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Accuracy and Efficiency of Artificial Intelligence-Driven Treatment Planning in Clear Aligner Therapy: A Comparative Study with Conventional Methods in Bandung, Indonesia

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A B S T R A C T

Introduction: Clear aligner therapy (CAT) has gained popularity as an esthetic alternative to traditional braces. Artificial intelligence (AI) is increasingly being integrated into CAT treatment planning, promising improved accuracy and efficiency. This study aimed to compare the accuracy and efficiency of AI-driven treatment planning with conventional methods in Bandung, Indonesia. **Methods:** A retrospective study was conducted involving 100 patients treated with CAT in Bandung. Fifty patients were treated using conventional methods (CM) by experienced orthodontists, while the other 50 were planned with AI-driven software. Accuracy was assessed by comparing the planned tooth movement with the actual outcome using Little's Irregularity Index (LII) and Peer Assessment Rating (PAR) scores at the end of treatment. Efficiency was evaluated by comparing the time required for treatment planning and the number of refinements needed. **Results:** The AI-driven group demonstrated significantly lower LII scores ($p<0.05$) and higher PAR scores ($p<0.05$) compared to the CM group, indicating greater accuracy in achieving the planned tooth movement. Additionally, the AI-driven group showed a significant reduction in treatment planning time ($p<0.05$) and fewer refinement aligners required ($p<0.05$) compared to the CM group. **Conclusion:** AI-driven treatment planning in CAT demonstrated superior accuracy and efficiency compared to conventional methods in Bandung, Indonesia. AI has the potential to optimize treatment outcomes and reduce treatment time, offering a valuable tool for orthodontists.

1. Introduction

Orthodontics, a specialized branch of dentistry focusing on the diagnosis, prevention, and treatment of dental and facial irregularities, has undergone a profound transformation in recent decades. This evolution is largely attributed to the advent of innovative treatment modalities, such as clear aligner therapy (CAT), which has emerged as a popular alternative to traditional fixed appliances. CAT utilizes a series of custom-made, virtually invisible aligners to gradually reposition teeth, offering patients a more aesthetically pleasing and comfortable orthodontic experience. The growing demand for minimally invasive and aesthetically oriented treatments, coupled with advancements in digital technology, has fueled the widespread adoption of CAT across the globe. The success of CAT, however, hinges on the accuracy and efficiency of the treatment planning process. Traditionally, CAT treatment planning has relied on conventional methods (CM) involving manual assessment of patient records, including dental casts, radiographs, and photographs, by skilled orthodontists. This process entails meticulous analysis of dental and skeletal relationships, prediction of tooth movement, and design of an appropriate aligner sequence to achieve the desired occlusal outcome. While CM remains the cornerstone of orthodontic treatment planning, it is inherently subjective and time-consuming, potentially influencing treatment accuracy and efficiency. The inherent subjectivity of CM stems from the reliance on human perception and interpretation of diagnostic records. Orthodontists' expertise, experience, and individual preferences can introduce variability in treatment planning decisions, potentially affecting the predictability and consistency of treatment outcomes. Moreover, CM can be labor-intensive and time-consuming, requiring orthodontists to dedicate significant chairside time to treatment planning, potentially delaying treatment initiation and affecting overall treatment duration.[1-4]

In recent years, artificial intelligence (AI) has emerged as a transformative technology with the potential to revolutionize various industries, including healthcare. AI encompasses a range of computational techniques that enable machines to mimic human intelligence, such as learning, problem-solving, and decision-making. The application of AI in dentistry has gained significant traction, particularly in the realm of orthodontics, where it promises to enhance the accuracy and efficiency of treatment planning. AI-driven software, specifically designed for CAT planning, utilizes sophisticated algorithms to analyze patient data and generate customized treatment plans. These algorithms are trained on vast datasets of orthodontic cases, encompassing diverse dentofacial characteristics and treatment outcomes. By leveraging machine learning, a subfield of AI, these algorithms can discern complex patterns and relationships within the data, enabling them to predict tooth movement with greater precision and accuracy compared to human perception alone.[5-7]

The integration of AI in CAT treatment planning offers several potential advantages. Firstly, AI algorithms can objectively analyze patient records, eliminating the subjectivity inherent in CM. This can lead to more consistent and predictable treatment outcomes, minimizing the variability associated with human interpretation. Secondly, AI can automate various aspects of treatment planning, reducing the time and effort required for orthodontists. This enhanced efficiency can streamline the workflow, allowing orthodontists to treat more patients efficiently without compromising the quality of care. Thirdly, AI can aid in the design of more precise aligner sequences, potentially reducing the need for refinement aligners and minimizing treatment duration. While the potential benefits of AI in CAT are promising, it is essential to critically evaluate its performance in diverse clinical settings and patient populations. Existing research on AI-driven CAT planning has primarily been conducted in developed countries, with limited data from developing nations. Furthermore, cultural and ethnic variations in dentofacial characteristics may influence the accuracy and applicability of AI algorithms developed in other populations. Therefore, it is crucial to assess the performance of AI-driven CAT planning in the context of specific populations to ensure its clinical utility and generalizability.[8-10] This study aims to compare the accuracy and efficiency of AI-driven treatment planning with conventional methods in CAT in Bandung, Indonesia.

2. Methods

This retrospective study was conducted at a private orthodontic clinic in Bandung, Indonesia, a bustling metropolis known for its diverse population and rich cultural heritage. The study was designed to evaluate the accuracy and efficiency of AI-driven treatment planning in comparison to conventional methods in the context of clear aligner therapy (CAT). Ethical approval was obtained from the CMHC Indonesia, the institutional review board responsible for overseeing research involving human subjects, before commencing the study.

The study population comprised 100 patients who had undergone CAT between January 2021 and December 2022 at the aforementioned private orthodontic clinic. These patients were purposively divided into two distinct groups based on the treatment planning method employed; Conventional Method (CM) Group: This group consisted of 50 patients whose CAT treatment plans were meticulously crafted by experienced orthodontists using conventional methods. These methods entail manual assessment of dental casts, radiographs, and photographs, coupled with the orthodontist's expertise and clinical judgment; AI-Driven Group: This group comprised 50 patients whose CAT treatment plans were generated using a commercially available AI-driven treatment planning software. The SPSS software (version 28) utilizes sophisticated algorithms to analyze patient data and generate customized treatment plans, promising enhanced accuracy and efficiency.

To ensure the integrity and validity of the study, specific inclusion and exclusion criteria were established to define the eligibility of patients for participation. Inclusion criteria; Patients aged 18 years or older, ensuring skeletal maturity and reducing the potential for growth-related changes to influence treatment outcomes; Patients with mild to moderate malocclusion, specifically Angle Class I or II Division 1 malocclusions, representing the majority of orthodontic cases amenable to CAT; Patients who had completed the full course of CAT treatment as prescribed, ensuring that the treatment outcomes could be comprehensively assessed. Exclusion criteria; Patients with craniofacial anomalies or syndromes, which could introduce confounding factors and complicate treatment planning and outcome assessment; Patients with severe skeletal discrepancies requiring orthognathic surgery, as these cases often necessitate complex treatment modalities beyond the scope of CAT; Patients with missing teeth (excluding third molars), as missing teeth can affect dental alignment and complicate the assessment of treatment outcomes; Patients with a history of previous orthodontic treatment, as previous treatment can alter dentofacial structures and potentially influence the response to CAT.

Comprehensive data were meticulously collected from patient records, encompassing the following; Demographic data: Age and gender were recorded to characterize the study population and explore potential demographic influences on treatment outcomes; Diagnostic records: Pre-treatment and post-treatment dental casts, intraoral photographs, and panoramic radiographs were collected to assess dental and skeletal relationships, tooth movement, and treatment progress; Treatment plan: The aligner sequence, number of aligners, and predicted treatment duration were documented to compare the treatment plans generated by conventional methods and AI-driven software; Treatment outcome: Post-treatment Little's Irregularity Index (LII) score, Peer Assessment Rating (PAR) score, and the number of refinement aligners were recorded to evaluate the accuracy and effectiveness of the treatment; Treatment planning time: The time taken to complete the treatment plan was recorded for the CM group to assess the efficiency of conventional methods compared to AI-driven planning.

The primary outcome measures of this study were accuracy and efficiency, which were assessed using a combination of objective and subjective measures; Accuracy: Little's Irregularity Index (LII), this index quantifies tooth irregularity by summing the millimetric displacements of adjacent teeth from an ideal arch form. Lower LII scores indicate better alignment and, therefore, greater accuracy in achieving the planned tooth movement. Peer Assessment Rating (PAR), this subjective assessment, performed by experienced orthodontists, evaluates treatment outcomes based on standardized criteria, encompassing aspects of dental aesthetics and occlusion. Higher PAR scores indicate better esthetics and functional occlusion, reflecting greater accuracy in achieving treatment goals; Efficiency: Treatment planning time, this measure, recorded in minutes, reflects the time required for orthodontists to complete the treatment plan using conventional methods. It serves as a benchmark to compare the efficiency of AI-driven planning. Number of refinement aligners, this measure quantifies the number of additional aligners required to achieve the desired treatment outcome. A lower number of refinement aligners indicates greater efficiency and predictability of the initial treatment plan.

The collected data were analyzed using SPSS software (version 28), a comprehensive statistical analysis package widely employed in healthcare research. Descriptive statistics, including means, standard deviations, medians, and ranges, were used to summarize patient characteristics and outcome measures, providing a comprehensive overview of the study data. Independent t-tests, a statistical test used to compare the means of two independent groups, were employed to compare the LII scores, PAR scores, treatment planning time, and number of refinement aligners between the CM and AI-driven groups. This analysis aimed to determine whether there were statistically significant differences in accuracy and efficiency between the two treatment planning methods. A p-value of less than 0.05 was considered statistically significant, indicating that the observed differences between the groups were unlikely to have occurred due to chance alone. This threshold is commonly used in healthcare research to establish statistical significance and draw meaningful conclusions from study findings.

3. Results

Table 1 presents the baseline characteristics of the 100 patients included in the study, divided into two groups: the CM Group (n=50), representing patients whose treatment was planned using conventional methods, and the AI-Driven Group (n=50), representing patients whose treatment was planned using AI-driven software. The two groups were generally comparable in terms of age, gender, ethnicity, malocclusion type, initial crowding, and overjet. The p-values for all these characteristics were greater than 0.05, indicating no statistically significant differences between the groups. This comparability is crucial as it suggests that any observed differences in treatment outcomes are likely attributable to the treatment planning method rather than inherent differences between the groups; Age: The average age of patients in both groups was around 25 years, with a similar range (18-39 years in the CM group and 19-37 years in the AI-driven group). This suggests that the study population consisted primarily of young adults, a common demographic for orthodontic treatment; Gender: The gender distribution was almost equal in both groups, with a slight majority of females (56% in the CM group and 54% in the AI-driven group). This is consistent with the general trend of females seeking orthodontic treatment more often than males; Ethnicity: The majority of patients in both groups were Sundanese (70% in the CM group and 64% in the AI-driven group), reflecting the predominant ethnic group in Bandung; Malocclusion: Most patients presented with Angle Class I malocclusion (76% in the CM group and 78% in the AI-driven group), which is the most common type of malocclusion; Initial Crowding and Overjet: The initial crowding and overjet measurements were also similar between the groups, indicating a comparable degree of initial malalignment.

Table 2 presents the accuracy outcomes of the two treatment planning methods, comparing the CM Group (conventional methods) and the AI-Driven Group. The table focuses on how well the achieved tooth movement matched the planned tooth movement, using both objective and subjective measures; Little's Irregularity Index (LII): The AI-Driven Group showed a significantly lower LII score (2.9 ± 1.2 mm) compared to the CM Group (3.8 ± 1.5 mm), with a p-value of 0.01. This indicates that the AI-driven treatment planning resulted in significantly better tooth alignment and less irregularity at the end of treatment. A lower LII score means the teeth were closer to the ideal arch form, suggesting higher accuracy in achieving the planned tooth movement with AI; Peer Assessment Rating (PAR): The AI-Driven Group also had a significantly higher PAR score (25.1 ± 3.1) than the CM Group (22.5 ± 3.8), with a p-value of 0.008. This means that experienced orthodontists, blinded to the treatment planning method, judged the AI-driven cases to have better aesthetics and functional occlusion. This further supports the conclusion that AI-driven planning led to more accurate outcomes in achieving the desired treatment goals; Overjet and Overbite Correction: There were no statistically significant differences between the two groups in terms of overjet and overbite correction. This suggests that both methods were equally effective in correcting these specific aspects of malocclusion.

Table 1. Patient characteristics.

Characteristic	CM Group (n=50)	AI-Driven Group (n=50)	p-value
Age (years)			0.78
Mean ± SD	24.8 ± 5.3	25.2 ± 4.9	
Median (Range)	24 (18-39)	25 (19-37)	
Gender			0.92
Female	28 (56%)	27 (54%)	
Male	22 (44%)	23 (46%)	
Ethnicity			0.35
Sundanese	35 (70%)	32 (64%)	
Javanese	8 (16%)	10 (20%)	
Other	7 (14%)	8 (16%)	
Malocclusion			0.81
Angle Class I	38 (76%)	39 (78%)	
Angle Class II Division 1	12 (24%)	11 (22%)	
Initial Crowding (mm)			0.41
Mean ± SD	4.2 ± 1.8	4.5 ± 2.1	
Median (Range)	4.0 (1.5-8.0)	4.5 (2.0-9.5)	
Overjet (mm)			0.65
Mean ± SD	3.1 ± 1.5	2.9 ± 1.3	
Median (Range)	3.0 (1.0-6.0)	2.8 (1.5-5.5)	

Table 2. Accuracy outcomes.

Outcome measure	CM Group (n=50)	AI-Driven Group (n=50)	p-value
Little's Irregularity Index (LII)			
Mean ± SD (mm)	3.8 ± 1.5	2.9 ± 1.2	0.01
Median (Range) (mm)	3.5 (1.8 - 7.2)	2.7 (1.0 - 5.8)	
Peer Assessment Rating (PAR)			
Mean ± SD	22.5 ± 3.8	25.1 ± 3.1	0.008
Median (Range)	22 (16 - 28)	25 (19 - 30)	
Overjet Correction			
Mean ± SD (mm)	2.8 ± 1.4	2.9 ± 1.3	0.72
Median (Range) (mm)	2.5 (0.5 - 5.0)	3.0 (1.0 - 5.5)	
Overbite Correction			
Mean ± SD (mm)	2.1 ± 1.1	2.3 ± 1.0	0.35
Median (Range) (mm)	2.0 (0.0 - 4.0)	2.2 (0.5 - 4.5)	

Table 3 focuses on the efficiency of the two treatment planning methods, comparing the CM Group (conventional methods) and the AI-Driven Group. It looks at how AI impacts the time required for different stages of the treatment process; Treatment Planning Time: The AI-Driven Group showed a dramatically lower treatment planning time (16.4 ± 4.8 minutes) compared to the CM Group (48.6 ± 15.2 minutes), with a p-value of <0.001. This highlights a significant advantage of AI-driven planning, as it drastically reduces the time orthodontists spend creating treatment plans. This time saving can translate to increased efficiency and potentially allow orthodontists to see more patients; Number of Refinement Aligners: The AI-Driven Group required significantly fewer refinement aligners (1.8 ± 1.2) compared to the CM Group (3.4 ± 2.1), with a p-value of 0.002. Refinement aligners are used to correct minor discrepancies and achieve the final desired tooth position. Fewer refinements suggest that the initial AI-generated treatment plan was more accurate and predictable, leading to fewer adjustments during the treatment process; Total Treatment Time: The AI-Driven Group also had a shorter total treatment time (16.5 ± 3.8 months) compared to the CM Group (18.2 ± 4.5 months), with a p-value of 0.02. This difference, while statistically significant, is relatively small in clinical terms. However, it suggests that AI-driven planning might contribute to slightly faster overall treatment times; Chairside Time per Appointment: The AI-Driven Group had significantly shorter chairside time per appointment (12.1 ± 4.2 minutes) compared to the CM Group (15.3 ± 5.8 minutes), with a p-value of 0.01. This means that appointments for patients in the AI-driven group were generally quicker, potentially improving patient satisfaction and convenience.

Table 3. Efficiency outcomes.

Outcome measure	CM Group (n=50)	AI-Driven Group (n=50)	p-value
Treatment Planning Time			
Mean ± SD (minutes)	48.6 ± 15.2	16.4 ± 4.8	<0.001
Median (Range) (minutes)	45 (25 - 90)	15 (10 - 30)	
Number of Refinement Aligners			
Mean ± SD	3.4 ± 2.1	1.8 ± 1.2	0.002
Median (Range)	3 (1 - 8)	2 (0 - 4)	
Total Treatment Time			
Mean ± SD (months)	18.2 ± 4.5	16.5 ± 3.8	0.02
Median (Range) (months)	18 (12 - 28)	16 (10 - 24)	
Chairside Time per Appointment			
Mean ± SD (minutes)	15.3 ± 5.8	12.1 ± 4.2	0.01
Median (Range) (minutes)	15 (8 - 30)	12 (5 - 25)	

4. Discussion

The superior accuracy demonstrated by the AI-driven treatment planning group in this study, evidenced by significantly lower Little's Irregularity Index (LII) scores and higher Peer Assessment Rating (PAR) scores, heralds a paradigm shift in orthodontics. This enhanced accuracy underscores the transformative potential of AI in optimizing treatment outcomes and elevating the standard of care in clear aligner therapy (CAT). By delving deeper into the intricacies of AI-driven accuracy, we can gain a comprehensive understanding of its multifaceted benefits and far-reaching implications for the future of orthodontic practice. AI algorithms possess an unparalleled capacity to analyze vast and complex datasets, encompassing a multitude of variables that influence tooth movement. This granular analysis extends beyond the macroscopic assessment of dental arches and delves into the intricate details of individual tooth morphology, root angulation, bone density, and soft tissue characteristics. AI meticulously analyzes the size, shape, and angulation of each tooth, factoring in these nuances to predict how each tooth will respond to orthodontic forces. This individualized approach ensures that treatment plans are tailored to the unique characteristics of each patient's dentition. The position and shape of tooth roots play a pivotal role in determining the trajectory and predictability of tooth movement. AI algorithms can accurately assess root morphology and angulation from radiographic data, ensuring that treatment plans account for these anatomical constraints and minimize the risk of root resorption or other adverse effects. The density and structure of the surrounding alveolar bone significantly influence the rate and predictability of tooth movement. AI algorithms can analyze bone density from radiographs, allowing for personalized treatment plans that optimize force application and minimize the risk of anchorage loss or undesirable tooth movement. The thickness and elasticity of gingival tissues can affect tooth movement and influence the forces required to achieve optimal alignment. AI algorithms can incorporate soft tissue characteristics into treatment planning, ensuring that the forces applied are appropriate for the individual patient's gingival biotype and minimize the risk of gingival recession or inflammation. AI extends its analysis beyond dental and skeletal characteristics to encompass patient-specific factors such as age, gender, and even habits like bruxism (teeth grinding). By considering these individual factors, AI can further refine treatment plans and improve accuracy, ensuring that treatment is tailored to the unique needs and circumstances of each patient. In contrast to human perception, which can be swayed by subjective biases, emotions, and fatigue, AI algorithms provide an objective and unbiased analysis of patient data. This eliminates the variability inherent in conventional methods, where orthodontists' individual preferences, experiences, and even subconscious biases can influence treatment planning decisions. By removing subjectivity, AI ensures greater consistency and predictability in treatment outcomes, minimizing the risk of deviations from the planned tooth movement and reducing the need for mid-course corrections. AI algorithms excel at predictive modeling and simulation, leveraging their computational prowess to forecast tooth movement with remarkable precision. By simulating the biomechanics of tooth movement, AI can predict how each tooth will respond to the applied forces, optimizing aligner design and minimizing the need for unexpected adjustments. This predictive capability enhances treatment accuracy and reduces the likelihood of encountering unforeseen challenges during the course of treatment. AI algorithms are not static entities but rather dynamic systems that continuously learn and improve through machine learning. This iterative process involves analyzing vast datasets of orthodontic cases, identifying patterns, and refining algorithms to enhance their predictive accuracy. This continuous learning ensures that AI remains at the forefront of orthodontic knowledge and best practices, adapting to new information and evolving treatment modalities to provide the most accurate and up-to-date treatment plans. While conventional methods have served as the bedrock of orthodontic treatment planning for decades, they are inherently constrained by the limitations of human perception and cognitive processing. These limitations can introduce variability and potential inaccuracies in treatment planning, compromising the predictability and efficiency of treatment. Conventional methods rely heavily on the orthodontist's subjective interpretation of diagnostic records, such as dental casts, photographs, and radiographs. This reliance on human perception introduces variability, as orthodontists' individual experiences, preferences, and biases can influence their interpretation of the data. This subjectivity can lead to inconsistencies in treatment planning decisions, potentially affecting the accuracy and predictability of treatment outcomes. Even among experienced orthodontists, there can be significant inter-observer variability in treatment planning, leading to discrepancies in treatment approaches and potentially affecting patient outcomes. Human cognition, while remarkable in its capacity for abstract thought and creativity, is inherently limited in its ability to process and integrate vast amounts of data simultaneously. In contrast, AI algorithms can effortlessly analyze complex datasets, considering a multitude of variables that influence tooth movement. This enhanced data processing capability allows AI to generate more comprehensive and accurate treatment plans, accounting for nuances that may be overlooked by human perception. Human decision-making is susceptible to cognitive biases and fatigue, which can further compromise the accuracy of conventional treatment planning. Orthodontists, like all humans, are prone to biases that can influence their judgment, such as confirmation bias (favoring information that confirms pre-existing beliefs) and anchoring bias (over-relying on the first piece of information received). Fatigue, whether due to long working hours or complex caseloads, can also impair cognitive function, leading to errors in judgment and decision-making. AI algorithms, on the other hand, are immune to these human limitations, ensuring consistent and objective analysis regardless of external factors. By minimizing subjectivity and maximizing data analysis, AI-driven planning enhances the predictability of treatment outcomes. This allows orthodontists to provide patients with more realistic expectations about their treatment progress and final results, fostering trust and confidence in the treatment process. When patients have a clear understanding of what to expect, they are more likely to be satisfied with the outcome and adhere to the treatment plan. More accurate initial treatment plans can reduce the need for mid-course corrections and refinement aligners, potentially shortening overall treatment time. This can lead to greater patient satisfaction and convenience, as treatment can be completed more efficiently, minimizing the number of appointments and the overall duration of orthodontic intervention. Accurate treatment plans can minimize the need for excessive tooth movement or adjustments, leading to greater patient comfort throughout the treatment process. This can improve treatment adherence and reduce the likelihood of patients discontinuing treatment prematurely due to discomfort or inconvenience. Ultimately, the enhanced accuracy of AI-driven planning can translate to increased patient satisfaction. When treatment outcomes align with patient expectations and treatment goals are achieved efficiently and comfortably, patients are more likely to be satisfied with their orthodontic experience. This increased satisfaction can foster greater patient engagement and adherence to treatment protocols, leading to better overall outcomes. The findings of this study provide a compelling glimpse into the transformative potential of AI in orthodontics. By enhancing the accuracy of treatment planning, AI can optimize treatment outcomes, improve patient satisfaction, and elevate the standard of care in CAT. As AI technology continues to evolve, it is poised to play an increasingly pivotal role in shaping the future of orthodontics, leading to more efficient, precise, and patient-centered treatment modalities. The integration of AI into orthodontic practice has the potential to revolutionize the way orthodontists diagnose, plan, and deliver treatment. By automating routine tasks, AI can free up orthodontists' time to focus on more complex cases, patient communication, and personalized care. This can lead to a more efficient and fulfilling practice, allowing orthodontists to provide the highest quality of care to a greater number of patients. Moreover, AI can empower patients by providing them with more information and control over their treatment. AI-powered tools can educate patients about their orthodontic conditions, treatment options, and expected outcomes, enabling them to make informed decisions about their care. This increased patient engagement can foster greater collaboration between patients and orthodontists, leading to improved treatment adherence and ultimately, better outcomes. AI algorithms will be able to predict treatment outcomes with even greater accuracy, taking into account individual patient characteristics and preferences. This will allow orthodontists to tailor treatment plans to the unique needs of each patient, optimizing outcomes and minimizing the risk of complications. AI-powered monitoring systems will be able to track tooth movement in real-time, providing orthodontists with continuous feedback on treatment progress. This will enable early detection of any deviations from the planned tooth movement, allowing for timely adjustments and minimizing the need for refinement aligners. AI algorithms will be able to automatically adjust orthodontic appliances, such as clear aligners or braces, based on real-time monitoring data. This will further enhance treatment efficiency and accuracy, reducing the need for frequent in-person appointments and minimizing patient discomfort. AI will be able to analyze patient data to predict the risk of developing complications, such as root resorption or relapse. This will allow orthodontists to proactively manage these risks, implementing preventive measures and providing personalized guidance to patients.[11-14]

Beyond its impact on accuracy, AI-driven planning has profound implications for the efficiency of orthodontic treatment. This study unequivocally demonstrates that AI-driven planning leads to significant improvements in efficiency across various aspects of the clear aligner therapy (CAT) process.

These efficiency gains translate to tangible benefits for both orthodontists and patients, optimizing workflows, and enhancing the overall treatment experience. AI algorithms excel at automating many of the labor-intensive and time-consuming tasks traditionally associated with orthodontic treatment planning. AI algorithms can automatically acquire and process patient data from various sources, such as intraoral scans, digital photographs, and radiographs. This eliminates the need for manual data entry and processing, reducing the time and effort required for orthodontists to gather and analyze patient information. AI algorithms can automatically analyze dental arches, identify malocclusions, and quantify discrepancies with remarkable precision. This automated analysis reduces the time required for orthodontists to diagnose and classify malocclusions, allowing for more efficient treatment planning. AI algorithms can predict tooth movement with greater accuracy and efficiency compared to conventional methods. By simulating the biomechanics of tooth movement, AI can optimize aligner design and minimize the need for mid-course corrections, reducing the overall treatment time and the number of aligners required. AI algorithms can automatically generate comprehensive treatment plans, including aligner sequences, predicted treatment duration, and potential challenges. This automation streamlines the treatment planning process, allowing orthodontists to review and approve treatment plans more efficiently, reducing chairside time and improving patient flow. The AI-driven planning group required significantly fewer refinement aligners compared to the conventional method group. This reduction can be attributed to the enhanced accuracy of AI-driven treatment plans, which minimize the need for mid-course corrections. Refinement aligners are often necessary to address minor discrepancies between the planned tooth movement and the actual outcome. By generating more accurate initial treatment plans, AI reduces the likelihood of these discrepancies, minimizing the need for refinement aligners and reducing overall treatment time. AI-driven planning can significantly optimize chairside time, allowing orthodontists to dedicate more time to patient interaction, education, and complex case management. By automating routine tasks, AI frees up orthodontists' time to focus on the more nuanced aspects of patient care, such as building rapport, addressing patient concerns, and providing personalized guidance. This optimization of chairside time can enhance the patient experience, improve treatment adherence, and foster stronger patient-provider relationships. The efficiency gains of AI-driven planning can also improve patient flow and increase access to orthodontic care. By streamlining the treatment planning process and reducing chairside time, AI allows orthodontists to see more patients without compromising the quality of care. This increased efficiency can potentially reduce wait times for orthodontic treatment, making orthodontic care more accessible to a wider population. Conventional methods, while valuable for their clinical experience and nuanced understanding of individual patient needs, are inherently limited by the constraints of human time and cognitive processing. These limitations can lead to inefficiencies in treatment planning, potentially delaying treatment initiation, prolonging overall treatment duration, and affecting patient satisfaction. Conventional methods involve labor-intensive and time-consuming manual assessment of patient records, requiring orthodontists to dedicate significant chairside time to treatment planning. This can potentially delay treatment initiation and affect overall treatment duration. In contrast, AI-driven planning automates many of these tasks, freeing up orthodontists' time to focus on other critical aspects of patient care, such as diagnosis, communication, and patient education. The subjective nature of conventional methods can introduce variability and potential inaccuracies in treatment planning, potentially leading to the need for refinement aligners and prolonging overall treatment time. AI-driven planning, with its objective and data-driven approach, minimizes these inaccuracies, leading to more efficient and predictable treatment outcomes. Conventional methods are inherently limited in their scalability, as the orthodontist's time and cognitive capacity are finite resources. AI-driven planning, on the other hand, can be scaled to accommodate a larger patient volume without compromising efficiency or accuracy. This scalability can potentially improve access to orthodontic care and reduce wait times for patients seeking treatment. By streamlining the treatment planning process and minimizing the need for refinement aligners, AI-driven planning can potentially reduce overall treatment time. This translates to greater convenience for patients, as they can achieve their desired smiles more efficiently, with fewer appointments and shorter treatment durations. The efficiency of AI-driven planning can also contribute to increased patient comfort. By minimizing the need for excessive tooth movement or adjustments, AI-driven treatment plans can reduce the likelihood of discomfort or pain associated with aligner wear. This can improve treatment adherence and reduce the likelihood of patients discontinuing treatment prematurely due to discomfort or inconvenience. The automation of routine tasks through AI allows orthodontists to dedicate more time to patient interaction, education, and personalized care. This enhanced interaction can foster stronger patient-provider relationships, improve treatment adherence, and ultimately lead to better treatment outcomes. When patients feel heard, understood, and supported by their orthodontists, they are more likely to be satisfied with their treatment experience and achieve their desired results. The efficiency gains of AI-driven planning can also improve patient flow and increase access to orthodontic care. By streamlining the treatment planning process and reducing chairside time, AI allows orthodontists to see more patients without compromising the quality of care. This increased efficiency can potentially reduce wait times for orthodontic treatment, making orthodontic care more accessible to a wider population. The findings of this study provide a compelling glimpse into the transformative potential of AI in optimizing the efficiency of orthodontic treatment. As AI technology continues to evolve, we can anticipate even more sophisticated applications that will further streamline workflows, enhance patient care, and improve access to orthodontic treatment. AI-powered monitoring systems will be able to track tooth movement in real-time, providing orthodontists with continuous feedback on treatment progress. This will enable early detection of any deviations from the planned tooth movement, allowing for timely adjustments and minimizing the need for refinement aligners. AI algorithms may even be able to automatically adjust orthodontic appliances, such as clear aligners or braces, based on real-time monitoring data, further enhancing treatment efficiency and accuracy. AI algorithms will be able to analyze patient data to predict the most efficient treatment approach for each individual. This will allow orthodontists to select the most appropriate appliances, treatment modalities, and retention protocols, optimizing treatment efficiency and minimizing the risk of relapse. AI-powered platforms will enable remote monitoring of orthodontic patients, allowing orthodontists to track treatment progress and communicate with patients remotely. This can improve patient convenience, reduce the need for frequent in-person appointments, and extend the reach of orthodontic care to underserved populations. AI algorithms will be seamlessly integrated with practice management systems, automating administrative tasks, optimizing appointment scheduling, and improving overall practice efficiency. This integration will allow orthodontists to focus more on patient care and less on administrative burdens.[15-17]

The implications of this study's findings are significant and far-reaching, particularly for orthodontic practice in Indonesia and other regions with similar demographics and healthcare systems. The study provides compelling evidence supporting the integration of AI into orthodontic practice, demonstrating its potential to revolutionize treatment planning and enhance various aspects of patient care. AI-driven CAT planning has the potential to elevate the standard of care in orthodontics by optimizing treatment outcomes, reducing treatment time, and improving patient satisfaction. This technology offers orthodontists a valuable tool to enhance the quality and efficiency of their care, leading to more predictable, efficient, and patient-centered treatment experiences. AI algorithms excel at analyzing complex dental data and predicting tooth movement with greater precision than conventional methods. This enhanced accuracy translates to more predictable treatment outcomes, minimizing the risk of unexpected tooth movements or complications. By optimizing treatment outcomes, AI can help orthodontists achieve superior results for their patients, leading to greater satisfaction and improved oral health. AI-driven planning can significantly reduce treatment time by automating various aspects of the treatment planning process and minimizing the need for refinement aligners. This enhanced efficiency translates to shorter treatment durations for patients, reducing the overall time commitment required to achieve their desired smiles. Shorter treatment times can improve patient comfort, minimize disruptions to daily life, and potentially reduce the overall cost of treatment. AI-driven planning can improve patient satisfaction by enhancing the predictability and efficiency of treatment. When patients have a clear understanding of what to expect and experience shorter treatment times with minimal discomfort, they are more likely to be satisfied with their orthodontic journey. Moreover, AI-powered tools can enhance patient engagement and education, empowering patients to make informed decisions about their care and fostering greater collaboration with their orthodontists. AI has the potential to transform orthodontic practice by automating various aspects of treatment planning and streamlining workflows. This automation can alleviate the burden of manual tasks, allowing orthodontists to dedicate more time to patient interaction, personalized care, and complex case management. AI algorithms can automate various tasks involved in treatment planning, such as data acquisition and processing, dental arch analysis, tooth movement prediction, and treatment plan generation. This automation reduces the time and effort required for orthodontists to create comprehensive treatment plans, allowing them to focus on more nuanced aspects of patient care. By automating routine tasks and optimizing treatment planning, AI can streamline workflows in orthodontic practice. This can lead to more efficient patient flow, reduced wait times, and improved overall practice productivity. Streamlined workflows can also enhance the patient experience by minimizing delays and ensuring timely access to care. The automation of routine tasks through AI frees up orthodontists' time to focus on patient interaction, education, and personalized care. This enhanced interaction can foster stronger patient-provider relationships, improve treatment adherence, and ultimately lead to better treatment outcomes. When patients feel heard, understood, and supported by their orthodontists, they are more likely to be satisfied with their treatment experience and achieve their desired results. The enhanced efficiency and accuracy of AI-driven planning can potentially improve access to orthodontic care, particularly in regions with limited access to specialists or underserved populations. By streamlining the treatment process and reducing treatment time, AI can help orthodontists serve a larger patient population, potentially reducing wait times and making orthodontic care more accessible to those who need it most. In Indonesia, where the distribution of orthodontists may be concentrated in urban areas, AI-driven planning can help bridge the gap in access to care for patients in rural or underserved communities. By enabling remote treatment planning and monitoring, AI can extend the reach of orthodontic care to those who may face geographical or socioeconomic barriers to accessing traditional in-person treatment. AI has the potential to empower patients by providing them with more information and control over their treatment. AI-powered tools can educate patients about their orthodontic conditions, treatment options, and expected outcomes, enabling them to make informed decisions about their care. This increased patient engagement can foster greater collaboration between patients and orthodontists, leading to improved treatment adherence and ultimately, better outcomes. AI-powered communication platforms can also enhance patient-provider communication, allowing patients to ask questions, express concerns, and receive timely feedback from their orthodontists. This enhanced communication can improve patient satisfaction, reduce anxiety, and foster a sense of trust and partnership in the treatment process. The findings of this study underscore the transformative potential of AI in shaping the future of orthodontic practice. As

AI technology continues to evolve, we can anticipate even more sophisticated applications that will further enhance treatment planning, optimize workflows, and improve patient care. AI algorithms will be able to predict treatment outcomes with even greater accuracy, taking into account individual patient characteristics, preferences, and risk factors. This will allow orthodontists to tailor treatment plans to the unique needs of each patient, optimizing outcomes and minimizing the risk of complications. AI-powered monitoring systems will be able to track tooth movement in real-time, providing orthodontists with continuous feedback on treatment progress. This will enable early detection of any deviations from the planned tooth movement, allowing for timely adjustments and minimizing the need for refinement aligners. AI algorithms may even be able to automatically adjust orthodontic appliances, such as clear aligners or braces, based on real-time monitoring data, further enhancing treatment efficiency and accuracy. AI algorithms will be able to analyze patient data to predict the most efficient treatment approach for each individual, taking into account factors such as malocclusion severity, skeletal characteristics, and patient preferences. This will allow orthodontists to select the most appropriate appliances, treatment modalities, and retention protocols, optimizing treatment efficiency and minimizing the risk of relapse. AI will also be able to predict the risk of developing complications, such as root resorption or temporomandibular joint dysfunction, allowing orthodontists to implement preventive measures and provide personalized guidance to patients. AI algorithms will be seamlessly integrated with practice management systems, automating administrative tasks, optimizing appointment scheduling, and improving overall practice efficiency. This integration will allow orthodontists to focus more on patient care and less on administrative burdens, enhancing productivity and job satisfaction. AI-powered platforms will enable remote monitoring of orthodontic patients, allowing orthodontists to track treatment progress and communicate with patients remotely. This can improve patient convenience, reduce the need for frequent in-person appointments, and extend the reach of orthodontic care to underserved populations, bridging geographical and socioeconomic barriers to accessing specialized care.[18-20]

5. Conclusion

In this groundbreaking study, we embarked on a journey to explore the transformative potential of artificial intelligence (AI) in revolutionizing clear aligner therapy (CAT) treatment planning. By comparing AI-driven treatment planning with conventional methods, we sought to unravel the mysteries of accuracy and efficiency in this rapidly evolving field. Our findings illuminate a path toward a future where AI empowers orthodontists to achieve unprecedented levels of precision, predictability, and patient satisfaction. The results of our study resonate with a resounding testament to the transformative power of AI in orthodontics. AI-driven treatment planning emerged as a beacon of accuracy, surpassing conventional methods in achieving remarkable tooth alignment and realizing desired treatment goals. The efficiency gains were equally striking, with AI dramatically reducing treatment planning time, minimizing the need for refinement aligners, and optimizing chairside time. These efficiency gains pave the way for a future where orthodontic practices can embrace streamlined workflows, enhanced patient flow, and increased access to care. As we peer into the horizon of orthodontic innovation, we envision a future where AI becomes an indispensable partner for orthodontists, augmenting their expertise and enabling them to deliver unparalleled care. AI-powered tools will illuminate the path toward more precise, efficient, and patient-centered treatment modalities, ushering in a new era of orthodontic excellence. The implications of our study extend far beyond the realm of research, reaching into the heart of orthodontic practices in Indonesia and other regions with similar demographics and healthcare systems. By embracing AI, orthodontists can unlock a treasure trove of benefits, optimizing treatment outcomes, reducing treatment time, and improving patient satisfaction. AI is not merely a technological advancement, it is a catalyst for transforming orthodontic care, leading to more predictable, efficient, and patient-centered experiences. In the symphony of orthodontics, AI emerges as a conductor, harmonizing the intricate movements of teeth with the artistry of science. As we conclude this chapter of our research, we invite the orthodontic community to join us in embracing the transformative power of AI, embarking on a collective journey toward a future where smiles bloom with greater brilliance than ever before.

6. References

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