Research Article

Early Detection Of Malocclusion Patterns In Adolescents Using Digital Orthodontic Screening Tools

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Abstract

Background: Malocclusion represents a significant oral health concern among adolescents, affecting masticatory function, aesthetics, and psychosocial well-being. Early detection enables timely intervention during optimal growth periods, yet traditional screening methods remain resource-intensive and examiner-dependent. Digital orthodontic screening tools offer potential solutions for standardized, efficient malocclusion identification. Objective: This study aimed to evaluate the diagnostic accuracy and clinical utility of digital orthodontic screening tools for early detection of malocclusion patterns among adolescents compared to conventional clinical examination. Methods: A cross-sectional diagnostic accuracy study was conducted among 612 adolescents aged 11–16 years. Participants underwent both digital screening using intraoral scanning with automated analysis software and conventional clinical examination by calibrated orthodontists. Malocclusion was classified according to Angle's classification and Dental Aesthetic Index (DAI). Diagnostic accuracy metrics including sensitivity, specificity, positive and negative predictive values, and area under receiver operating characteristic curves (AUC-ROC) were calculated. Results: Overall malocclusion prevalence was 67.3% (n=412). Digital screening demonstrated high sensitivity (94.2%) and specificity (89.5%) for detecting any malocclusion, with AUC-ROC of 0.943 (95% CI: 0.921–0.965). Agreement between digital and conventional methods was excellent (Cohen's kappa=0.847). Class II malocclusion showed highest detection accuracy (sensitivity 96.1%, specificity 91.8%), while Class III demonstrated slightly lower sensitivity (88.4%). Mean screening time was significantly reduced with digital tools (4.23±1.12 minutes vs 12.67±3.45 minutes; p<0.001). Severe malocclusion (DAI≥36) was identified with 97.3% sensitivity. Conclusion: Digital orthodontic screening tools demonstrate excellent diagnostic accuracy for early malocclusion detection in adolescents, offering significant time efficiency advantages while maintaining clinical reliability. Implementation in school-based screening programs may facilitate earlier orthodontic intervention and improved treatment outcomes.

Keywords: malocclusion, digital orthodontics, intraoral scanning, adolescent screening, diagnostic accuracy, early detection.

1. Introduction

Malocclusion encompasses a diverse range of dental and skeletal deviations from normal occlusal relationships, representing one of the most prevalent oral conditions affecting adolescent populations worldwide [1]. Epidemiological studies indicate that malocclusion affects approximately 56–70% of adolescents globally, with significant variations attributed to genetic, environmental, and behavioral factors [2]. Beyond aesthetic concerns, untreated malocclusion may contribute to temporomandibular disorders, impaired masticatory efficiency, increased susceptibility to dental trauma, periodontal complications, and compromised oral health-related quality of life [3].

Adolescence represents an optimal period for orthodontic screening and intervention, as the combination of active skeletal growth, mixed or early permanent dentition, and patient cooperation capacity creates favorable conditions for both interceptive and comprehensive treatment approaches [4]. Early detection of malocclusion patterns enables timely referral to orthodontic specialists, potentially reducing treatment complexity, duration, and cost through growth modification strategies and preventive interceptive measures [5]. However, systematic screening programs remain inconsistently implemented across healthcare settings, partially due to resource constraints and the examiner-dependent nature of conventional assessment methods [6].

Traditional clinical examination for malocclusion detection relies upon visual inspection, manual palpation, and various clinical indices including Angle's classification, the Index of Orthodontic Treatment Need (IOTN), and the Dental Aesthetic Index (DAI) [7]. While these methods demonstrate acceptable validity when performed by trained clinicians, substantial inter-examiner variability has been documented, potentially affecting screening reliability in large-scale programs [8]. Furthermore, conventional examination requires significant chairside time and specialized training, limiting feasibility for integration into routine dental or school-based health assessments [9].

The digital transformation of orthodontic practice has introduced innovative technologies with potential applications for malocclusion screening and diagnosis [10]. Intraoral scanners generate high-resolution three-dimensional digital models enabling precise morphological analysis, while advances in artificial intelligence and machine learning have facilitated development of automated analysis algorithms capable of detecting occlusal anomalies [11]. These digital tools offer advantages including standardized assessment protocols, quantitative measurements, permanent digital records, and reduced operator dependency [12].

Recent investigations have begun evaluating digital screening methodologies in various clinical contexts, demonstrating promising accuracy for specific malocclusion features [13]. Studies examining automated cephalometric analysis and digital model assessment have reported high correlation with expert clinical judgments [14]. However, comprehensive evaluation of integrated digital screening systems encompassing multiple malocclusion patterns in adolescent populations remains limited [15].

Furthermore, practical considerations including screening time efficiency, learning curve requirements, and cost-effectiveness relative to conventional methods require systematic investigation to inform implementation decisions [16]. The optimal integration of digital screening tools within existing healthcare frameworks, particularly school-based programs targeting adolescent populations, represents an important translational research priority [17].

Therefore, this study aimed to evaluate the diagnostic accuracy and clinical utility of digital orthodontic screening tools for early detection of malocclusion patterns among adolescents compared to conventional clinical examination, with assessment of screening efficiency and pattern-specific detection performance.

2. Materials and Methods

2.1 Study Design and Setting

This cross-sectional diagnostic accuracy study was conducted between February and November 2024 at the Department of Orthodontics, University Dental Hospital, in collaboration with six participating secondary schools within the metropolitan area. The study protocol received ethical approval from the Institutional Review Board (Protocol #ORTHO-2024-0234) and adhered to the Standards for Reporting of Diagnostic Accuracy Studies (STARD) guidelines.

2.2 Sample Size Determination

Sample size was calculated using MedCalc software for diagnostic test evaluation, based on anticipated sensitivity of 90%, specificity of 85%, disease prevalence of 65%, desired precision of 5%, and 95% confidence level. The minimum required sample was 578 participants, increased to 650 to accommodate potential data incompleteness.

2.3 Participant Selection

Adolescents aged 11–16 years attending participating schools were eligible for inclusion. Specific inclusion criteria comprised: (1) age between 11–16 years; (2) permanent dentition or late mixed dentition with eruption of all first permanent molars and incisors; (3) ability to tolerate intraoral scanning procedures; (4) provision of written parental consent and participant assent.

Exclusion criteria included: (1) current or previous orthodontic treatment; (2) craniofacial syndromes or cleft lip/palate; (3) severe dental anomalies (oligodontia, amelogenesis imperfecta); (4) active dental infections or significant tooth loss affecting occlusal assessment; (5) medical conditions precluding clinical examination; and (6) inability to maintain adequate mouth opening for scanning procedures.

Stratified random sampling was employed across schools and grade levels to ensure representative demographic distribution.

2.4 Digital Screening Protocol

Digital screening was performed using a portable intraoral scanner (3Shape TRIOS 4, Copenhagen, Denmark) operated by two trained dental hygienists who completed manufacturer certification and additional calibration training (8-hour protocol). Full-arch maxillary and mandibular scans were acquired following standardized protocols, with participants seated upright and instructed to occlude in habitual intercuspation for bite registration.

Acquired digital impressions were processed through proprietary orthodontic analysis software (OrthoAnalyzer™ Version 3.2) incorporating machine learning algorithms trained on 50,000+ annotated orthodontic cases. The automated analysis generated standardized reports including:

- Angle's classification determination (Class I, II Division 1, II Division 2, III)
- Overjet and overbite measurements (mm)
- Crowding and spacing quantification (mm)
- Midline discrepancy assessment
- Crossbite identification (anterior, posterior, unilateral, bilateral)
- Dental Aesthetic Index (DAI) calculation
- Treatment need recommendation (none, elective, highly desirable, mandatory)

Digital screening results were electronically stored and blinded from clinical examiners.

2.5 Conventional Clinical Examination (Reference Standard)

Within two weeks of digital screening, participants underwent comprehensive clinical orthodontic examination by two calibrated specialist orthodontists serving as reference standard. Examiners were blinded to digital screening results. Inter-examiner reliability was established through independent assessment of 50 participants (Cohen's kappa=0.91).

Clinical examination included:

- Visual and instrumental assessment of dental alignment
- Angle's classification using molar and canine relationships
- Direct measurement of overjet and overbite using periodontal probe
- Assessment of crowding/spacing using dental floss and probe
- Crossbite evaluation in static and functional occlusion
- DAI calculation according to WHO methodology
- IOTN Dental Health Component and Aesthetic Component grading

Examination findings were recorded on standardized forms and subsequently digitized for analysis.

2.6 Classification Criteria

Malocclusion was defined according to established criteria:

Angle's Classification

- Class I: Normal molar relationship with other anomalies (crowding, spacing, rotations)
- Class II Division 1: Distal molar relationship with proclined maxillary incisors
- Class II Division 2: Distal molar relationship with retroclined maxillary incisors
- Class III: Mesial molar relationship

DAI Severity Categories

- Normal/Minor (DAI≤25): No treatment needed

• Definite (DAI 26–30): Elective treatment

• Severe (DAI 31–35): Highly desirable treatment

• Handicapping (DAI≥36): Mandatory treatment

2.7 Outcome Measures
Primary outcomes included diagnostic accuracy metrics (sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], and area under receiver operating characteristic curve [AUC-ROC]) for digital screening compared to clinical examination. Secondary outcomes included screening time comparison, agreement statistics (Cohen's kappa), and pattern-specific detection accuracy.

2.8 Statistical Analysis
Data were analyzed using SPSS version 28.0 and MedCalc version 20.0. Descriptive statistics included frequencies, percentages, means, and standard deviations. Diagnostic accuracy metrics were calculated with 95% confidence intervals. McNemar's test evaluated differences in classification proportions between methods. Bland-Altman analysis assessed agreement for continuous measurements (overjet, overbite). Independent samples t-tests compared screening times. Cohen's kappa coefficients interpreted agreement as: slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00). Statistical significance was established at $p<0.05$.

3. Results

3.1 Participant Characteristics
Of 650 initially recruited adolescents, 612 completed both screening protocols and were included in final analysis (participation rate: 94.2%). Exclusions resulted from incomplete scans (n=21), absence during clinical examination (n=12), and withdrawn consent (n=5). The sample comprised 318 females (51.9%) and 294 males (48.1%), with mean age of 13.42±1.58 years. Demographic characteristics were balanced across participating schools.

3.2 Malocclusion Prevalence and Distribution
According to clinical examination (reference standard), overall malocclusion prevalence was 67.3% (n=412). Distribution by Angle's classification showed Class I malocclusion in 42.0% (n=173), Class II Division 1 in 31.3% (n=129), Class II Division 2 in 9.2% (n=38), and Class III in 17.5% (n=72). Normal occlusion was present in 32.7% (n=200) of participants.

DAI severity distribution indicated 38.7% (n=237) with normal/minor malocclusion (DAI≤25), 26.5% (n=162) with definite malocclusion, 21.2% (n=130) with severe malocclusion, and 13.6% (n=83) with handicapping malocclusion requiring mandatory treatment.

3.3 Diagnostic Accuracy of Digital Screening
Digital screening demonstrated high overall diagnostic accuracy for malocclusion detection. For identification of any malocclusion (present vs absent), sensitivity was 94.2% (95% CI: 91.5–96.2%), specificity 89.5% (95% CI: 84.4–93.4%), PPV 94.9% (95% CI: 92.3–96.8%), and NPV 88.2% (95% CI: 82.9–92.3%). The AUC-ROC was 0.943 (95% CI: 0.921–0.965), indicating excellent discriminative ability.

Table 1: Diagnostic Accuracy of Digital Screening for Malocclusion Detection by Angle's Classification

Classification	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	AUC-ROC (95% CI)
Any Malocclusion	94.2 (91.5–96.2)	89.5 (84.4–93.4)	94.9 (92.3–96.8)	88.2 (82.9–92.3)	0.943 (0.921–0.965)
Class I	91.3 (86.1–95.1)	87.2 (83.6–90.3)	73.8 (67.8–79.2)	96.1 (93.7–97.8)	0.912 (0.884–0.940)
Class II Div 1	96.1 (91.1–98.7)	91.8 (88.9–94.2)	75.9 (68.9–82.0)	98.6 (96.9–99.5)	0.958 (0.938–0.978)

Classification	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	AUC-ROC (95% CI)
Class II Div 2	89.5 (75.2–97.1)	94.6 (92.4–96.3)	52.3 (39.5–64.9)	99.2 (97.9–99.8)	0.934 (0.897–0.971)
Class III	88.9 (79.3–95.1)	93.9 (91.5–95.8)	66.0 (55.5–75.4)	98.5 (96.9–99.4)	0.927 (0.896–0.958)

Class II Division 1 malocclusion demonstrated the highest detection accuracy (sensitivity 96.1%, AUC-ROC 0.958), while Class III showed slightly lower sensitivity (88.9%) but maintained high specificity (93.9%).

3.4 Agreement Between Digital and Clinical Assessment

Agreement analysis revealed excellent concordance between digital screening and clinical examination across multiple parameters. Overall agreement for Angle's classification was 87.4% (n=535/612), with Cohen's kappa of 0.847 (95% CI: 0.812–0.882), indicating almost perfect agreement.

Table 2: Agreement Between Digital Screening and Clinical Examination

Parameter	Agreement %	Cohen's Kappa (95% CI)	Interpretation
Angle's Classification (overall)	87.4%	0.847 (0.812–0.882)	Almost Perfect
Normal vs Malocclusion	92.8%	0.867 (0.828–0.906)	Almost Perfect
Class I Identification	89.2%	0.734 (0.678–0.790)	Substantial
Class II Identification	91.5%	0.823 (0.772–0.874)	Almost Perfect
Class III Identification	93.8%	0.789 (0.718–0.860)	Substantial
DAI Severity Category	84.6%	0.792 (0.751–0.833)	Substantial
Crossbite Detection	90.4%	0.812 (0.756–0.868)	Almost Perfect
Crowding Presence	88.7%	0.778 (0.728–0.828)	Substantial

Bland-Altman analysis for continuous measurements demonstrated mean differences of 0.23mm (95% limits of agreement: -0.87 to 1.33mm) for overjet and 0.18mm (95% limits of agreement: -0.72 to 1.08mm) for overbite, indicating clinically acceptable agreement.

3.5 Screening Efficiency and DAI Severity Detection

Digital screening demonstrated significantly reduced examination time compared to conventional clinical assessment. Mean digital screening time was 4.23±1.12 minutes versus 12.67±3.45 minutes for clinical examination (mean difference: 8.44 minutes; 95% CI: 7.98–8.90; $p<0.001$).

Detection accuracy improved with increasing malocclusion severity, with handicapping malocclusion (DAI≥36) demonstrating highest sensitivity.

Table 3: Digital Screening Performance by DAI Severity Category

DAI Category	Clinical n (%)	Digital n (%)	Sensitivity %	Specificity %	Correct Classification %
Normal/Minor (≤25)	237 (38.7%)	224 (36.6%)	86.5%	91.2%	89.4%
Definite (26–30)	162 (26.5%)	158 (25.8%)	81.5%	88.7%	85.8%
Severe (31–35)	130 (21.2%)	134 (21.9%)	90.8%	92.3%	91.7%

DAI Category	Clinical n (%)	Digital n (%)	Sensitivity %	Specificity %	Correct Classification %
Handicapping (≥36)	83 (13.6%)	86 (14.1%)	97.6%	94.5%	95.4%
Overall	-	-	-	-	89.7%

The detection of severe and handicapping malocclusion requiring treatment demonstrated combined sensitivity of 93.4% and specificity of 93.8%, indicating excellent performance for identifying cases requiring orthodontic intervention.

Mean DAI scores showed strong correlation between digital (23.87±8.45) and clinical (24.12±8.67) assessments (Pearson r=0.934, p<0.001; ICC=0.928, 95% CI: 0.912–0.942).

4.Discussion

This diagnostic accuracy study demonstrated that digital orthodontic screening tools incorporating intraoral scanning and automated analysis software achieved excellent performance for early malocclusion detection in adolescents, with overall sensitivity of 94.2%, specificity of 89.5%, and AUC-ROC of 0.943. These findings support the potential integration of digital screening methodologies into adolescent oral health programs for timely identification of orthodontic treatment needs.

The observed diagnostic accuracy exceeds minimum thresholds recommended for screening instruments and compares favorably with reported performance of other digital diagnostic tools in dentistry [18]. Our AUC-ROC of 0.943 indicates excellent discriminative capacity, approaching accuracy levels achieved by experienced orthodontists while offering significant efficiency advantages [19]. The high negative predictive value (88.2%) is particularly important for screening applications, ensuring that adolescents without significant malocclusion are appropriately reassured while minimizing false-negative results that could delay necessary treatment [20].

Pattern-specific analysis revealed differential detection accuracy across Angle's classifications, with Class II Division 1 malocclusion demonstrating highest sensitivity (96.1%) and AUC-ROC (0.958). This superior performance likely reflects the distinctive morphological features of Class II Division 1 malocclusion, including increased overjet and characteristic incisor relationships, which are readily quantifiable through digital measurements [21]. The slightly lower sensitivity for Class III malocclusion (88.9%) may relate to the heterogeneity of this classification, encompassing both dental and skeletal components that may be incompletely captured by intraoral scanning alone [22].

The excellent agreement between digital and clinical assessments (Cohen's kappa=0.847) validates the reliability of automated analysis algorithms for orthodontic classification [23]. This agreement level exceeds inter-examiner reliability commonly reported for conventional clinical assessment and suggests that digital screening may reduce examiner-dependent variability inherent in traditional methods [24]. The standardization offered by digital protocols addresses longstanding concerns regarding reproducibility of orthodontic screening in diverse clinical settings [25].

The substantial time efficiency advantage of digital screening (4.23 versus 12.67 minutes) has important implications for implementation feasibility, particularly in resource-constrained settings or large-scale screening programs [26]. The threefold reduction in examination time translates to significantly increased throughput capacity, potentially enabling integration of orthodontic screening into routine dental visits or school health assessments without substantial disruption to existing workflows [27]. Furthermore, reduced examination time may improve adolescent cooperation and acceptance, particularly for individuals with dental anxiety or limited attention capacity [28].

The graduated accuracy corresponding to malocclusion severity, with handicapping malocclusion detected at 97.6% sensitivity, suggests that digital screening effectively prioritizes cases requiring immediate intervention [29]. From a public health perspective, this performance characteristic ensures that adolescents with the greatest treatment needs are identified with high reliability, facilitating appropriate referral and resource allocation [30]. The slightly lower sensitivity for mild malocclusion categories (86.5% for DAI≤25) is clinically acceptable given that these cases typically require only monitoring rather than immediate treatment [31].

The strong correlation between digital and clinical DAI scores (r=0.934) supports the validity of automated severity quantification for treatment planning purposes [32]. Accurate DAI calculation enables standardized treatment need assessment according to established criteria, facilitating communication between screening personnel, general dentists, and orthodontic specialists [33]. The digital generation of permanent records also supports longitudinal monitoring of malocclusion progression during the adolescent growth period [34].

Our findings align with emerging evidence supporting artificial intelligence applications in orthodontic diagnosis, while extending previous research by evaluating an integrated screening system encompassing multiple malocclusion parameters [35]. The machine learning algorithms underlying the automated analysis have demonstrated improved accuracy through training on extensive case databases, suggesting continued performance enhancement as digital orthodontic datasets expand [36].

Several limitations warrant consideration. The cross-sectional design precluded evaluation of longitudinal screening accuracy or treatment outcome prediction. The study population was drawn from an urban metropolitan area, potentially limiting generalizability to rural or underserved populations with different malocclusion prevalence patterns. The reference standard of clinical examination, while performed by calibrated specialists, represents an imperfect gold standard subject to inherent measurement variability [37].

Clinical implementation considerations include equipment costs, operator training requirements, and integration with existing dental informatics systems. While initial capital investment for intraoral scanning equipment may be substantial, the efficiency gains and reduced personnel requirements may offset costs over time, particularly in high-volume screening contexts [38]. Future research should incorporate cost-effectiveness analyses and evaluate implementation outcomes in real-world screening programs.

5.Conclusion

This study demonstrated that digital orthodontic screening tools utilizing intraoral scanning with automated analysis software achieve excellent diagnostic accuracy for early malocclusion detection in adolescents. Overall sensitivity of 94.2%, specificity of 89.5%, and AUC-ROC of 0.943 indicate performance suitable for clinical screening applications, while almost perfect agreement with specialist clinical examination (kappa=0.847) validates classification reliability.

Digital screening offers substantial efficiency advantages, with threefold reduction in examination time compared to conventional assessment, facilitating integration into routine dental care or school-based health programs. Detection accuracy increases with malocclusion severity, ensuring reliable identification of cases requiring orthodontic intervention while appropriately classifying milder presentations.

The findings support implementation of digital orthodontic screening tools for early malocclusion detection during adolescence, enabling timely specialist referral and intervention during optimal growth periods. Integration of such technologies into systematic screening programs may improve orthodontic treatment access, reduce treatment complexity through earlier intervention, and ultimately enhance oral health outcomes for adolescent populations.

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