Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 18s (2025)
https://www.jneonatalsurg.com

The Impact of 3D Imaging on Orthodontic Diagnosis and Treatment Planning: A Systematic Literature Review

Anju Yadav[1], Jatin Gupta[2], Rashmi Rukshana[3], Vishaka Yadav[4], Khushbu Kumari[5], Jyotsana[6]

[1]Senior Lecturer, Department of Orthodontics & Dentofacial Orthopaedics, Eklavya Dental College & Hospital, Jaipur, Rajasthan, India, anjuyadav24@gmail.com

[2]Consultant orthodontist, Bahadurgarh, Haryana, India, jatin4gupta@gmail.com

[3]Senior Lecturer, Department of Orthodontics & Dentofacial Orthopaedics, Ragas Dental College & Hospital, Chennai, Tamil Nadu, India, dr.rashmisuja@gmail.com

[4]Post Graduate, Department of Oral Medicine, Diagnosis & Radiology, Faculty of Dental Sciences, PDM University, Bahadurgarh, Haryana, India, dr.vishakhayadav03@gmail.com

[5]Post Graduate, Department of Orthodontics & Dentofacial Orthopaedics, Faculty of Dental Sciences, PDM University, Bahadurgarh, Haryana, India, khushbukumari10197@gmail.com

[6]Post Graduate, Department of Oral Medicine, Diagnosis & Radiology, Faculty of Dental Sciences, PDM University, Bahadurgarh, Haryana, India, prem.ib.bwn@gmail.com

Corresponding author: Anju Yadav

anjuyadav24@gmail.com

Cite this paper as: Anju Yadav, Jatin Gupta, Rashmi Rukshana, Vishaka Yadav, Khushbu Kumari, Jyotsana, (2025) The Impact of 3D Imaging on Orthodontic Diagnosis and Treatment Planning: A Systematic Literature Review. *Journal of Neonatal Surgery*, 14 (18s), 869-876.

ABSTRACT

The introduction of three-dimensional (3D) imaging in orthodontics has significantly transformed diagnosis, treatment planning, and patient care. Traditional two-dimensional (2D) imaging techniques, such as X-rays and cephalometric radiographs, provide limited insight into the complex 3D structures of the craniofacial region. Recent advancements in 3D imaging technologies like Cone Beam Computed Tomography (CBCT), 3D facial scanning, and digital models have provided more accurate and detailed visualizations, leading to improved orthodontic practices.

Objective

This systematic literature review aims to evaluate the applications, advantages, limitations, and clinical impacts of 3D imaging technologies in orthodontics. The review synthesizes findings from multiple studies to provide an in-depth analysis of the role of 3D imaging in enhancing diagnostic accuracy and treatment planning.

Methods

A comprehensive search of peer-reviewed articles was conducted using databases such as PubMed, Scopus, and Web of Science. The inclusion criteria focused on clinical trials, observational studies, and systematic reviews published between 2000 and 2024, involving human subjects and discussing 3D imaging in orthodontic applications. A total of 8 studies were selected for inclusion based on relevance and quality.

Results

The review highlights the significant benefits of 3D imaging, including improved diagnostic precision, detailed visualization of craniofacial structures, and more accurate treatment planning. CBCT has become particularly valuable in diagnosing complex cases, while 3D facial scanning and digital models have enhanced clear aligner therapy. Despite these advancements, challenges remain, including the high cost of equipment, radiation exposure concerns, and the need for specialized software and training.

Conclusion

3D imaging technologies have revolutionized orthodontics, offering enhanced diagnostic tools, better treatment outcomes, and personalized care. However, barriers to widespread adoption, such as cost and radiation exposure, need to be addressed. Future research should focus on optimizing these technologies for broader accessibility and improving patient safety.

Keywords: 3D Imaging, CBCT, Digital Models, Diagnosis, Orthodontics, Patient Outcomes, Radiation Exposure, Treatment Planning.

1. INTRODUCTION

The field of orthodontics has seen significant advancements in recent decades, primarily driven by technological innovations [1]. One of the most transformative developments has been the introduction of three-dimensional (3D) imaging. Traditional 2D imaging modalities, such as X-rays and cephalometric radiographs, have long been essential for diagnosis and treatment planning in orthodontics. However, these methods are inherently limited in providing a comprehensive and accurate representation of the complex three-dimensional structures of the craniofacial region [2]. The advent of 3D imaging technologies, such as cone beam computed tomography (CBCT), 3D facial scanning, and digital models, has revolutionized the way orthodontists diagnose, plan, and monitor treatment [3].

In recent years, 3D imaging has been lauded for its potential to provide more precise, accurate, and detailed visualizations of the craniofacial anatomy, facilitating better decision-making and improving patient outcomes [4]. Unlike traditional 2D imaging, which presents a flattened view of the anatomy, 3D imaging allows for the visualization of structures from multiple angles and perspectives, helping clinicians assess and diagnose more effectively [5]. As a result, 3D imaging has not only enhanced diagnostic accuracy but has also become indispensable in complex treatment planning, including surgical orthodontics and clear aligners [6].

Despite its advantages, integrating 3D imaging into routine orthodontic practice remains an area of ongoing exploration. The cost, radiation exposure, and the need for specialized equipment and software can present significant barriers to widespread adoption [7]. Furthermore, while 3D imaging has been shown to improve the precision of orthodontic treatment planning, its impact on clinical outcomes, treatment duration, and overall effectiveness is still under investigation. Consequently, a comprehensive review of the current literature on 3D imaging in orthodontics is essential to understand its applications, challenges, and future prospects [8].

This systematic literature review aims to thoroughly examine the role of 3D imaging in orthodontics, with a particular focus on its applications, advantages, limitations, and clinical impact. By analyzing and synthesizing existing studies, this review seeks to offer a critical evaluation of the evidence supporting the use of 3D imaging in orthodontic diagnosis and treatment planning. Moreover, it aims to identify gaps in the current research, highlight areas for future investigation, and provide recommendations for clinical practice. The history of orthodontic imaging can be traced back to the early 20th century, with the introduction of the cephalometric radiograph in the 1930s [9]. This 2D imaging technique allowed orthodontists to study the craniofacial skeleton and its growth patterns, providing invaluable insights into orthodontic diagnosis and treatment planning. However, while cephalometric radiographs remain widely used, they offer limited information about the three-dimensional morphology of the head and face. Additionally, the inherent distortion in 2D imaging can potentially lead to diagnostic errors, which can affect treatment outcomes [10, 11].

The evolution of imaging technology in orthodontics took a significant leap forward with the advent of computed tomography (CT) in the late 20th century. CT scanning provided a three-dimensional view of the craniofacial anatomy, but its high radiation dose and expense made it impractical for routine use in orthodontics [12]. In response to these limitations, CBCT development emerged as a game-changer. CBCT offers a 3D view with lower radiation exposure and cost than traditional CT, making it a viable option for orthodontic practice. Since its introduction in the early 2000s, CBCT has become one of the most widely used imaging techniques in orthodontics, particularly for complex cases requiring surgical intervention [13].

In addition to CBCT, other 3D imaging technologies have gained prominence, including 3D facial scanning, which creates a digital model of the patient's face, and intraoral scanning, which generates 3D models of the teeth and oral cavity [14]. These technologies have significantly expanded the range of diagnostic and treatment options available to orthodontists, particularly in areas such as clear aligner therapy, where precise digital modeling is crucial for treatment success [15, 16]. The primary advantage of 3D imaging in orthodontics is its ability to provide a comprehensive and accurate view of the craniofacial anatomy. This has profound implications for both diagnosis and treatment planning. One of the most significant applications of 3D imaging is in the assessment of skeletal and dental relationships [17]. Traditional 2D radiographs provide limited information about the spatial relationships between the teeth, bones, and soft tissues. In contrast, 3D imaging offers a more detailed and accurate representation of these relationships, allowing for more precise diagnosis and treatment planning [18].

3D imaging also plays a crucial role in designing and implementing clear aligner therapy. In contrast to traditional methods of creating orthodontic appliances, which relied on physical impressions, digital scanning allows for creating highly accurate 3D models of the patient's teeth [19]. These digital models can be used to plan treatment more precisely, simulate tooth movements, and design customized aligners. Furthermore, 3D imaging facilitates the monitoring of treatment progress by allowing orthodontists to compare pre-treatment and post-treatment digital models, providing valuable feedback on the effectiveness of the aligners [20].

Despite its many advantages, using 3D imaging in orthodontics is not without challenges. One of the primary concerns is the cost of acquiring and maintaining the necessary equipment. CBCT machines, 3D facial scanners, and intraoral scanners represent significant financial investments for orthodontic practices, and their maintenance requires specialized knowledge and skills. The software cost for image processing and analysis also adds to the economic burden [21, 22]. Another challenge is radiation exposure. While CBCT offers lower radiation than traditional CT scans, it still carries some risk, particularly in pediatric patients who may be more sensitive to radiation. Consequently, orthodontists must weigh the benefits of 3D imaging against the potential risks and use these technologies judiciously, particularly in cases where 2D imaging may be sufficient [23, 24].

2. METHODOLOGY

This systematic literature review aims to evaluate the applications, advantages, limitations, and clinical impacts of 3D imaging technologies in orthodontics by synthesizing findings from eight relevant studies. The methodology for this review follows established guidelines for systematic reviews, ensuring a structured, transparent, and reproducible process for selecting, analyzing, and interpreting the included studies.

3. SEARCH STRATEGY

The literature search was conducted to identify peer-reviewed articles, clinical studies, and research papers relevant to 3D imaging in orthodontics. The search was performed across multiple databases, including PubMed, Scopus, Web of Science, and Google Scholar, to capture a wide range of studies. The following key terms and phrases were used in the search:

- "3D imaging in orthodontics"
- "Cone beam computed tomography (CBCT) in orthodontics"
- "3D facial scanning orthodontics"
- "Orthodontic digital models"
- "Impact of 3D imaging on orthodontic treatment planning"
- "Advantages of 3D imaging in orthodontics"
- "Limitations of CBCT in orthodontics"

The search was limited to studies published between 2000 and 2024 to capture the most recent advancements in 3D imaging technologies. No language restrictions were applied, and only studies published in peer-reviewed journals were considered. Studies that were not directly related to orthodontics or did not focus on 3D imaging applications were excluded.

4. INCLUSION AND EXCLUSION CRITERIA

The inclusion and exclusion criteria for selecting studies were defined to ensure the relevance and quality of the literature included in the review.

Inclusion Criteria:

- **Study Type:** Clinical trials, observational studies, randomized controlled trials (RCTs), case studies, and systematic reviews.
- **Participants:** Studies involving human subjects, including both pediatric and adult orthodontic patients.
- **Technology Focus:** Studies focusing on 3D imaging technologies, including CBCT, 3D facial scanning, and digital models in orthodontics.
- **Publication Date:** Studies published from 2000 to 2024.
- **Relevance:** Studies that addressed the applications, advantages, limitations, and clinical impact of 3D imaging in orthodontics, particularly in diagnosis, treatment planning, and outcome prediction.

Exclusion Criteria:

- **Non-Clinical Studies:** Studies not involving human participants, such as animal studies or in vitro research.
- **Non-Orthodontic Focus:** Studies that do not focus on orthodontic applications of 3D imaging.
- **Non-3D Imaging Studies:** Studies that primarily focus on 2D imaging techniques or do not discuss 3D imaging technologies.
- **Language Limitations:** Studies not published in English or those with inaccessible abstracts.

5. STUDY SELECTION PROCESS

The study selection process followed a rigorous, multi-step approach to ensure that only the most relevant studies were included in the review. The steps are as follows:

1. **Initial Search:** The initial search yielded a total of 45 articles from the selected databases.

2. **Screening of Titles and Abstracts:** The titles and abstracts of the retrieved articles were screened for relevance based on the inclusion and exclusion criteria. This process resulted in the elimination of 20 articles that were not relevant or did not meet the criteria.
3. **Full-Text Review:** The remaining 25 articles were reviewed in full to determine if they met the inclusion criteria. This step led to the exclusion of 15 studies due to reasons such as a focus on non-orthodontic applications, lack of focus on 3D imaging, or insufficient information.
4. **Final Selection:** After the full-text review, 8 studies were selected for inclusion in the review, as they met all the inclusion criteria and provided significant insights into the

Data Extraction

Data were extracted from the selected studies to address key themes related to the use of 3D imaging in orthodontics. The following information was collected for each study:

- **Study Details:** Author(s), year of publication, study design, and sample size
- **Objectives:** The main aim or research question addressed by the study
- **Technology Focus:** The type of 3D imaging technology used (e.g., CBCT, 3D facial scanning, digital models)
- **Applications:** The specific orthodontic applications of 3D imaging discussed in the study (e.g., diagnosis, treatment planning, clear aligners, surgical orthodontics)
- **Advantages:** Key benefits identified, such as improved diagnostic accuracy, better treatment planning, and enhanced patient outcomes.
- **Limitations:** Any drawbacks or challenges identified, such as cost, radiation exposure, or equipment limitations.
- **Findings:** The main results and conclusions of the study regarding the effectiveness of 3D imaging in orthodontic practice.

Quality Assessment

The quality of the included studies was assessed using a standardized tool, such as the Critical Appraisal Skills Programme (CASP) checklist or the Cochrane Risk of Bias tool, depending on the study design. The assessment focused on the following aspects:

- **Study Design:** Was the study design appropriate for answering the research question? Was there a transparent methodology?
- **Sample Size and Population:** Was the sample size sufficient to ensure the reliability of the results? Were the participants' representatives of the broader orthodontic patient population?
- **Bias and Confounding Factors:** Were any potential biases identified, such as selection bias, measurement bias, or reporting bias?
- **Data Analysis:** Was the data analysis appropriate and robust? Were statistical methods used appropriately to analyze the results?

Each study was rated for quality, and studies with a high risk of bias were noted, while studies with a lower risk were given more weight in the synthesis.

6. SYNTHESIS OF FINDINGS

The studies' results were synthesized narratively and thematically. The synthesis focused on identifying common themes, trends, and disparities in the findings related to the advantages, applications, limitations, and clinical impacts of 3D imaging in orthodontics. The studies were compared and contrasted to draw broader conclusions regarding the utility and effectiveness of 3D imaging technologies.

PRISMA Flowchart of the study is shown in **Figure 1**.

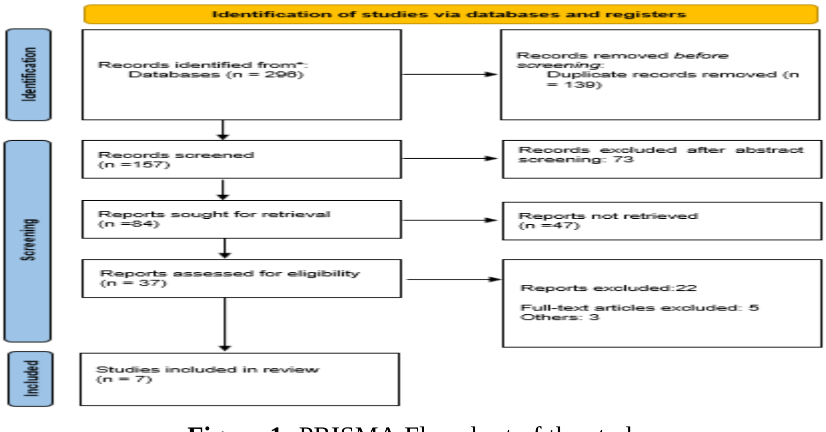

Figure 1: PRISMA Flowchart of the study

Review

3D imaging technology has revolutionized the field of orthodontics, offering significant advantages over traditional 2D imaging techniques. Integrating 3D imaging, particularly through methods such as CBCT, 3D facial scanning, and intraoral scanning, has provided orthodontists with more accurate, detailed, and comprehensive insights into craniofacial anatomy. These advancements enable better diagnostic accuracy, more precise treatment planning, and improved patient outcomes [25, 26].

CBCT, in particular, has become an invaluable tool in orthodontics, offering high-resolution, three-dimensional images with reduced radiation exposure compared to traditional CT scans [27]. It allows for detailed visualization of bone structures, soft tissues, and the positional relationships between teeth, making it ideal for diagnosing complex cases such as impacted teeth or craniofacial anomalies. This level of precision has greatly enhanced treatment planning, especially in surgical orthodontics, where accurate pre-operative imaging is essential [28]. Additionally, the ability to manipulate 3D images and view them from multiple angles provides a clearer understanding of the patient's anatomy, aiding orthodontists in making informed decisions [29]. **Table 1** depicts studies highlight how 3D imaging, especially CBCT, enhances orthodontic diagnosis, treatment planning, precision, and integration with emerging technologies.

Table 1: Literature Review of the study

3D facial scanning and digital models have similarly enhanced the precision of orthodontic treatments. These technologies enable the creation of highly accurate virtual representations of a patient's teeth and facial structures, which can be used to plan orthodontic treatments, design customized appliances, and monitor treatment progress over time [37]. Clear aligner therapy, in particular, has benefited from these advancements, as digital models allow orthodontists to simulate tooth movements and design aligners tailored to each patient's unique needs [38].

However, the adoption of 3D imaging in orthodontics has its challenges. The high cost of equipment and software remains a significant barrier for many practices, particularly in smaller or less technologically advanced settings [39]. Furthermore, while CBCT offers lower radiation than traditional CT scans, concerns about radiation exposure persist, especially in pediatric patients. As such, 3D imaging must be carefully considered, particularly when simpler 2D imaging methods may suffice [40].

3D imaging technologies have undeniably transformed orthodontic practice, providing better diagnostic and treatment planning tools that enhance patient care. Despite the challenges related to cost and radiation exposure, the benefits of these technologies make them a valuable asset in modern orthodontics. Future advancements may further improve accessibility, reduce costs, and enhance the safety of these imaging techniques, ensuring broader adoption and continued positive impact on patient outcomes.

7. DISCUSSION

The integration of 3D imaging in orthodontics has marked a significant advancement in the field, offering numerous benefits over traditional 2D imaging techniques. As highlighted in several studies, 3D imaging modalities such as CBCT and digital three-dimensional image fusion have transformed orthodontic diagnosis, treatment planning, and outcomes [41].

One of the key contributions of 3D imaging is its ability to provide precise, high-resolution visualizations of dental and skeletal structures. Its detailed 3D representation of the craniofacial anatomy allows orthodontists to assess better skeletal relationships, malocclusions, and even soft tissue, which are not easily discernible in traditional 2D radiographs [42].

Moreover, 3D imaging facilitates the use of digital treatment planning software, which enhances the customization of orthodontic appliances. According to authors, integrating 3D imaging with technologies like CAD/CAM allows orthodontists to create patient-specific aligners and brackets, thus improving treatment efficiency and reducing the need for frequent adjustments [43]. This digital approach streamlines the treatment process and contributes to more predictable outcomes. As a result, patients experience shorter treatment times and fewer clinical visits, increasing patient satisfaction [44].

While the benefits of 3D imaging in orthodontics are evident, addressing some challenges is essential. The cost of CBCT equipment and radiation exposure concerns remain a consideration in its widespread adoption. However, studies like that of Cattaneo and Melsen (2008) demonstrate that the long-term clinical benefits outweigh these concerns, especially considering improved accuracy and reduced treatment errors [45].

8. FUTURE AIMS AND SCOPE

The future of 3D imaging in orthodontics holds vast potential for continued advancements in diagnostic precision, treatment planning, and patient care. With the integration of artificial intelligence (AI) and machine learning (ML), orthodontists can automate and optimize treatment planning, enhancing accuracy and efficiency [46]. Personalized and predictive orthodontics will emerge, allowing for dynamic treatment plans that simulate and predict treatment outcomes with higher precision. Reducing radiation exposure, particularly for pediatric patients, will be a key focus, with developments in low-dose or radiation-free 3D imaging technologies [47]. Real-time 3D imaging during procedures, such as surgeries or aligner fittings, will enable immediate adjustments, further improving treatment outcomes. As the role of 3D imaging in orthognathic surgery grows, its ability to guide precise surgical interventions will lead to better recovery times and reduced complications [48]. Additionally, with decreasing costs, 3D imaging will become more accessible, expanding its use globally, particularly in developing regions, and making high-quality orthodontic care available to a broader population. Collaboration with other medical fields will also become more common, allowing for comprehensive, multidisciplinary care in complex cases. Overall, the future of 3D imaging in orthodontics is marked by enhanced customization, greater efficiency, and improved patient satisfaction [49, 50].

9. CONCLUSION

In conclusion, 3D imaging has revolutionized orthodontics by enhancing diagnostic accuracy, improving treatment planning, and reducing treatment time. As technology continues to evolve, it is expected that 3D imaging will play an increasingly central role in orthodontic practice, further shaping the future of patient care.

CONFLICTS OF INTEREST: Nil
FINANCIAL SUPPORT: Nil

REFERENCES

[1] Kashwani R, Ahuja G, Narula V, Jose AT, Kulkarni V, Hajong R, et al. Controversies around Orthodontic Treatment and TMD Etiologies. Dent Pract J. 2024;6(2):180092.

[2] Karatas OH, Toy E. Three-dimensional imaging techniques: A literature review. Eur J Dent. 2014; 8(1):132–40.

[3] Abdelkarim A. Cone-Beam Computed Tomography in Orthodontics. Dent J (Basel). 2019; 7(3):89.

[4] Venkatesh E, Elluru SV. Cone beam computed tomography: basics and applications in dentistry. J Istanb Univ Fac Dent. 2017; 51(3 Suppl 1):S102–21.

[5] Kenkare P, Shetty S, Mangal U, Ashith MV, Shetty S. The Utilization of Three-Dimensional Technology for an Accurate Diagnosis and Precise Treatment Planning in the Field of Orthodontics. Biomed Pharmacol J. 2021; 14(4).

[6] Palomo JM, Yang C, Hans MG. Clinical Application of Three-Dimensional Craniofacial Imaging in Orthodontics. J Med Sci. 2005:269–78.

[7] Lane C, Harrell W Jr. Completing the 3-dimensional picture. Am J Orthod Dentofacial Orthop. 2008; 133(4):612–20.

[8] Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the conebeam technique: preliminary results. Eur Radiol. 1998; 8(9):1558–64.

[9] Botticelli S, Verna C, Cattaneo PM, Heidmann J, Melsen B. Two- versus three-dimensional imaging in subjects with unerupted maxillary canines. Eur J Orthod. 2011; 33(4):344–9.

[10] Toureno L, Park JH, Cederberg RA, Hwang EH, Shin JW. Identification of supernumerary teeth in 2D and 3D: review of literature and a proposal. J Dent Educ. 2013; 77(1):43–50.

[11] Oberoi S, Gill P, Chigurupati R, Hoffman WY, Hatcher DC, Vargervik K. Three-dimensional assessment of the eruption path of the canine in individuals with bone-grafted alveolar clefts using cone beam computed tomography. Cleft Palate Craniofac J. 2010; 47(5):507–12.

[12] Wadhawan R, Dhir G, Borah MJ, Patil MS, Yadav P, Soni D. The digital dentition: 3D printing's impact on orthodontic care. Nanotechnol Percept. 2024; 20(S16):e3867.

[13] Meehan M, Teschner M, Girod S. Three-dimensional simulation and prediction of craniofacial surgery. Orthod Craniofac Res. 2003; 6:102–7.

[14] Kim YK, Lee NK, Moon SW, Jang MJ, Kim HS, Yun PY. Evaluation of soft tissue changes around the lips after bracket debonding using three-dimensional stereophotogrammetry. Angle Orthod. 2015; 85(5):833–40.

[15] Ayoub AF, Siebert P, Moos KF, Wray D, Urquhart C, Niblett TB. A vision based 3D capture system for maxillofacial assessment and surgical planning. Br J Oral Maxillofac Surg. 1998; 36(5):353–7.

[16] Coban G, Yavuz I, Karadas B, Demirbas AE. Three-dimensional assessment of nasal changes after maxillary advancement with impaction using stereophotogrammetry. Korean J Orthod. 2020; 50(4):249–57.

[17] Hall RK. The role of CT, MRI and 3D imaging in the diagnosis of temporomandibular joint and other orofacial disorders in children. Aust Orthod J. 1994; 13(2):86–94.

[18] Mah J, Hatcher D. Current status and future needs in craniofacial imaging. Orthod Craniofac Res. 2003; 6(Suppl 1):10–6.

[19] Hajeer MY, Ayoub AF, Millett DT, Bock M, Siebert JP. Three-dimensional imaging in orthognathic surgery: the clinical application of a new method. Int J Adult Orthodon Orthognath Surg. 2002; 17(4):318–30.

[20] Aboul-Hosn Centenero S, Hernández-Alfaro F. 3D planning in orthognathic surgery: CAD/CAM surgical splints and prediction of the soft and hard tissues results–our experience in 16 cases. J Craniomaxillofac Surg. 2012; 40(2):162–8.

[21] Lane C, Harrell W Jr. Completing the 3-dimensional picture. Am J Orthod Dentofac Orthop. 2008; 133(4):612–20.

[22] Scholz RP. Considerations in selecting a digital camera for orthodontic records. Am J Orthod Dentofac Orthop. 1998; 114(5):603–5.

[23] Smith SL, Throckmorton GS. A new technique for three-dimensional ultrasound scanning of facial tissues. J Forensic Sci. 2004; 49(3):451–7.

[24] Kau CH, Richmond S, Incrapera A, English J, Xia JJ. Three-dimensional surface acquisition systems for the study of facial morphology and their application to maxillofacial surgery. Int J Med Robot. 2007; 3(2):97–110.

[25] Zhang GX, Zhao ZH, Wang BY, Xu LJ, Feng GC, Qian WY. The application of multi-slice CT and MRI on maxillofacial region soft tissue measurement. Shanghai J Stomatol. 2010;19(5):460–3.

[26] Hwang HS, Kim K, Moon DN, Kim JH, Wilkinson C. Reproducibility of facial soft tissue thicknesses for craniofacial reconstruction using cone-beam CT images. J Forensic Sci. 2012; 57(2):443–8.

[27] Tomášik J, Zsoldos M, Oravcová Ľ, Lifková M, Pavleová G, Strunga M, et al. AI and Face-Driven Orthodontics: A Scoping Review of Digital Advances in Diagnosis and Treatment Planning. AI. 2024; 5(1):158–176.

[28] Ma L, Yu S, Xu X, Moses Amadi S, Zhang J, Wang Z. Application of Artificial Intelligence in 3D Printing Physical Organ Models. Mater Today Bio. 2023; 23:100792.

[29] Tsolakis IA, Gizani S, Panayi N, Antonopoulos G, Tsolakis AI. Three-Dimensional Printing Technology in Orthodontics for Dental Models: A Systematic Review. Children. 2022; 9(8):1106.

[30] Cattaneo PM, Melsen B. The use of cone-beam computed tomography in an orthodontic department in between research and daily clinic. World J Orthod. 2008;9(3):269–82.

[31] Jyothikiran H, Shanthara JR, Subbiah P, Thomas M. Craniofacial imaging in orthodontics--past present and future. Int J Orthod Milwaukee. 2014; 25(1):21–6.

[32] Plooij JM, Maal TJ, Haers P, Borstlap WA, Kuijpers-Jagtman AM, Bergé SJ. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery: A systematic review. Int J Oral Maxillofac Surg. 2011; 40(4):341–52.

[33] Erten O, Yılmaz BN. Three-Dimensional Imaging in Orthodontics. Turk J Orthod. 2018; 31(3):86–94.

[34] Thawri SR, Paul P, Reche A, Rathi HP. 3D Technology Used for Precision in Orthodontics. Cureus. 2023;15(10):e47170.

[35] Polizzi A, Serra S, Leonardi R. Use of CBCT in Orthodontics: A Scoping Review. J Clin Med. 2024; 13(22):6941.

[36] Kashwani R, Ahuja G, Narula V, Jose AT, Kulkarni V, Hajong R, et al. Future of dental care: integrating AI, metaverse, AR/VR, teledentistry, CAD & 3D printing, blockchain and CRISPR innovations. Community Pract. 2024; 21(6):123–37.

[37] Savková N, Harvan Ľ, Jusku A, Saygili S, Jezdinská K, Hulvert J. Summary of Knowledge About 3D Printing and Its Use in Dentistry. ČSPZL. 2021;121(2):55–64.

[38] Jeong M, Radomski K, Lopez D, Liu JT, Lee JD, Lee SJ. Materials and Applications of 3D Printing Technology in Dentistry: An Overview. Dent J. 2023;12(1):1.

[39] Guerrero-Gironés J, López-García S, Pecci-Lloret MR, Pecci-Lloret MP, Rodríguez Lozano FJ, García-Bernal D. In Vitro Biocompatibility Testing of 3D Printing and Conventional Resins for Occlusal Devices. J Dent. 2022;123:104163.

[40] Wuersching SN, Hickel R, Edelhoff D, Kollmuss M. Initial Biocompatibility of Novel Resins for 3D Printed Fixed Dental Prostheses. Dent Mater. 2022;38(10):1587–97.

[41] Del Hougne M, Di Lorenzo I, Höhne C, Schmitter M. A retrospective cohort study on 3D printed temporary crowns. Sci Rep. 2024;14(1):17295.

[42] Knode V, Ludwig B, Hamadeh S, Pandis N, Fleming PS. An In Vitro Comparison of the Dimensional Stability of Four 3D-Printed Models Under Various Storage Conditions. Angle Orthod. 2024; 94(3):346–52.

[43] Lo LJ, Weng JL, Ho CT, Lin HH. Three-dimensional region-based study on the relationship between soft and hard tissue changes after orthognathic surgery in patients with prognathism. PLoS One. 2018; 13(8):e0200589.

[44] Slaymaker J, Hirani S, Woolley J. Direct 3D Printing Aligners—Past, Present and Future Possibilities. Br Dent J. 2024; 236(5):401–5.

[45] Cattaneo PM, Dalstra M, Melsen B. Moment-to-force ratio, center of rotation, and force level: a finite element study predicting their interdependency for simulated orthodontic loading regimens. Am J Orthod Dentofacial Orthop. 2008; 133(5):681–9.

[46] Kashwani R, Sawhney H. Dentistry and metaverse: A deep dive into potential of blockchain, NFTs, and crypto in healthcare. Int Dent J Stud Res. 2023; 11(3):94–8.

[47] Kashwani R, Jose AT, Gambhir S, Virk S, Roy S. The role of the metaverse in revolutionizing dental practice: implications across all departments. Int Dent J Stud Res. 2024; 12(3):157–60.

[48] Suresh A, Naidu SN, Inginshetty V. ENDO AI: A Novel Artificial Intelligence Framework for Predicting Treatment Outcomes in Endodontic Therapy. J Med Dent Sci Res. 2025; 12(2):12–19.

[49] Naidu S, Suresh A. Evolution of orthodontic appliances—Then and now. Int J Dent Health Sci. 2018; 3:319–29.

[50] Sawhney H, Salam S, Singh S, Kashwani R, Sonawane A, Gupta S, et al. Kap assessment for exploring quick response code integration in teleradiography, diagnosis, and digital imaging. Commun Pract J Commun Pract Health Visitors' Assoc. 2024; 21(4):1450–7.