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Artificial Intelligence–Driven Alerts to Detect Poor Oral Hygiene and Appliance Misuse in Orthodontic Patients: A Feasibility Study

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Abstract: Orthodontic treatment outcomes depend heavily on patient cooperation and oral hygiene, yet monitoring adherence remains a major challenge in clinical practice. This retrospective feasibility study evaluated an artificial intelligence (AI)–driven alert system designed to detect poor oral hygiene and appliance misuse in orthodontic patients. A total of 260 patients treated with either fixed appliances (n = 160) or aligners (n = 100) between January 2018 and January 2019 were included. Archived intraoral photographs, clinical notes, and aligner usage logs were analyzed using a two-module AI system: a convolutional neural network for plaque and hygiene detection, and an object recognition module for appliance misuse. Diagnostic accuracy was assessed against orthodontist documentation. The AI system demonstrated high diagnostic performance, with overall sensitivity and specificity of 86.7% and 82.0% for hygiene detection, and 81.6% and 83.1% for appliance misuse, respectively. Agreement with clinician documentation was substantial (κ = 0.67–0.73). Younger patients generated the highest frequency of alerts, particularly in the fixed appliance group, reflecting greater challenges with compliance. On average, analysis time was less than three minutes per case, and only 12.3% of alerts required orthodontist override. Operational feasibility was supported by simulated integration into electronic health records and high inferred patient acceptability. These findings suggest that AI-driven alerts can provide accurate, efficient, and clinically relevant monitoring of orthodontic patients. By enabling early detection of hygiene lapses and misuse, such systems hold promise for reducing preventable complications, enhancing patient accountability, and supporting a proactive model of orthodontic care. Prospective trials are warranted to validate effectiveness in real-world practice.

Keywords: Artificial Intelligence, Poor Oral Hygiene, Appliance Misuse, Orthodontic Patients

Introduction

Orthodontic treatment, whether through fixed appliances or removable aligners, remains one of the most common dental interventions worldwide, aimed at correcting malocclusion, improving aesthetics, and enhancing oral function. Despite the clinical benefits, treatment success is highly dependent on patient cooperation and oral hygiene maintenance. Fixed appliances, in particular, provide new plaque-retentive sites that increase the risk of enamel demineralization, white spot lesions, gingivitis, and periodontal complications. Similarly, improper use of removable aligners, such as insufficient daily wear or poor cleaning practices, can compromise treatment outcomes and extend treatment duration[1-3]. These challenges underscore the crucial role of adherence and hygiene in orthodontics. However, traditional methods of patient monitoring—relying on self-reporting and periodic in-office assessments—are often insufficient to detect noncompliance or suboptimal hygiene at an early stage.

In recent years, digital health technologies have emerged as promising adjuncts to orthodontic care. Smartphone applications, wearable sensors, and teleorthodontics platforms have introduced mechanisms for remote engagement and monitoring. While these innovations improve patient connectivity, they still require active patient input and are prone to inaccuracies due to recall bias or intentional misreporting[4]. Furthermore, most systems lack real-time analytic capabilities to identify early warning signs of poor hygiene or appliance misuse. The result is that orthodontists are often reactive rather than proactive, intervening only after complications, such as white spot lesions or treatment delays, become clinically evident.

Artificial intelligence (AI) offers a transformative solution in this context. AI algorithms, particularly those based on machine learning and computer vision, can process vast amounts of data to detect subtle patterns that may be imperceptible to clinicians. In dentistry, AI applications have already demonstrated value in radiographic interpretation, caries detection, cephalometric landmark identification, and prediction of orthodontic treatment outcomes[5-6]. Extending this capability to behavioural and hygiene monitoring presents an opportunity to shift orthodontic care from episodic assessment to continuous, proactive surveillance. For example, AI-driven analysis of intraoral photographs captured via smartphones could automatically detect plaque accumulation or appliance breakages. Similarly, smart sensors embedded in aligner cases or brackets could feed usage data into AI systems that flag suboptimal wear time. Such approaches promise to improve treatment adherence, reduce the burden of preventable complications, and enhance patient education.

The development of AI-driven alert systems is particularly relevant to orthodontic patients, who are often adolescents and young adults with variable motivation and self-discipline. Early detection of poor oral hygiene or appliance misuse through automated alerts could serve as both a behavioural nudge for patients and a clinical prompt for providers[7]. Alerts delivered directly to patients via mobile applications can reinforce instructions, while notifications to orthodontists allow timely intervention without waiting for routine follow-up visits. Importantly, the feasibility of such systems must be established in real-world clinical settings, taking into account technical performance, patient acceptance, workflow integration, and ethical considerations regarding data privacy.

Several pilot studies in dentistry have explored the use of digital reminders or monitoring devices to improve compliance, yet the integration of true AI-driven alerts remains in its infancy. Existing literature indicates that while patients generally respond positively to digital engagement, sustained compliance depends on the personalization, accuracy, and non-intrusiveness of the system. Moreover, orthodontic outcomes are long-term, necessitating solutions that remain effective and acceptable throughout the treatment course. Thus, a feasibility study is an essential first step before large-scale clinical implementation[8-10]. It allows researchers to evaluate system performance metrics such as sensitivity, specificity, and false alert rates, as well as patient-centred outcomes including usability, satisfaction, and perceived benefits.

This study, therefore, aims to investigate the feasibility of an AI-driven alert system designed to detect poor oral hygiene and appliance misuse in orthodontic patients. By integrating computer vision for hygiene assessment with sensor-based data on appliance use, the system seeks to provide real-time feedback to both patients and clinicians. The authors hypothesize that such an approach will be technically feasible, well-tolerated by patients, and capable of detecting noncompliant behaviours earlier than standard care. Findings from this feasibility study will inform the refinement of AI algorithms, guide future randomized controlled trials, and contribute to the growing evidence base on digital transformation in orthodontics. Ultimately, the integration of AI-driven alerts into orthodontic practice has the potential to reduce treatment complications, optimize clinical outcomes, and support a more proactive, patient-centred model of care.

Methodology

Study Design and Setting

This investigation was designed as a retrospective observational feasibility study conducted at the Department of Orthodontics, a tertiary dental care and teaching hospital. The study reviewed electronic health records (EHR), digital orthodontic records, and stored intraoral images of patients who underwent orthodontic treatment between January 2018 and January 2019. The retrospective design was selected to leverage the availability of large volumes of archived data, enabling the assessment of an artificial intelligence (AI)–based system in detecting oral hygiene lapses and appliance misuse without requiring new prospective patient enrolment. The study protocol was approved by the Institutional Ethics Committee and it adhered to the Declaration of Helsinki principles regarding retrospective data usage and patient confidentiality.

Study Population

The study population consisted of orthodontic patients aged 12–30 years who received treatment with either fixed appliances (metal or ceramic brackets) or removable clear aligners. Inclusion and exclusion criteria were applied to ensure appropriate selection:

- Inclusion Criteria:

1. Patients with at least six months of documented orthodontic treatment.
2. Availability of pre-treatment, interim, and follow-up intraoral photographs.
3. Documented compliance notes, orthodontist progress records, and, where available, appliance usage logs (for aligner patients).
4. Patients without systemic illnesses that could affect oral hygiene status (e.g., uncontrolled diabetes, immunodeficiency).

- Exclusion Criteria:

1. Patients with incomplete or missing photographic or clinical records.
2. Patients with craniofacial syndromes or cleft anomalies requiring specialized orthodontic care.
3. Patients with prior periodontal disease that may confound the interpretation of hygiene outcomes.

A total of 260 patients met the eligibility criteria and were included in the final analysis, comprising 160 fixed appliance cases and 100 aligner cases.

Data Sources and Collection

Data were extracted from three primary sources:

1. Intraoral photographs: standardized images (frontal, buccal, and occlusal views) routinely captured during each clinical visit.
2. Electronic health records (EHR): orthodontic progress notes, hygiene scores documented using a modified Plaque Index, and compliance remarks by treating clinicians.
3. Aligner usage logs: where available, these included embedded wear-time data from smart aligner cases and self-reported usage diaries.

All data were anonymized prior to analysis. Patient identifiers were removed, and each record was assigned a unique alphanumeric study ID.

AI System Development and Training

The AI-driven alert system consisted of two modules:

1. Oral Hygiene Detection Module (computer vision):
    - Trained using convolutional neural networks (CNNs) applied to intraoral photographs.

- Training dataset: 5,000 labeled images obtained from archived clinical records, annotated by two calibrated orthodontists for presence/absence of plaque, gingival inflammation, and white spot lesions.
- The CNN architecture was based on ResNet-50 pertained weights, fine-tuned for classification into three hygiene categories: good, moderate, and poor.

2. Appliance Misuse Detection Module (usage pattern recognition):
   - For aligner patients: analyzed smart case sensor logs and temporal adherence patterns.
   - For fixed appliance patients: identified broken brackets, loose arch wires, or missing ligatures from photographs using object detection (YOLOv5 model).
   - Ground truth labels were generated by cross-checking orthodontist notes with image-based annotations.

Both modules generated alerts when noncompliance or poor hygiene was detected. Alerts were retrospectively compared against clinical notes to evaluate system performance.

Outcome Measures

The study focused on assessing feasibility and diagnostic performance of the AI system.

- Primary outcomes:
  1. Sensitivity and specificity of AI-driven alerts for detecting poor oral hygiene.
  2. Sensitivity and specificity for detecting appliance misuse.
- Secondary outcomes:
  3. Concordance between AI alerts and orthodontist records (Cohen's kappa).
  4. Distribution of alert frequencies across age groups and appliance types.
  5. Patient acceptability (assessed indirectly through documented compliance notes indicating satisfaction or resistance to digital monitoring).

Statistical Analysis

All statistical analyses were conducted using SPSS version 27.0 (IBM Corp, Armonk, NY) and Python 3.10 libraries. Descriptive statistics were used to summarize demographic and treatment characteristics (means ± standard deviations for continuous variables; frequencies and percentages for categorical variables). Diagnostic performance of the AI system was assessed using confusion matrix analysis, calculating sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Agreement between AI alerts and clinician documentation was measured using Cohen's kappa coefficient, with interpretation as: <0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (moderate), 0.61–0.80 (substantial), and >0.80 (almost perfect). Subgroup analysis was performed to compare performance between fixed appliance and aligner cohorts. A p-value <0.05 was considered statistically significant.

Ethical Considerations

Given the retrospective design, no direct patient interventions were carried out. Data anonymity was maintained, and only de-identified datasets were used for AI training and analysis. Patient consent for retrospective review was waived under institutional policy, but all patients had previously consented to the storage and secondary use of clinical images for research and teaching purposes. Additionally, retrospective evaluation precluded direct patient feedback on acceptability of AI-driven alerts. These limitations will be addressed in future prospective trials.

Results

Study Cohort Characteristics

A total of 260 orthodontic patients were included in this retrospective study, comprising 160 fixed appliance users and 100 aligner users. The mean age of the cohort was 18.6 ± 4.2 years, with 62% female and 38% male. Table 1 presents the baseline demographic and treatment characteristics.

Table 1. Baseline Demographic and Treatment Characteristics (n = 260)

Variable	Fixed Appliances (n = 160)	Aligners (n = 100)	Total (n = 260)
Mean age (years) ± SD	17.9 ± 4.3	19.8 ± 3.9	18.6 ± 4.2
Sex (Female, %)	100 (62.5%)	61 (61.0%)	161 (62.0%)
Mean treatment duration (months)	18.5 ± 4.6	14.2 ± 3.8	16.8 ± 4.7
Baseline Plaque Index (mean ± SD)	1.8 ± 0.6	1.4 ± 0.5	1.6 ± 0.6
Documented appliance misuse (%)	38 (23.8%)	29 (29.0%)	67 (25.8%)

The majority of the cohort consisted of adolescents and young adults, reflecting the typical orthodontic patient demographic. Aligners were more frequently chosen by slightly older patients. Baseline plaque indices indicated suboptimal hygiene across both groups, with fixed appliance patients showing higher scores. Appliance misuse was documented in roughly one-quarter of all patients, slightly higher among aligner users.

AI System Performance: Oral Hygiene Detection

The AI-driven hygiene detection module demonstrated robust diagnostic performance compared with orthodontist-documented hygiene notes. Table 2 summarizes sensitivity, specificity, and predictive values.

Table 2. Performance of AI in Detecting Poor Oral Hygiene

Metric	Fixed Appliances	Aligners	Total Cohort
Sensitivity (%)	88.2	84.6	86.7
Specificity (%)	81.0	83.3	82.0
Positive Predictive Value (%)	79.6	80.5	80.0
Negative Predictive Value (%)	89.2	86.4	87.9

The AI system achieved an overall sensitivity of 86.7% and specificity of 82.0% for poor hygiene detection. Performance was slightly higher in fixed appliance patients, likely due to more obvious visual cues such as plaque accumulation around brackets. High negative predictive values indicate that when the AI classified hygiene as adequate, it was very reliable.

AI System Performance: Appliance Misuse Detection

For appliance misuse, the AI system was able to detect broken brackets, missing ligatures, or reduced aligner wear with reasonable accuracy. Table 3 outlines diagnostic performance.

Table 3. Performance of AI in Detecting Appliance Misuse

Metric	Fixed Appliances	Aligners	Total Cohort
Sensitivity (%)	83.1	79.3	81.6
Specificity (%)	85.4	80.0	83.1
Positive Predictive Value (%)	77.4	71.8	75.0
Negative Predictive Value (%)	89.6	85.7	87.9

Sensitivity and specificity values above 80% indicate that the AI system effectively identified appliance misuse in both groups. The lower PPV in aligner users suggests occasional overestimation of noncompliance, such as mistaking staining or reflection for absence of aligner wear. However, the high NPV confirmed reliability when no misuse was detected.

Agreement Between AI Alerts and Orthodontist Documentation

Agreement analysis using Cohen's kappa values showed substantial concordance between AI alerts and orthodontist documentation. Table 4 illustrates agreement levels.

Table 4. Agreement Between AI Alerts and Orthodontist Records

Parameter	Fixed Appliances	Aligners	Total Cohort
Hygiene Detection (κ)	0.74	0.71	0.73
Appliance Misuse (κ)	0.69	0.64	0.67

Cohen's kappa values of 0.67–0.73 reflect substantial agreement. Slightly lower agreement for appliance misuse in aligners suggests that clinician documentation was less consistent compared with the AI system, which had more uniform criteria.

Distribution of AI Alerts

The frequency and distribution of AI-generated alerts varied by appliance type and age group. Table 5 provides an overview of alert distribution.

Table 5. Distribution of AI-Generated Alerts

Age Group (years)	Fixed Appliances (alerts per patient, mean ± SD)	Aligners (alerts per patient, mean ± SD)
12–15	2.8 ± 1.1	2.2 ± 1.0
16–20	2.5 ± 1.0	2.0 ± 0.9
21–30	2.0 ± 0.8	1.8 ± 0.7

Younger patients (12–15 years) generated the highest number of alerts, particularly in the fixed appliance group, indicating greater difficulty with maintaining hygiene and adherence. Older patients demonstrated fewer alerts, reflecting better compliance.

Feasibility Outcomes

Operational feasibility was assessed by examining alert review time and integration potential into clinical workflow. Table 6 summarizes key feasibility indicators.

Table 6. Feasibility Indicators of AI System

Indicator	Mean ± SD or %
Average time for AI analysis per case (minutes)	2.5 ± 0.6
Alerts requiring orthodontist override (%)	12.3
Image sets excluded due to poor quality (%)	8.5
Potential integration into EHR (yes, %)	91.2
Simulated patient acceptability (from notes, %)	84.6

On average, AI analysis required less than three minutes per case, demonstrating technical feasibility. Only 12.3% of alerts required manual override, suggesting reliability. Poor-quality images accounted for 8.5% exclusions, a manageable limitation. Importantly, simulated integration into the EHR was rated feasible in over 90% of cases, and patient acceptability inferred from clinician notes was high (84.6%).

Discussion

This retrospective feasibility study evaluated an artificial intelligence (AI)–based alert system for detecting poor oral hygiene and appliance misuse in orthodontic patients. The findings demonstrate that AI can provide accurate, timely, and clinically meaningful insights, with high sensitivity and specificity for both hygiene and compliance monitoring[11-13]. Substantial agreement with orthodontist documentation, coupled with strong feasibility indicators, supports the potential integration of AI-driven alerts into routine orthodontic practice.

The AI system achieved sensitivity and specificity values above 80% for both oral hygiene and appliance misuse detection. These results are comparable to other AI applications in dentistry, such as caries detection and cephalometric landmark identification, which have shown similar diagnostic accuracy[14]. The slightly higher performance in fixed appliance patients may be attributed to the distinct visual markers of plaque accumulation around brackets and wires, which are easier for convolutional neural networks to identify. Conversely, aligner-related misuse was more challenging, as subtler cues—such as staining or reflection—occasionally led to false-positive alerts. Nonetheless, the high negative predictive value across both groups indicates that the system is highly reliable in ruling out problems. The distribution of alerts across age groups is consistent with existing literature that highlights compliance challenges in adolescents. Younger patients, particularly those aged 12–15 years, demonstrated higher frequencies of hygiene and misuse-related alerts, underscoring the importance of early behavioural interventions[16]. AI-driven alerts may serve as a valuable reinforcement tool for this demographic by providing immediate feedback, thereby reducing the reliance on infrequent clinic visits for corrective guidance.

Previous research on orthodontic compliance monitoring has primarily focused on smartphone applications, self-report diaries, and smart wear sensors. While these methods have improved patient engagement, they often rely heavily on patient honesty and motivation. Our findings extend the literature by showing that AI can analyze routinely captured clinical images and sensor logs to provide objective, automated alerts. This represents a shift from patient-dependent to system-driven monitoring. Comparable initiatives have been reported in preventive dentistry, where AI-based plaque detection from smartphone images has shown promise in promoting oral hygiene[17-20]. Our study builds on these foundations by integrating both hygiene and appliance misuse monitoring into a single framework. To our knowledge, this is one of the first feasibility studies to combine these two dimensions of orthodontic compliance under an AI-driven system.

The integration of AI alerts into orthodontic workflows has significant clinical implications. Real-time alerts could prompt orthodontists to intervene earlier, potentially reducing the incidence of white spot lesions, gingival inflammation, and prolonged treatment times. Alerts delivered directly to patients could serve as behavioural nudges, fostering accountability and encouraging adherence to instructions. Moreover, the system's short processing time (<3 minutes per case) supports its practicality for chair-side or remote use. For orthodontists, such systems can enhance efficiency by highlighting patients at higher risk of complications, thereby prioritizing clinical attention. In addition, AI-driven monitoring aligns with the broader trend toward digital orthodontics, where technologies such as 3D imaging, teleorthodontics, and digital treatment planning are becoming increasingly mainstream. Our results also emphasize feasibility. Only a small proportion of alerts required orthodontist overrides, suggesting high reliability. Importantly, more than 90% of cases demonstrated potential integration into electronic health records (EHRs), reinforcing operational viability. These findings are consistent with the growing evidence that AI-based systems can be seamlessly embedded within digital dental infrastructures. However, retrospective reliance on archived images introduces variability in image quality, which accounted for 8.5% of data exclusions. Prospective implementations may mitigate this limitation by ensuring standardized image capture protocols.

Limitations

Several limitations must be acknowledged. First, the retrospective design precludes real-time patient feedback regarding acceptability of AI-driven alerts. Although indirect inferences from clinical notes suggested high patient acceptance, prospective studies with structured surveys are necessary. Second, sensor-based aligner data were not available for all patients, limiting the generalizability of misuse detection findings. Third, this study was conducted at a single tertiary centre, and results may not be directly transferable to general practice settings with different patient populations and resource availability.

Future Directions

Future research should focus on prospective validation of AI-driven alerts in multicenter, diverse populations. Randomized controlled trials are warranted to evaluate the impact of these alerts on clinical outcomes, including incidence of white spot lesions, treatment duration, and patient satisfaction. Additionally, integration of natural language processing into orthodontic records may enable a more nuanced understanding of patient behaviours and compliance challenges. Ethical considerations, particularly regarding data privacy and patient autonomy, must also remain central in scaling such systems.

Conclusion

This feasibility study provides strong preliminary evidence that AI-driven alerts can reliably detect poor oral hygiene and appliance misuse in orthodontic patients. The system demonstrated high accuracy, substantial agreement with clinician documentation, and operational practicality. While limitations inherent to retrospective design remain, these findings lay the foundation for larger prospective trials. If validated, AI-driven alerts could transform orthodontic care by enabling proactive, personalized, and digitally integrated monitoring, ultimately enhancing both clinical outcomes and patient experience.

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