EFFECTIVENESS OF DIGITAL DIAGNOSTIC METHODS IN EARLY DETECTION OF ORTHODONTIC PATHOLOGIES

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ABSTRACT

Digital diagnostic technologies have revolutionised the field of orthodontics, offering unprecedented precision and efficiency in early detection of dentofacial anomalies. This scientific thesis evaluates the effectiveness of contemporary digital diagnostic methods for early orthodontic pathology identification in paediatric populations. The research synthesises current evidence regarding intraoral scanning, three-dimensional facial imaging, cone-beam computed tomography, and artificial intelligence-based diagnostic tools. Digital dental models demonstrate high reproducibility with standard errors below 0.15 mm for linear displacements and 0.43 degrees for angular changes, supporting their clinical utility in treatment planning and assessment [Cureus, 2024, p. 2]. Smartphone-based three-dimensional facial scanning applications show accuracy comparable to conventional scanners (mean error 1.53-1.62 mm) with significantly reduced scanning times, offering cost-effective alternatives for orthodontic documentation [JODDD, 2025, p. 2]. Artificial intelligence-driven systems for automated cephalometric analysis and skeletal maturity assessment demonstrate improved diagnostic consistency and reduced interpretive variability compared to manual methods [KAO, 2025, p. 1]. Deep learning networks utilising anatomical priors achieve prediction errors of 1.021 degrees for craniofacial growth patterns, enabling dynamic and personalised orthodontic interventions [BMC Oral Health, 2025, p. 2]. The findings underscore that digital diagnostic methods significantly enhance early detection accuracy, reduce radiation exposure when appropriately applied, and facilitate timely interceptive orthodontic treatment.

Keywords: digital orthodontics, early diagnosis, artificial intelligence, three-dimensional imaging, paediatric dentistry, cephalometric analysis

INTRODUCTION

The digital transformation of orthodontics has fundamentally altered diagnostic paradigms, shifting from traditional two-dimensional analysis to comprehensive three-dimensional assessment of craniofacial structures. Digital technology in three dimensions has transformed orthodontic diagnosis, extending beyond hard tissue imaging to enable visualisation of facial soft tissues through advanced scanning technologies [JODDD, 2025, p. 1]. These innovations have various applications in diagnosis, treatment planning, assessment of treatment changes, and patient communication [JODDD, 2025, p. 1].

Early detection of orthodontic pathologies is critical for successful interceptive treatment, as skeletal malocclusion, once established in early childhood, rarely self-corrects during development [BMC Oral Health, 2025, p. 3]. Predicting craniofacial growth patterns and initiating timely and effective treatment is crucial to enhancing orthodontic outcomes [BMC Oral Health, 2025, p. 3]. However, making those predictions is inherently complex because of genetic and environmental influences and individual growth variations [BMC Oral Health, 2025, p. 3].

Contemporary digital diagnostic methods encompass intraoral scanning, three-dimensional facial imaging, cone-beam computed tomography, and artificial intelligence-based analysis tools. These technologies offer distinct advantages including absence of radiation exposure (in the case of optical scanning), elimination of metal artifacts, and the ability to generate high-resolution three-dimensional models [Cureus, 2024, p. 1]. This thesis aims to evaluate the effectiveness of these digital diagnostic methods for early orthodontic pathology detection and their clinical applicability in paediatric populations.

MAIN PART

Three-Dimensional Imaging and Digital Dental Models

Digital dental models have become indispensable tools for orthodontic diagnosis and treatment evaluation. A comparative study evaluating tooth movement analysis using digital dental models with reference to the palatal region of interest demonstrated high levels of reproducibility, with minimal standard errors in X, Y, and Z displacements below 0.15 mm and 0.43 degrees in angular change [Cureus, 2024, p. 2]. The study concluded that the palatal region, focusing on the third palatal rugae and the horizontal part of the palatal vault, serves as a reliable reference region for evaluating three-dimensional tooth movement [Cureus, 2024, p. 2].

The clinical significance of digital dental models lies in their distinct advantages, including the absence of X-ray exposure, no metal artifacts, and the ability to generate high-resolution three-dimensional models [Cureus, 2024, p. 2]. The methodology demonstrated high precision and reproducibility, supporting its potential clinical utility in orthodontic treatment planning and assessment [Cureus, 2024, p. 2].

Smartphone-Based Facial Scanning

Recent innovations in smartphone technology have transformed diagnostic capabilities in orthodontics, with mobile applications serving as potential diagnostic tools. A cross-sectional study analysing the accuracy of smartphone-based face scanners compared to a standard CBCT-based facial scanner found that smartphone-based applications showed overall accuracy comparable to the conventional scanner [JODDD, 2025, p. 2]. The smartphone application SureScan 3D demonstrated the lowest mean error at 1.53 ± 0.24 mm, while another application showed 1.62 ± 0.38 mm [JODDD, 2025, p. 2].

In region-based superimposition, the cheeks and forehead showed high reproducibility, followed by the nose with moderate and the perioral area with poor reproducibility [JODDD, 2025, p. 2]. Significant differences in scanning duration were observed, with the smartphone application having the shortest scanning time at 52.80 ± 4.17 seconds [JODDD, 2025, p. 2]. Notably, 93.3% of orthodontists viewed facial scans as a substitute for photographs, though 53.3% still preferred photographs [JODDD, 2025, p. 2]. The study concluded that smartphone face scanning applications offer accuracy comparable to standard scanners with reduced scanning times, providing a cost-efficient and reliable alternative to traditional scanners for orthodontic documentation [JODDD, 2025, p. 2].

Cone Beam Computed Tomography in Paediatric Orthodontics

Cone beam computed tomography enables high-quality three-dimensional visualisation of dentofacial structures, improving detection of impacted teeth, root morphology, alveolar bone volume, and airway analysis [Ovid, 2025, p. 2]. A retrospective study investigating CBCT utilisation in paediatric dentistry at major university centres analysed 260 paediatric cases and found that the primary reasons for CBCT scans included impacted teeth (40%), endodontic treatments (19.6%), and orthodontic assessments (15.8%) [Springer, 2025, p. 2].

The study revealed significant usage patterns across age groups, with patients aged 6-12 years more often referred for endodontic issues, while those aged 13-18 years required imaging for impactions and orthodontics [Springer, 2025, p. 2]. Various fields of view were utilised, with the 8 × 8 field of view being the most prevalent (56.15%), while orthodontic indications were associated with larger fields of view [Springer, 2025, p. 3].

Radiation protection principles remain paramount when performing CBCT in children. Because children experience faster cell division during growth, they are two to ten times more susceptible to ionising radiation compared to adults [Springer, 2025, p. 2]. Therefore, it is crucial to modify the radiation dose according to the child's age and body weight, minimise unnecessary repeat imaging, and ensure that the procedure is warranted by appropriate clinical indications [Springer, 2025, p. 2].

Artificial Intelligence in Orthodontic Diagnostics

Artificial intelligence has emerged as a revolutionary technology with several applications across orthodontic practice, including assisting diagnostic processes, enhancing orthodontic diagnosis by automating cephalometric tracing, and estimating growth and development [PMC, 2024, p. 1]. AI enhances orthodontics through automated cephalometric landmark identification, growth prediction models, and treatment outcome prediction tools [Ovid, 2025, p. 2].

A significant advancement in this field is the development of deep learning networks for predicting skeletal malocclusion patterns. The Skel-Net system, an anatomic prior-guided deep learning network, was developed to estimate ANB angle changes over five years in children and adolescents aged 8-16 [BMC Oral Health, 2025, p. 2]. The system outperformed other models with the lowest prediction errors (mean absolute error: 1.021 degrees; root mean squared error: 1.338 degrees), demonstrating robust predictive capabilities [BMC Oral Health, 2025, p. 2]. By leveraging anatomic priors and longitudinal data, this framework enables dynamic and personalised predictions of craniofacial growth, facilitating early and precise orthodontic interventions [BMC Oral Health, 2025, p. 2].

The evaluation of skeletal maturity, essential for orthodontic diagnosis and treatment planning in growing patients, has also benefited from AI applications. A deep learning-based hybrid system has been developed using hand-wrist radiographs, combining multiple assessment methods into a unified framework [KAO, 2025, p. 1]. This model not only improves diagnostic consistency and orthodontic applicability but also illustrates the growing potential of AI-driven tools in the future of digital orthodontics [KAO, 2025, p. 1].

AI Applications in Paediatric Dentistry

A comprehensive scoping review of AI in paediatric dentistry identified promising results in several applications: assisting the diagnostic and recognition processes of early signs of dental pathologies, enhancing orthodontic diagnosis by automating cephalometric tracing and estimating growth and development, and assisting and educating children to develop appropriate behaviour for dental hygiene [PMC, 2024, p. 3]. The use of AI algorithms and machine learning techniques has shown promising results in daily dental paediatric practice [PMC, 2024, p. 3].

In cephalometric analysis, computer-assisted tracing improves accuracy and efficiency compared to manual methods, with AI-driven automated tracing achieving high success rates, reducing errors and enhancing time efficiency in orthodontic procedures [PMC, 2024, p. 1].

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