Current Aspects in Orthodontic Diagnosis

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Abstract
Orthodontic diagnostics have evolved significantly, moving from a traditional focus on hard tissue relationships to a more inclusive approach that considers both hard and soft tissues. Originally based on the Angle paradigm, which emphasized ideal dental occlusion, the field now recognizes the importance of soft tissue evaluation. Modern diagnostics incorporate various records, such as dental casts, photographs, radiographs, and clinical measurements. Technological advancements have introduced tools like digitized dental models, virtual dental setups, and intraoral scanners, which improve the accuracy of treatment outcomes. Additionally, three-dimensional (3D) facial imaging and advanced imaging technologies like multi-slice computed tomography (MSCT) and cone-beam computed tomography (CBCT) have enhanced diagnostic precision. While traditional two-dimensional (2D) records remain common, artificial intelligence (AI), especially convolutional neural networks (CNNs), has shown potential for diagnostic accuracy comparable to human examiners, particularly in cephalometric X-ray analysis. These advancements provide efficient and reliable diagnostic methods, improving treatment planning and decision-making in orthodontics.

Keywords: Digitized dental models, Virtual dental setups, Intraoral scanners, 3D facial imaging, Multi-slice computed tomography (MSCT), Cone-beam computed tomography (CBCT), Two-dimensional (2D) records, Artificial intelligence (AI), Convolutional neural networks (CNNs)

INTRODUCTION

In the field of orthodontics, diagnosis is the foundational process, akin to the art of distinguishing one condition from another.[1] Traditional diagnosis focused heavily on hard tissue relationships and adhered to the Angle paradigm, which deemed ideal dental occlusion as "nature's intended ideal form”.[2] As orthodontics evolved, there emerged a growing recognition of the critical role of soft tissue evaluation in Diagnosis and treatment planning. Clinicians began integrating soft tissue assessment alongside hard tissue analysis, marking a pivotal shift towards a more holistic diagnostic approach.[3] For accurate diagnosis of hard and soft tissues, various diagnostic tools have been used includes various records such as dental casts, intra- and extra-oral photographs, different radiographic images, and clinical measurements.[4]

Recent technological advancements have revolutionized orthodontic diagnosis, offering new methods for both hard and soft tissue analysis. Innovations such as digitized dental model[5], virtual dental set-ups[6], and intraoral scanners (IOSs)[7] simulate anticipated orthodontic outcomes, while three-dimensional (3D) facial imaging enhances soft tissue visualization for comprehensive diagnosis and treatment planning. Tools like multi-slice computed tomography (MSCT)[8] and lower dose Cone-Beam Computed Tomography (CBCT)[9] have improved diagnostic precision. Although conventional two-dimensional (2D) records[4] remain prevalent, these new technologies enable more individualized record selection. Artificial Intelligence (AI)[10] applications, especially those utilizing Convolutional Neural Networks (CNNs), have shown promise in achieving diagnostic accuracy comparable to human examiners, particularly in cephalometric X-ray analysis.[11] These digital diagnostic techniques, which have evolved significantly over the past decade, offer reliable and fast methods that can match the efficiency of experienced clinicians, thereby enhancing diagnosis, treatment planning, and decision making.

CURRENT ADVANCED DIAGNOSIS PROCESS VS CONVENTIONAL DIAGNOSIS PROCESS IN ORTHODONTICS

The current advanced diagnosis process in orthodontics utilizes state-of-the-art methods and tools to improve treatment planning and outcomes. Key advancements include cloud-based 3D data storage, allowing remote access[12] and analysis of patient information, and neural networks that use deep learning algorithms[13] to predict outcomes based on input data. Orthodontists can enhance these predictions by updating the network with treatment results, fostering continuous learning and refinement. This iterative process results in more precise treatment planning and superior patient outcomes compared to traditional diagnostic methods.

RECENT ADVANCES IN DIAGNOSTIC AIDS USED IN ORTHODONTIC DIAGNOSIS ARE:

1. Digital Photography
2. 3D and 4D Imaging
3. 3D Radiography
4. Intraoral scanners and Digital dental models
5. Artifcial Intelligence (AI), Machine learning and data mining.

DENTAL PHOTOGRAPHY IN ORTHODONTIC DIAGNOSIS: TRADITIONAL VS. DIGITAL APPROACHES

In orthodontics, where precision is crucial, photography has become an essential tool for diagnosis, treatment planning, and patient documentation.[14] From its inception in the 1800s to its modern application, photography has significantly evolved.

The transition from traditional chemical film to electronic digital sensor changed the essence of photography[15] and has following advantages:

- **Accurate Representation:** 3D photography captures volumetric data of the face and dentition, providing a precise depiction of three-dimensional structures and asymmetries.
- **Enhanced Diagnostic Capabilities:** It improves assessment of dental alignment, soft tissue balance, and facial aesthetics, leading to more comprehensive Diagnosis and treatment planning.
- **Digital Storage and Archiving:** 3D images are stored digitally, reducing physical storage needs and enhancing record access.
- **Precise Analysis:** Software programs enable detailed analysis with features like zooming and rotation, improving diagnostic accuracy.
- **Noninvasive and Radiation-Free:** 3D photography is noninvasive and radiation-free, useful for tracking soft tissue changes and evaluating outcomes, especially in complex cases.
- **Detailed 3D Models:** It allows creation of detailed models for better understanding of craniofacial anatomy and improved treatment planning.

Application of Digital Photography[12]**:** Digital photography, including Digital Smile Design (DSD), enhances orthodontic diagnosis and has the following applications:

- **Smile Enhancement:** DSD uses 2D photos and advanced software like Digital Smile Design (DSD) software with the integration of cutting-edge technologies like iTero, 3Shape, and others[16] to visualize optimal tooth positioning in 3D, improving communication, diagnosis and treatment planning.
- **3D Facial Analysis:** DSD software places markers on facial photos to assess symmetry and guide treatment. Horizontal and vertical guidelines help evaluate facial symmetry.
- **3D Dental Analysis:** Digital tools align teeth based on facial aesthetics, using software like Invisalign and SureSmile and OnyxCeph[17.] This approach integrates facial information for accurate 3D design.
- **Converting 2D to 3D:** 2D images are transformed into (pseudo) 3D models using software like DSD CONNECT, G DESIGN[16] aiding in treatment planning and verification of design parameters.

Digital Imaging and Communications in Medicine (DICOM)[18]**:** DICOM, developed by ACR and NEMA, standardizes medical image transfer and data management. It supports diagnosis, treatment planning, and provides a 3D record of malocclusion and treatment outcomes.

3D TO 4D IMAGING FOR ORTHODONTIC DIAGNOSIS

The use of two-dimensional (2D) imaging technology, including cephalometric and panoramic radiographs and photographs has been common in orthodontics. However, these methods have limitations. They often suffer from radiographic projection errors, distortion, and enlargement, as well as exposure to radiation. Landmark identification can be challenging, leading to inaccuracies in measurements. Additionally, assessing soft tissue balance is restricted with 2D imaging.[19]

3D and 4D imaging in orthodontics are:

A) Conventional computed and cone-beam computerized tomography (CT/CBCT)
B) 3D Laser Scanning
C) Stereophotogrammetry
D) Magnetic Resonance Imaging
NEW DIMENSION- 4D AND ITS APPLICATIONS
E) 4D Imaging and Video Stereophotogrammetry
D) Ultrasonography

CONVENTIONAL COMPUTED AND CONE-BEAM COMPUTERIZED TOMOGRAPHY (CT/CBCT)

CT (Computerized Axial Tomography) technology has revolutionized medical imaging by providing three-dimensional views of anatomical structures through cross-sectional images. It offers valuable information on both hard and soft tissues, making it a powerful tool in various medical fields, including orthodontics. Traditional fan beam tomography, while effective, is associated with high radiation doses and expense, limiting its practicality for routine orthodontic applications.[20] In response to these limitations, CBCT was introduced as an alternative imaging modality. CBCT offers several advantages over traditional CT , including lower cost and radiation dose, while still providing detailed 3D visualization of craniofacial structures.[21] As a result, CBCT has become increasingly popular in orthodontic practice, enabling more accurate diagnosis, treatment planning, and assessment of treatment outcomes.[22]

Uses of CBCT in orthodontics[19]

CBCT can be used for several approaches in orthodontic patients.

- Enhances diagnosis such as identification of the location of impacted and supernumerary
- teeth.
- Quantifies the magnitude of the defect such as in patients with CLP.
- Improves differential diagnosis of malocclusions such as craniofacial anomalies and syndromes.
- Determination whether the discrepancy is uni- or bilateral is required such as facial asymmetry especially for patients with orthognathic surgery.
- Helps to identify the etiology of the malocclusion such as TMJ disorders.
- Determination of the quality and quantity of bone and the anatomical structures
- Determination of alveolar boundary conditions is needed.
- 3D airway morphology is needed especially for the therapy of obstructive sleep apnea.

3D LASER SCANNING

Laser scanning offers a non-invasive approach for capturing facial morphology and soft tissue. Laser scanning has accuracy in producing 3D facial models while being less expensive and easy to handle compared to other techniques.[23]

Applications of Laser Scanning[19]:

- 3D analysis of facial morphology
- Evaluation of facial symmetry
- Assessment of cross-sectional growth changes
- Evaluation of treatment and surgical outcomes
- Assessment of patients with cleft lip palate (CLP)
- Examination of soft tissue landmarks
- Scanning of dental casts
- Reliability and Measurement Accuracy

Laser scanning, along with stereophotogrammetry, is a reliable soft tissue imaging system, with a maximum measurement error of less than 1mm

STEREOPHOTOGRAMMETRY

Stereophotogrammetry is a technique involves photographing objects with a pair of configured cameras , used to create 3D models of objects or subjects by analyzing multiple 2D images taken from different angles.[24]

Uses of stereophotogrammetry in diagnosis

- Stereophotogrammetry captures intricate details of facial morphology, including the shape and contours of soft tissues
- provides accurate preoperative assessments. Surgeons can analyze the 3D facial model to plan the exact adjustments needed to achieve facial harmony and functional improvements.
- allows for detailed evaluation of facial deformities in cleft lip and palate, facilitating personalized treatment plans tailored to each patient's unique anatomy and needs.

MAGNETIC RESONANCE IMAGING (MRI)

- MRI provides accurate and detailed information about craniofacial abnormalities and disorders, particularly in the temporomandibular joint (TMJ).[25]
- used to assess the tongue size and volume correctly
- valuable for studying velopharyngeal function[26], especially in patients with cleft palate[27], allowing measurement of airway space, motion, and function to determine velopharyngeal incompetence.

ULTRASONOGRAPHY[28]

In orthodontics, ultrasonography (USG) is gaining traction as a complementary diagnostic tool to traditional radiographic techniques, providing additional information while addressing radiation exposure concerns. It is valuable for assessing structural changes in masticatory muscles, reliably quantifying muscle thickness and cross-sectional area, particularly in the masseter muscle, aiding orthodontic diagnosis and treatment planning.

Ultrasonography enables visualization of the TMJ dynamics, including disc position, condylar movement, and joint morphology. It can aid in diagnosing TMJ disorders and also useful for assessing tongue volume, posture, and movement dynamics during swallowing and speech. It can also visualize hyoid bone displacement, providing insights into oropharyngeal function and airway patency

INTRAORAL SCANNING AND DIGITAL MODELS IN ORTHODONTICS

Intraoral scanning and digital models revolutionized orthodontic diagnosis and treatment planning by eliminating the discomfort, inaccuracies, and complexities of traditional impressions.[29] Introduced with CAD/CAM technology in 1971 and advanced by systems like CEREC[30] and OrthoCAD[31], digital scanning offers precise, comfortable, and allergy-free alternatives, particularly benefiting young children and those with gag reflexes.

INTRAORAL SCANNERS (IOSs)[32]

Intraoral scanners (IOS) are noninvasive devices that capture optical impressions of dental arches and tissues by projecting light onto them. Imaging sensor cameras capture these images, which are processed into 3D surface models of the teeth and tissues. The resulting 3D image, displayed digitally rather than as traditional stone or plaster models, is stored in STL (Standard Tessellation Language) file format and can be transferred globally.

Commercially Available Intraoral Scanners[33]

TRIOS Classic and TRIOS 3 Mono Intraoral Scanner by 3Shape, Copenhagen, Denmark

- LAVA C.O.S. by 3M ESPE, St. Paul, MN, USA
- CEREC Omnicam by Sirona Dental Systems, Bensheim, Germany
- iOC intraoral scanner by Cadent, Carlstadt, NJ, USA
- CS3600 Carestream by Dental, Rochester, NY, USA
- iTero Element intraoral scan by Align Technologies, San Jose, CA, USA(Fig.42.)
- Lythos by Ormco, Orange, CA, USA
- 3 Shape R700 3D Scanner; 3 Shape A/S, Copenhagen, Denmark.

Advantages of Intraoral Scanners[34]

Intraoral scanners offer several advantages over traditional impression-taking methods in orthodontics like Accurate Digital Impressions and offers highly accurate digital impressions, improving patient comfort and eliminating the need for physical storage, facilitate easy electronic data transfer and immediate access, enhancing efficiency and streamlining orthodontic practices.

DIGITAL MODELS[35]

Traditional plaster study models, essential for orthodontic diagnosis and treatment, have limitations such as susceptibility to breakage, cumbersome storage, and high costs for transport and duplication. Digital models address these issues by offering durability, reducing storage needs, and facilitating easy data transfer and sharing. This makes digital models a more efficient and cost-effective alternative to plaster models in orthodontic practice.

Various computer-based three-dimensional models:

- SureSmile (OraMetrix Inc, Dallas, Tex)
- OrthoCAD (Cadent Inc, Carlstadt, NJ)
- E-Models (GeoDigm Corporation Inc, Chanhassen, Minn)
- OrthoProof USA digital models

Digital models offer durability, ease of storage, remote accessibility, and easy sharing, while being cost-efficient and enhancing patient engagement. They also support environmental sustainability and provide high accuracy in capturing dental anatomy.

Intraoral scanners and digital models have revolutionized orthodontic diagnosis by providing precise measurements of parameters like arch width, tooth size, and occlusal relationships, enhancing treatment accuracy.[33] Digital models enable detailed assessments of tooth alignment, arch form, and discrepancies, using specialized software for comprehensive analysis and improved treatment planning.[36] Intraoral scanners enhance orthodontic diagnosis by integrating data on dental classification, overjet, and overbite into digital models, allowing for personalized treatment plans. They improve communication with patients through digital simulations of proposed treatments, offer additional diagnostic insights like root shape and bone density, and enable virtual setups for detailed case presentations, aesthetic predictions, and optimized treatment planning.[37]

ARTIFICIAL INTELLIGENCE (AI)

Artificial intelligence (AI) is a new breakthrough in technological advancements based on the concept of simulating human intelligence. These emerging technologies highly influence the diagnostic process in the field of medical sciences, with enhanced accuracy in diagnosis.[38]

1. **AI Models**[5,39]:
   - **Machine Learning (ML):** AI models use ML algorithms trained on large datasets for predictive accuracy, often without human intervention.
   - **Deep Learning:** A subset of ML using neural networks with multiple layers, including:
     - Artificial Neural Networks (ANNs): Consist of interconnected layers of neurons for complex data processing.
     - Convolutional Neural Networks (CNNs): Specialized for image analysis, using convolutional and pooling layers to extract and process features.
2. **Applications in Orthodontic Diagnosis:**
   - **Facial and Intraoral Photographs**[10]: AI analyzes images to identify malocclusions, facial asymmetries, and other issues, improving diagnostic accuracy and treatment planning.

- **Cephalometric Analysis[40]**: AI automates landmark identification and measurement on cephalometric images, enhancing accuracy and reducing analysis time. In orthodontics, the adoption of AI has led to the creation of various AI-based programs, such as: WeDoCeph (Audax, Ljubljana, Slovenia), WebCeph (Assemble Circle, Seoul, Republic of Korea), CephX (ORCA Dental AI, Las Vegas, NV, USA)[40] .
- **Cone Beam Computed Tomography (CBCT)[10]:** AI algorithms, such as random forest algorithm and deep convolutional neural networks (CNNs), have been developed to automate the segmentation process, demonstrating high accuracy and efficiency compared to manual methods. Therefore AI improves segmentation and landmark identification in CBCT scans, increasing efficiency and accuracy. Companies like Materialize, Relu and Diagnocat have recently introduced AI-based segmentation and registration tools for CBCT.
- **Digital Dental Models[10]**: AI assists in tooth segmentation and landmark localization in digital models, improving diagnostic precision and reducing human error.
- **Skeletal Age Determination1[41]:** AI enhances skeletal maturity assessments using cervical vertebral maturation (CVM) or wrist X-rays, offering more reliable evaluations.
- **TMJ Evaluation[40]:** AI systems can conduct automated, detailed assessments of joint morphology, potentially enabling early. Integrating AI algorithms capable of detecting changes across all TMJ structures could significantly enhance the accuracy and effectiveness of TMJ diagnosis like temporomandibular joint osteoarthritis (TMJOA).
- Biomarker Analysis[40]: AI combines imaging and biomarker data to predict temporomandibular joint osteoarthritis (TMJOA), enhancing early detection and patient outcomes.

3. AI and Genomics[42]:

- AI processes vast genomic data, identifying genetic variations and predicting pathogenicity.
- Deep learning models accurately identify and predict the effects of genetic variants.
- AI predicts the functional impacts of noncoding variants and enhancer regions.
- AI analyzes gene expression data for insights into gene regulation and disease mechanisms.
- AI detects DNA binding sites and methylation changes, impacting gene expression regulation.

AI advancements are transforming orthodontics through improved diagnostic accuracy, efficiency, and personalization, while also addressing practical challenges and integrating with genomics for precision medicine.

CONCLUSION

Technological advancements have significantly transformed orthodontic diagnosis, marking a departure from traditional methods that relied heavily on hard tissue analysis. Modern diagnostic approaches now integrate both hard and soft tissue evaluations, utilizing tools such as digitized dental models, intraoral scanners, 3D and 4D imaging, and AI.

Digital innovations, including advanced imaging techniques like CBCT and laser scanning, provide detailed and accurate assessments of craniofacial structures, improving diagnosis and treatment planning. AI further enhances diagnostic precision through machine learning algorithms and neural networks, optimizing treatment outcomes and integrating with genomics for personalized care.

The evolution from conventional methods to advanced digital and AI-driven approaches has led to more accurate, efficient, and personalized orthodontic care, streamlining workflows and enhancing patient outcomes. As technology continues to advance, orthodontic practice is poised to benefit from ongoing innovations, paving the way for even more precise and effective treatments in the future.

RECENT APPLICATIONS AND SOFTWARES USED FOR ORTHODONTIC DAIGNOSIS

1. MOBILE APPLICATIONS FOR CEPHALOMETRIC TRACING

S No	Mobile Applications	Developer Company Name
1.	OneCeph (v Beta 9)	NXS
2.	CephNinja S or Pro (v 3.66)	Cyncronus LLC
3.	Cephalometric analysis	Bogdan SCANTEIE
4.	Orthonet	Bogdan SCANTEIE
5.	Cephalometria de Ricketts	CR Education
6.	Cephalometria de Steiner	CR Education
7.	Cephalometria de Ricketts 2	CR Education
8.	EasyCeph (v 3.2)	Dr KTSS Rajajee
9.	CEPH App	Technocenter Orthokinetor
10.	WebCeph	Assemble circle

2. DIGITAL SMILE DESIGN SOFTWARES

S No.	Digital smile design softwares	Developer Company Nam
1.	Photoshop CS6	Adobe Systems Incorporated
2.	Keynote	iWork, Apple, Cupertino, California, USA
3.	Aesthetic Digital Smile Design	ADSD- Dr. Valerio Bini
4.	Cerec SW 4.2	Sirona Dental Systems Inc.
5.	Smile Designer Pro (SDP)	Tasty Tech Ltd.
6.	Planmeca Romexis Smile Design (PRSD)	Planmeca Romexis
7.	VisagiSMile	Web Motion Ltd.
8.	DSS	EGSolution
9.	Microsoft PowerPoint	Microsoft Office, Microsoft, Redmond, Washington, USA
10.	DSD App	DSDApp LLC by Coachman
11.	Guided Positioning System (GPS)	Navstar GPS,USA
12.	NemoDSD (3D)	NEOTech,Chatsworth, CA
13.	Exocad	DentalCAD 2.3, Spain
14.	Smilecloud, ADN3D biotech	ADN3D biotech

3. INTRAORAL SCANNERS

S No.	INTRAORAL SCANNERS	Developer Company Name
1.	CEREC Omnicam	Sirona Dental Systems, Bensheim, Germany
2.	Carestream CS 3700	Dental, Rochester, NY, USA
3.	CEREC Primescan	Sirona Dental Systems, Bensheim, Germany
4.	Medit i500	Medit, Seoul, South Korea
5.	iTero element 5d	Align Technologies, San Jose, CA, USA
6.	Virtuo Vivo	Dental Wings,Straumann AG
7.	TRIOS Classic and TRIOS 3 and TRIOS 4	3Shape, Copenhagen, Denmark
8.	True Definition Scanner	3M ESPE, St. Paul, MN, USA
9.	CondorScan	Condor Technologies NV, Ghent, Belgium
10.	Planmeca Emerald S and Planmeca Romexis	Planmeca OY, Finland
11.	LAVA C.O.S	3M ESPE, St. Paul, MN, USA
12.	3 Shape R700	3 Shape A/S, Copenhagen, Denmark
13.	Lythos	Ormco, Orange, CA, USA
14.	iOC intraoral scanner	Cadent, Carlstadt, NJ, USA

4. COMPUTER-BASED THREE-DIMENSIONAL MODELS

S No.	Computer-based three-dimensional models	Developer Company Name
1.	SureSmile	OraMetrix Inc, Dallas, Tex
2.	OrthoCAD (Cadent Inc, Carlstadt, NJ)	Cadent Inc, Carlstadt, NJ
3.	E-Models	GeoDigm Corporation Inc, Chanhassen, Minn)
4.	OrthoProof	USA digital models

5. AI-BASED ORTHODONTIC DIAGNOSTIC SOFTWARES

S No.	AI-based orthodontic diagnostic softwares	Developer Company Name
1.	Dental Monitoring (DM)	2023 Dental Monitoring, Paris
2.	Invisalign Virtual Care AI	Align Technology, Inc,USA

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