	Facilitates early treatment, prevents complications, improves oral health	Imaging artifacts may lead to misinterpretations; false results need human confirmation
Remote Treatment Monitoring [10,35]	Vision Transformers (ViTs), Deep CNNs	Analyzes patient-uploaded images/videos to monitor treatment progress remotely	Decreases office visits, boosts compliance with real-time tracking	Relies on high-quality patient images and consistent participation
3D Printing for Orthodontic Appliances [26,52]	Generative Design, Evolutionary Algorithms	Customizes aligners, retainers, and splints using AI-driven 3D printing	Speeds up appliance creation, supports tailored treatments	AI-design integration is developing; requires orthodontist oversight
Robotic Orthodontic Systems [71]	Reinforcement Learning, Motion Planning Algorithms	Employs robotics for wire bending, bracket placement, and appliance customization	Enhances precision, reduces labor, ensures procedural consistency	High costs; robotic applications in orthodontics are still emerging

Overall, these technologies improve diagnostic precision, treatment planning, and monitoring, while decreasing manual workload and human error. Nonetheless, challenges persist, including dependence on high-quality training datasets, limited accuracy in complex cases, and the ongoing necessity for orthodontist oversight. Integration with technologies such as robotics, 3D printing, and telemonitoring further extends AI's scope, but issues such as implementation cost, variability across patient populations, and compliance must be addressed.
This structured evaluation underscores that AI should be regarded as an auxiliary tool rather than a substitute for clinicians. With continual refinement of algorithms and their incorporation into clinical workflows, orthodontics can achieve more precise, efficient, and accessible treatments while preserving the central role of human expertise in clinical judgment.

Accuracy and precision
A major advantage of incorporating AI into orthodontics lies in its ability to deliver treatment plans with exceptional precision and accuracy. Conventional methods depend largely on manual assessment and the clinician's judgment, which can lead to inconsistent results. By contrast, AI systems analyze vast amounts of patient information—including dental records, radiographs, 3D images, and prior treatment outcomes—to build detailed digital models of individual dental structures [34]. These models allow AI to simulate tooth movement more reliably and tailor treatment to each patient's needs. By optimizing the magnitude and direction of applied forces, AI ensures controlled and effective movement, which lowers the risk of complications and minimizes the need for mid-course corrections. Evidence shows that AI predictions reduce error rates compared with manual approaches, improving treatment reliability and success rates [10]. One investigation demonstrated that AI-based workflows outperform traditional methods: when plaster casts were compared to AI-enabled 3D digital models, the latter showed superior accuracy and reduced measurement time by more than 60% [72].

Faster treatment times
AI also contributes to shortening treatment duration by optimizing biomechanics and minimizing unnecessary tooth movements. Through analysis of individual patient datasets, AI identifies the most efficient path of movement, ensuring that appropriate forces are applied directly toward the target position [11, 73]. Standard orthodontic care using braces or aligners typically requires 18–24 months or more [74]. AI-driven optimization can cut this timeline by determining strategies tailored to each patient's unique dental anatomy. This acceleration not only leads to quicker results and higher satisfaction but also enhances comfort throughout the process [31]. Reports indicate that AI-supported orthodontic systems can decrease total treatment length by up to 26%, primarily by eliminating inefficient or redundant tooth movements [73].

Reduced number of in-person visits
Another clear benefit of AI-based orthodontics is the reduction in clinic appointments. Conventional treatment requires patients to return regularly for monitoring and adjustments. In AI-supported care, however, progress can be tracked remotely using digital tools [62]. Patients upload intraoral photos or scans via smartphones or dedicated applications, which AI then evaluates to determine whether the teeth are moving as intended. When deviations occur, the system alerts the orthodontist, who can recommend modifications without requiring a face-to-face consultation [61]. This feature is especially useful for patients in remote or underserved regions, as it increases accessibility and convenience. Consequently, AI-assisted systems significantly cut down on unnecessary office visits, saving both patient and provider time and resources [62].

Cost-Effective treatments
The integration of AI also makes orthodontic therapy more cost-efficient. One of the main financial advantages stems from shortened treatment courses, which reduce the number of aligners or adjustments needed. Streamlined processes lower labor and material requirements, thereby cutting overall expenses. AI also improves the design and fabrication of aligners, minimizing the need for repeated modifications, which in turn lowers production costs [26, 75]. In addition, the reduction in in-person visits further decreases clinical overhead, creating savings for both providers and patients. As these technologies continue to advance, the potential for high-quality, personalized orthodontic treatment at a reduced cost will increase accessibility for a wider patient population.

Enhanced patient experience

Beyond efficiency and cost, AI substantially improves patient experience. Because AI customizes aligners and appliances according to individual dental anatomy, patients benefit from devices with a more accurate fit and greater comfort, reducing discomfort during treatment [76]. Optimized movement paths and shorter treatment times also boost satisfaction. AI further enhances engagement by offering real-time updates and progress reports, allowing patients to track their progress throughout the process [10, 62]. The ability to visualize expected results through AI-generated 3D models provides patients with clear expectations and motivation. Many patients report increased compliance when they can see the anticipated outcomes before treatment begins, as well as the incremental changes during the process [77]. Remote monitoring additionally provides convenience for those with demanding schedules, reducing the burden of frequent in-office visits while maintaining quality care.

Technologies, tools, and workflow

Adopting Artificial Intelligence (AI) in orthodontics requires a blend of advanced imaging systems, digital platforms, and specialized software. For practitioners, implementing an AI-enhanced workflow demands structured integration of diagnostic tools, predictive planning, and continuous monitoring [44]. The process begins with data capture, where high-resolution imaging methods—such as Cone Beam Computed Tomography (CBCT), intraoral scanners, and digital radiographs—collect detailed anatomical information. These datasets are analyzed by AI-based computer vision systems that identify malocclusions, dental angulation, and skeletal discrepancies, delivering greater diagnostic precision than conventional methods [40].

Following data collection, orthodontists employ AI-supported planning platforms such as ClinCheck (Invisalign), OrthoAnalyzer, 3Shape Ortho System, and Dental Monitoring to simulate multiple treatment outcomes. These predictive systems allow clinicians to select optimized treatment strategies tailored to each case [35]. AI further refines aligner sequencing by forecasting tooth movement patterns, lowering the number of mid-treatment modifications required. Coupled with 3D printing, AI-generated appliance designs—such as aligners, retainers, and brackets—can be produced directly in-office, reducing turnaround time and improving patient convenience [78].

During active treatment, AI-enabled monitoring technologies facilitate progress evaluation with fewer clinic visits. Remote platforms like Grin Remote Monitoring and Dental Monitoring use smartphone-based intraoral image capture, enabling continuous assessment of tooth movement. Uploaded photos are reviewed by AI software, which flags discrepancies and alerts the orthodontist if intervention is necessary [31]. Experimental use of robotic orthodontics, integrating AI into bracket positioning and wire bending, is also underway to enhance precision and reduce manual errors [40].

For successful adoption, interoperability with existing orthodontic software and Electronic Health Records (EHRs) is critical. AI tools must integrate with systems such as Dolphin Imaging, OrthoCAD, and SureSmile to allow smooth data transfer and workflow efficiency [40, 79]. Cloud-based AI applications further expand access, enabling remote collaboration, case sharing, and secure documentation. While integrating AI requires substantial digital infrastructure, its long-term impact—greater precision, efficiency, and improved patient experience—positions it as a transformative element in orthodontics.

By applying these technologies, orthodontic practice is shifting from traditional approaches to AI-optimized workflows, delivering faster, more predictable, and patient-centered care. Rather than being a minor enhancement, AI represents a paradigm shift that reshapes clinical planning, streamlines processes, and redefines personalization in orthodontic treatments [80].

The role of the orthodontist in AI-driven treatment and its impact on clinical practice

The growing presence of AI in orthodontics does not diminish the role of clinicians but instead supports their expertise by assisting in decision-making and treatment efficiency. AI can automate simulations, assist in diagnostics, and enable remote monitoring, but orthodontists remain indispensable, especially for complex cases requiring human judgment and nuanced understanding of facial harmony, patient preferences, and biomechanical constraints. Continuous supervision of AI-generated plans is essential to ensure accuracy, applicability, and customization for each patient. Positioning AI as a complementary tool prevents misconceptions that it can independently replace clinical expertise [42].

AI as a tool, not a replacement: The learning curve and time considerations

Although AI accelerates treatment planning, orthodontists must adapt to new workflows, requiring time to master integration. Traditional planning is often lengthy, involving multiple appointments, manual evaluation, and iterative adjustments. AI-powered systems shorten this process by rapidly processing scans and generating predictive treatment paths, in some cases reducing initial planning time by nearly half. Nonetheless, orthodontists must still review and refine these AI-driven recommendations, introducing new time considerations related to oversight. While automation reduces repetitive workload, it does not eliminate the need for expert interpretation and patient-specific customization. Achieving the right balance between automation and human input is crucial to ensure efficiency without compromising quality [15].

The impact of ai on patient trust, engagement, and personalized care

AI adoption also raises important questions about the patient–orthodontist relationship. Remote monitoring and automated planning may reduce direct interaction, yet trust and reassurance gained from in-person consultations remain fundamental to patient adherence and satisfaction. Some patients may hesitate to rely solely on AI, fearing reduced personalization or potential errors that only an experienced orthodontist could detect [10]. Over-reliance on automation could also weaken clinical intuition if orthodontists begin to defer too heavily to AI predictions. To prevent this, AI must be integrated in a way that strengthens, rather than diminishes, human involvement. Maintaining clear communication about AI's role, ensuring orthodontist oversight, and continuing regular face-to-face interactions safeguard trust while leveraging technological benefits. In this way, AI can improve efficiency while reinforcing patient engagement and individualized care [15].

Future Prospects of AI in Orthodontics

With rapid progress in Artificial Intelligence, the future of AI-supported orthodontics holds major potential to reshape the specialty. These advancements promise gains in precision, workflow efficiency, and broader accessibility, benefiting both clinicians and patients. **Figure 3** highlights the anticipated areas of growth, which include robotics guided by AI, predictive orthodontic modeling, real-time device fabrication using 3D printing, and expanded integration with tele-orthodontics.

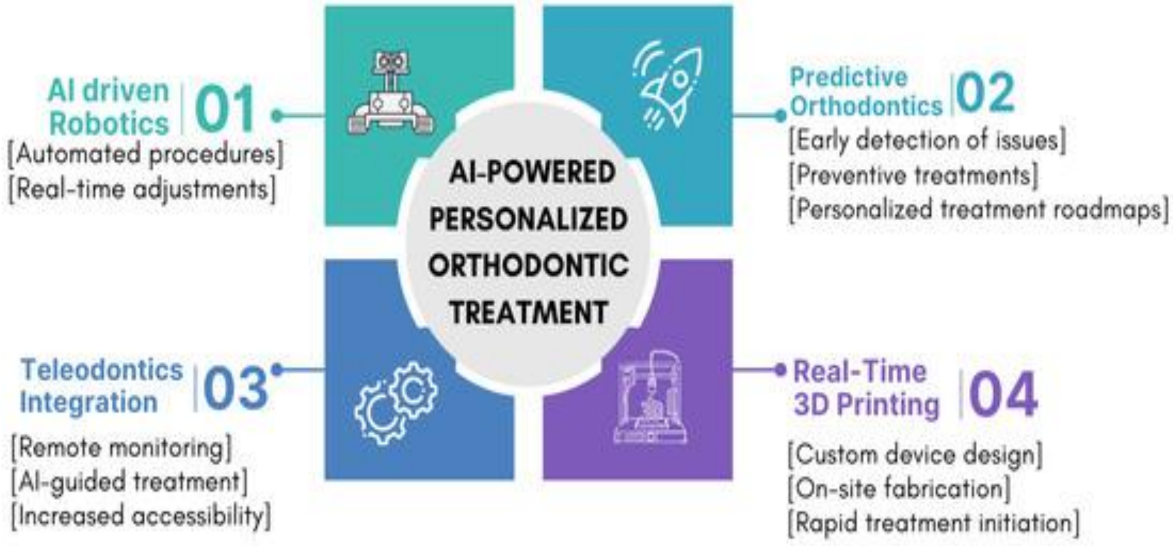

Figure 3. Future prospects of AI in orthodontics

AI-Guided robotics in orthodontic applications

One major direction involves merging robotics with AI. While robotics is already established in some branches of dentistry, its pairing with AI's analytical and predictive strengths may allow automation of orthodontic tasks. Potential applications include bracket positioning, archwire modifications, or digital impression-taking, all executed with extreme precision, minimizing errors, and enhancing speed [81]. Real-time AI guidance could help robots adjust dynamically during procedures, standardizing outcomes and reducing treatment variability [82]. In addition, robotic systems might continuously track intra-procedural changes and modify actions autonomously, shortening chair time and expanding patient access to reliable, consistent orthodontic care.

Predictive orthodontics using AI

AI's forecasting ability is expected to play a critical role in early detection and preventive care. By examining childhood dental records, imaging data, genetic indicators, and other medical inputs, AI could identify misalignments long before they manifest clinically [17]. Such predictive insights may allow orthodontists to intervene early, applying minor, non-invasive corrections during developmental stages, thereby preventing extensive treatment later. This would not only improve long-term oral health trajectories but also lower financial and time burdens associated with traditional orthodontic interventions [1, 34]. Essentially, AI could provide a step-by-step developmental roadmap, allowing orthodontists to guide growth with targeted, preventive strategies.

Real-Time 3D printing for orthodontic appliances

Another future pathway involves combining AI analysis with 3D printing to manufacture devices almost instantaneously. At present, aligners or braces require design and fabrication cycles that delay treatment initiation. By contrast, AI could rapidly process patient scans and create customized digital models, which are then printed immediately, either chairside or potentially at the patient's home [11, 26]. For instance, after an initial scan, AI could instantly generate a treatment plan and fabricate the first aligners or appliances within minutes. This rapid production system could shorten waiting times, boost patient satisfaction, and allow more frequent device adjustments throughout treatment [11, 52].

AI integration with tele-orthodontics

Tele-orthodontics is already in use, but its future evolution alongside AI could make care almost fully remote. Current systems enable patients to submit photos and receive digital feedback, but the next stage could involve end-to-end management of treatment plans outside of the clinic [83]. AI might autonomously review progress, recommend modifications, and alert orthodontists only for complex cases [84]. Such a system would allow clinicians to supervise numerous patients simultaneously, offering consultations and plan adjustments without physical visits. This model could greatly benefit populations with limited access to orthodontic care, whether due to geography or cost [62, 85]. Moreover, it would minimize travel for routine appointments, creating a hybrid of virtual and in-person treatment that combines accessibility with efficiency [86].

Ethical challenges, data protection, and AI limitations in orthodontics

Although AI integration brings major advances in personalized care, efficiency, and diagnostic accuracy, it also raises concerns around ethics, privacy, and system limitations. Core issues include bias in training datasets, risks of algorithmic errors, excessive reliance on automated outputs, and safeguarding sensitive patient data [87, 88].

Ethical Issues in AI-supported orthodontics

AI systems depend on large amounts of patient information such as radiographs, 3D scans, and medical histories, which introduces significant risks to confidentiality [89]. Data breaches remain one of the main threats, with unauthorized access potentially compromising patient privacy [90]. Since algorithm training requires massive datasets, orthodontic AI providers must apply strict data security standards.

Compliance with legal frameworks like HIPAA in the U.S. and GDPR in Europe is critical [91]. Regulations mandate encryption, restricted access, and anonymization of personal identifiers before data are used in AI training. Another debated issue involves ownership: questions often arise over whether the patient, clinician, or software company retains control of data collected for machine learning [92]. Ethical deployment therefore requires transparent governance, informed patient consent, and opt-in/opt-out mechanisms to ensure that data use remains confined to improving healthcare outcomes rather than commercial exploitation.

Data privacy and security in AI-orthodontic systems

AI-based orthodontic platforms depend on processing extensive patient information, including 3D scans, radiographs, intraoral images, and health records. Handling, storing, and transmitting these datasets introduces significant risks to confidentiality and data protection. Among the most pressing issues are breaches, where unauthorized access may expose highly sensitive personal details. Since large and diverse datasets are required for algorithm training and ongoing refinement, orthodontic AI providers must establish rigorous safeguards against such threats.

To ensure safety, these systems must adhere to international privacy standards such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States and Europe's General Data Protection Regulation (GDPR) [91]. Both frameworks require secure storage, encryption, and limited access exclusively for authorized users. Furthermore, anonymization—removing identifiable details before datasets are applied in model training—provides an additional layer of protection for patient confidentiality.

Another pressing issue concerns ownership of digital health information. When AI vendors collect and manage large-scale datasets, uncertainty arises over who controls the data and how it is deployed. Patients and clinicians should be informed whether their information is stored locally, on remote servers, or distributed to third parties [92]. Ethical implementation of AI demands transparent governance frameworks, explicit consent, and opt-in/opt-out options, ensuring that patient data is applied solely for clinical improvement rather than commercial exploitation.

Challenges and limitations of AI in orthodontics

Although AI integration offers numerous advantages, there remain substantial limitations. Diagnostic errors pose a primary risk, since performance depends heavily on the diversity and accuracy of training data [87]. If datasets omit uncommon dental conditions, the system may fail to recognize them, resulting in incorrect treatment pathways. This underlines the importance of continuous model retraining using broad, high-quality data to expand diagnostic reliability.

Performance variability across demographics also presents concerns. Because models learn from existing records, their accuracy may be uneven across age groups, ethnic backgrounds, or unusual clinical cases. Evidence from AI use in medical imaging has shown reduced accuracy for underrepresented populations [93]. Addressing this requires inclusive training datasets that reflect global diversity, ensuring equitable performance for all patients.

In addition, reliance on AI without orthodontist oversight creates potential risks. Treatment recommendations generated by algorithms must be validated by specialists to account for biomechanical nuances or patient-specific factors that AI alone may overlook [94]. Clinical expertise remains central, with AI best utilized as an aid rather than a substitute.

Another barrier is the financial cost of adoption. High-end imaging devices, treatment-planning platforms, and subscription-based cloud services involve substantial investments [80]. For many small or medium-sized practices, these expenses can hinder adoption. Wider accessibility will require scalable and affordable solutions, along with flexible pricing that accommodates clinics of varying capacities.

Conclusion

AI-driven orthodontics marks a major shift in dental practice, offering unmatched precision, customization, and efficiency in treatment planning. Advanced predictive modeling enables orthodontists to anticipate tooth movement, streamline device design, and closely monitor progress, thereby reducing treatment time and improving overall outcomes. However, obstacles such as privacy concerns, data bias, cost barriers, and overdependence on automation remain. These must be addressed to ensure ethical, secure, and equitable implementation across different populations.

As AI continues to advance and merge with complementary innovations such as robotics and 3D printing, orthodontic care will likely become more affordable, accessible, and patient-centered. Ultimately, ongoing developments in AI are set to transform both the patient experience and the broader orthodontic landscape, contributing to improved oral health outcomes worldwide.

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