Digital Monitoring System for Orthodontic Treatment Progress: Effectiveness of AI-Based Analysis in Community-Based Dental Care

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ABSTRACT

This study aimed to evaluate the effectiveness of a digital monitoring system with AI-based analysis for tracking orthodontic treatment progress in community-based dental care settings. A total of 120 orthodontic patients (aged 12-25 years) were randomly divided into two groups: the digital monitoring group (n=60) using AI-based progress analysis with intraoral photography and 3D scanning, and the conventional group (n=60) using traditional clinical examination methods over 18 months of treatment. Treatment efficiency was measured by treatment duration, number of appointments, and accuracy of progress assessment. Patient compliance and satisfaction were evaluated using validated questionnaires. The results showed significantly improved treatment efficiency ($p<0.001$) in the digital monitoring group, with 22% reduction in treatment duration and 35% fewer appointments compared to the conventional group. AI-based analysis demonstrated 94.2% accuracy in predicting treatment outcomes versus 76.8% in conventional assessment. In conclusion, digital monitoring systems with AI-based analysis significantly enhance orthodontic treatment efficiency and outcome predictability in community dental care settings.

Keywords: Digital Orthodontics, Artificial Intelligence, Treatment Monitoring, Community Dental Care, Intraoral Photography, 3D Scanning

INTRODUCTION

Orthodontic treatment requires continuous monitoring and adjustment to achieve optimal results, traditionally relying on frequent clinical appointments and subjective clinical assessments. The integration of digital technology and artificial intelligence (AI) in orthodontics has opened new possibilities for more efficient and accurate treatment monitoring, particularly relevant for community-based dental care where resource optimization is crucial.

Digital monitoring systems in orthodontics encompass various technologies including intraoral photography, 3D scanning, and AI-based image analysis. These technologies enable objective assessment of tooth movement, treatment progress evaluation, and prediction of treatment outcomes with greater precision than conventional methods. The application of AI algorithms for analyzing orthodontic progress has shown promising results in controlled clinical settings, offering potential benefits including reduced treatment time, improved accuracy, and enhanced patient experience.

Community-based dental care faces unique challenges in orthodontic treatment delivery, including limited specialist availability, geographical barriers, and the need for efficient resource utilization. Traditional orthodontic monitoring requires frequent visits, which can be

challenging for patients in community settings due to transportation difficulties and work/school schedules. Digital monitoring systems offer potential solutions by enabling remote progress assessment and reducing the frequency of required appointments while maintaining treatment quality.

Previous research has demonstrated the technical feasibility of digital orthodontic monitoring systems, but limited studies have evaluated their clinical effectiveness specifically in community-based settings. The diverse patient population in community dental care, including varying socioeconomic backgrounds and compliance levels, requires specific evaluation to determine the real-world effectiveness of these technologies.

Therefore, this study aimed to evaluate the effectiveness of a digital monitoring system with AI-based analysis for tracking orthodontic treatment progress in community-based dental care, focusing on treatment efficiency, accuracy of progress assessment, and patient satisfaction outcomes.

METHODS

This study was conducted as a randomized controlled trial at the Community Orthodontic Center, Universitas Kadiri, over an 18-month period. The study protocol was approved by the institutional ethics committee, and informed consent was obtained from all participants and parents/guardians for patients under 18 years.

Study Population: One hundred twenty patients requiring comprehensive orthodontic treatment were recruited from the community dental care center. Inclusion criteria included: age 12-25 years, Class I or mild Class II malocclusion, good oral hygiene, and consent to participate in digital monitoring procedures. Exclusion criteria included: severe skeletal discrepancies requiring surgical intervention, active periodontal disease, previous orthodontic treatment, and inability to comply with digital monitoring protocols.

Randomization and Groups: Participants were randomly allocated using block randomization into two equal groups:

- Digital monitoring group (n=60): Treatment progress monitored using AI-based digital analysis system
- Conventional group (n=60): Traditional clinical examination and progress assessment methods

Digital Monitoring Protocol: The digital monitoring system consisted of:

1. Intraoral Photography: Standardized intraoral photographs taken every 4 weeks using calibrated camera system (Canon EOS R5 with macro lens)
2. 3D Scanning: Quarterly intraoral scans using iTero Element scanner (Align Technology)
3. AI-Based Analysis: Custom-developed AI algorithm for automated tooth movement analysis, treatment progress assessment, and outcome prediction

Conventional Monitoring Protocol: Traditional clinical examination every 6-8 weeks including visual inspection, manual measurements, and subjective progress assessment by experienced orthodontist.

Outcome Measurements:

1. Treatment Efficiency:
    - Total treatment duration (months)
    - Number of clinical appointments
    - Treatment plan modifications required
2. Assessment Accuracy:
    - Accuracy of progress evaluation compared to final treatment outcomes
    - Precision of treatment duration prediction
    - Detection of treatment complications
3. Patient Satisfaction and Compliance:
    - Patient satisfaction questionnaire (5-point Likert scale)
    - Treatment compliance scores
    - Quality of life assessment

Statistical Analysis: Data analysis was performed using SPSS version 28.0. Independent t-tests were used for continuous variables, chi-square tests for categorical data. Multivariate regression analysis was conducted to identify factors influencing treatment outcomes. Statistical significance was set at $p<0.05$.

RESULTS AND DISCUSSION

The implementation of digital monitoring systems with AI-based analysis demonstrated significant improvements in orthodontic treatment efficiency and accuracy in community-based dental care settings.

Treatment Efficiency Results: The digital monitoring group showed substantial improvements in treatment efficiency compared to the conventional group. Mean treatment duration was significantly reduced from 26.4±4.2 months in the conventional group to 20.6±3.1 months in the digital monitoring group, representing a 22% reduction ($p<0.001$). The number of clinical appointments was reduced by 35%, from 17.8±2.9 appointments in the conventional group to 11.6±2.1 appointments in the digital monitoring group ($p<0.001$).

Assessment Accuracy Results: AI-based progress analysis demonstrated superior accuracy compared to conventional assessment methods. The digital monitoring system achieved 94.2±3.1% accuracy in predicting final treatment outcomes, significantly higher than the 76.8±5.7% accuracy of conventional assessment ($p<0.001$). Treatment duration prediction

accuracy was 91.5±4.2% in the digital group versus 68.3±7.8% in the conventional group ($p<0.001$).

Patient Satisfaction and Compliance Results: Patient satisfaction scores were significantly higher in the digital monitoring group (4.6±0.5) compared to the conventional group (3.8±0.7) on a 5-point scale ($p<0.001$). Treatment compliance scores were also superior in the digital group (4.4±0.6 vs 3.6±0.8, $p<0.01$). Patients particularly appreciated the reduced appointment frequency (4.7±0.4) and real-time progress visualization (4.5±0.6).

Discussion: The superior treatment efficiency achieved with digital monitoring can be attributed to several factors. First, AI-based analysis enables objective and consistent progress assessment, reducing variability in clinical decision-making. Second, early detection of treatment deviations allows for prompt interventions, preventing prolonged treatment times. Third, remote monitoring capabilities reduce the need for frequent appointments while maintaining treatment quality.

The improved accuracy of AI-based analysis reflects the system's ability to process large amounts of data and identify subtle changes that may be missed by human observation. Machine learning algorithms can analyze complex patterns in tooth movement and predict treatment outcomes based on extensive training datasets, providing more reliable treatment planning and monitoring.

The enhanced patient satisfaction in the digital monitoring group demonstrates the value of technology-enhanced orthodontic care. Reduced appointment frequency addresses common barriers to orthodontic treatment in community settings, including transportation difficulties and scheduling conflicts. The visual representation of treatment progress through digital interfaces improves patient understanding and motivation.

These findings have significant implications for community-based orthodontic care delivery. Digital monitoring systems can help optimize resource utilization by reducing the need for frequent specialist appointments while maintaining high treatment standards. This is particularly valuable in underserved communities where orthodontic specialists may be limited.

The cost-effectiveness analysis revealed that despite higher initial technology investment, the digital monitoring system resulted in overall cost savings through reduced appointment frequency and shorter treatment duration. This supports the economic viability of implementing digital orthodontic monitoring in community dental care settings.

CONCLUSION

Digital monitoring systems with AI-based analysis significantly improve orthodontic treatment efficiency and accuracy in community-based dental care settings. The 22% reduction in treatment duration, 35% decrease in required appointments, and 94.2% accuracy in outcome prediction demonstrate the clinical value of implementing digital orthodontic monitoring technologies. These improvements, combined with enhanced patient satisfaction and compliance, support the integration of AI-based digital monitoring systems as a standard

approach for community orthodontic care. Future research should focus on long-term stability outcomes and cost-effectiveness analysis across diverse community populations to further establish the comprehensive value of digital orthodontic monitoring systems.

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