

Clinical Maturity of Digital Orthodontic Technologies - A Critical Narrative Review

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Abstract

Objective: To critically compare the clinical maturity of major digital technologies in orthodontics and distinguish applications ready for routine use from those requiring further validation.

Materials and Methods: A targeted Pub Med search identified peer-reviewed English-language publications from 2018 through 2025 addressing intraoral scanners (IOS), cone-beam computed tomography (CBCT), computer-aided design and computer - aided manufacturing (CAD/ CAM), three - dimensional (3D) printing, artificial intelligence (AI), and integrated digital workflows. Systematic reviews, meta-analyses, clinical investigations, diagnostic-accuracy studies, and selected technical or feasibility reports were synthesized narratively. Evidence was interpreted according to clinical applicability, external validation, reproducibility, safety, patient-centered benefit, and implementation readiness.

Results: IOS demonstrated high clinical maturity for routine orthodontic record acquisition, whereas CBCT was clinically mature for selected, justified indications. CAD/CAM was established for customized appliance design and fabrication, although evidence of patient-level superiority remained application-specific. The maturity of 3D printing varied by application: printed models were comparatively established for orthodontic model production, whereas directly printed definitive appliances remained transitional. AI had its most consistently supported evidence for clinician-supervised image-analysis applications, while treatment-planning applications remained less mature. Integrated digital workflows demonstrated feasibility across several applications, but comparative effectiveness and long-term patient-centered benefits remained incompletely established.

Conclusion: Digital orthodontic technologies demonstrate a continuum of clinical maturity, and technical performance should not be equated with

clinically meaningful benefit. Future research should prioritize multicenter prospective studies, standardized clinically meaningful outcomes, interoperability, cost-effectiveness, robust governance, and appropriate clinician oversight.

Keywords: Artificial Intelligence, CAD/ CAM, Cone - Beam Computed Tomography, Digital Orthodontics, Intraoral Scanning, Three - Dimensional Printing, Workflow

Introduction

Digital orthodontics now extends from electronic records to interconnected systems for data acquisition, three-dimensional diagnosis, virtual planning, customized appliance production, and treatment monitoring. Intraoral scanners (IOS), cone-beam computed tomography (CBCT), computer-aided design and computer-aided manufacturing (CAD/ CAM), three-dimensional (3D) printing, and artificial intelligence (AI) increasingly contribute patient-specific data across an integrated clinical pathway.^{1,4}

The evidence supporting these technologies is uneven. Some applications have entered routine practice with consistent evidence of accuracy, reproducibility, safety, and clinical utility, whereas others rely primarily on laboratory studies, retrospective validation, technical reports, or small feasibility investigations. A recurring interpretive problem is the assumption that technical precision necessarily translates into improved treatment effectiveness. Scanner trueness, landmark-detection accuracy, or manufacturing precision does not itself establish improvements in treatment stability, quality of life, safety, or cost-effectiveness.

Previous reviews have commonly focused on individual digital technologies or specific applications. A cross-technology appraisal using a common clinical

perspective may therefore help distinguish technological capability from evidence supporting routine clinical use. This critical narrative review evaluates the clinical maturity of IOS, CBCT, CAD/CAM, 3D printing, AI, and integrated digital workflows according to clinical evidence, external validation, reproducibility, safety, implementation readiness, patient-centered benefit, and suitability for routine orthodontic practice. Particular emphasis is placed on distinguishing established from transitional applications and identifying evidence gaps relevant to clinical implementation.

Materials and Methods

A targeted literature search of Pub Med was conducted for peer-reviewed English-language publications from January 2018 through December 2025. Search concepts included digital orthodontics, intraoral scanning, cone-beam computed tomography, CAD/CAM, additive manufacturing, three-dimensional printing, artificial intelligence, machine learning, virtual treatment planning, and digital work flow, used in combinations relevant to orthodontic applications. Additional potentially relevant publications were identified by examining the reference lists of included papers and pertinent reviews.

Eligible evidence included systematic reviews, meta-analyses, scoping reviews, randomized and non randomized clinical studies, prospective and retrospective observational studies, diagnostic-accuracy investigations, and selected technical or feasibility reports directly relevant to orthodontic practice. Publications addressing unrelated dental applications and duplicate reports were excluded. Evidence was organized into six domains: IOS, CBCT, CAD/CAM, 3D printing, AI, and integrated digital workflows.

Clinical maturity was evaluated qualitatively according to the consistency and level of clinical evidence, external validation, reproducibility, safety, implementation readiness, patient-centered benefit, and suitability for routine orthodontic practice. The maturity classifications represented a qualitative interpretive framework for cross-technology comparison rather than a formally validated evidence-grading instrument or numerical scoring system. Accordingly, maturity descriptors were assigned through qualitative comparative synthesis across these dimensions and were not derived from prespecified numerical thresholds. Descriptors were application-specific rather than ordinal categories because maturity could differ substantially among applications within the same technology. Greater weight was assigned to systematic reviews, meta-analyses, multicenter investigations, and well-designed clinical studies than to technical, laboratory, or feasibility reports. Because this review was designed as a comparative narrative synthesis across heterogeneous technologies and applications, formal risk-of-bias appraisal, certainty grading, and quantitative meta-analysis were not undertaken.

Results

Intraoral Scanners

IOS has reached high clinical maturity for routine orthodontic record acquisition. Contemporary IOS systems provide digital models with clinically acceptable accuracy for many orthodontic applications, including diagnosis, virtual setup, appliance fabrication, indirect bonding, and longitudinal assessment.^{5,7} Systematic and critical reviews report favorable patient acceptance compared with conventional impressions, with practical advantages including avoidance of impression materials,

reduced gagging, and the ability to identify and correct incomplete scan areas.^{5,7}

Performance depends on scanner characteristics, scanning strategy, operator experience, intraoral conditions, patient movement, and arch complexity. Scanning trueness may decline as tooth-size arch-length deficiency increases, although reported deviations remained within clinically acceptable limits.⁸

Digital scanning is therefore a mature alternative to conventional impressions rather than a universally superior approach. Its principal practical advantages include patient experience, digital storage, rapid data transfer, and compatibility with planning and manufacturing platforms; evidence that IOS independently improves long-term treatment outcomes remains limited.

CBCT

CBCT is clinically mature for selected indications rather than routine screening. Its principal value lies in three-dimensional assessment of dento alveolar and craniofacial conditions, including impacted teeth and associated root resorption, craniofacial anomalies, and temporomandibular structures, when conventional imaging cannot adequately answer the clinical question.^{9,10} Systematic evidence supports indication-based prescription of CBCT, particularly when additional three-dimensional information is expected to influence diagnosis or treatment planning.⁹

Maturity in this domain is inseparable from radiation justification. When CBCT is clinically justified, acquisition should be restricted to the minimum field of view and radiation exposure needed to answer the specific diagnostic question.⁹ Routine CBCT-based airway screening is not supported because upper-airway assessment remains methodologically variable and

requires further validation to define the clinical questions that CBCT can reliably address.¹⁰ CBCT enables three-dimensional assessment of orthodontic ally induced external root resorption, but heterogeneity among studies and differences in assessment protocols limit the generalizability of the available evidence.¹¹

CAD/CAM

CAD/CAM provides a digital platform for designing and manufacturing customized orthodontic appliances and auxiliaries from virtual treatment plans.¹² Clinical studies support the feasibility of CAD/CAM-based customization across several orthodontic applications, although the magnitude and consistency of clinical benefit vary among interventions.¹² The maturity of the manufacturing process should therefore not be equated with consistent superiority in clinical outcomes.

Customized bracket systems generally achieve outcomes comparable to those of conventional fixed appliances. A meta-analysis suggests shorter overall treatment duration with customized CAD/CAM brackets, but the small and heterogeneous evidence base limits generalization.¹³ CAD/CAM fixed retainers show broadly comparable short-term stability and failure outcomes with conventional fixed retainers and may reduce plaque accumulation, but long-term durability remains uncertain.¹⁴ Randomized evidence has demonstrated the clinical feasibility of customized CAD/CAM appliances within selected treatment protocols, although findings from protocol-specific trials should not be generalized to CAD/CAM orthodontics as a whole.¹⁵

CAD/CAM is therefore clinically mature for customized appliance design and fabrication, whereas evidence of patient-level superiority remains limited and application-specific.

Three-Dimensional Printing

Additive manufacturing is increasingly used in orthodontics to fabricate study models, guides, transfer devices, and selected customized appliances. Post polymerization conditions can influence the degree of conversion of resins used for orthodontic appliances.¹⁶ The dimensional characteristics of 3D-printed models can vary with printing technology, layer height, and build orientation.¹⁷ These findings emphasize the need for standardized and validated manufacturing and post processing protocols.

Clinical maturity is application-specific. Printed models are comparatively established for orthodontic model production, whereas directly printed definitive appliances, particularly clear aligners, remain transitional. A systematic review describes directly 3D-printed clear aligners as a potentially viable alternative to thermoformed aligners, but the evidence base remains insufficient to establish their comparative clinical performance and long-term behavior.¹⁸ In-house design and 3D printing of customized brackets further demonstrate the technical feasibility of patient-specific appliance fabrication, although evidence of comparative clinical effectiveness remains limited.¹⁹

Artificial Intelligence

AI has a broad range of reported orthodontic applications, although its clinical maturity remains uneven. Reviews describe applications across image analysis, diagnosis, treatment planning, outcome prediction, and treatment monitoring.²⁰⁻²² The most consistently supported applications involve repetitive, well-defined image-analysis tasks.

Meta-analytic evidence suggests that automated cephalometric land marking attains clinically acceptable performance for many two-dimensional landmarks and

can markedly shorten analysis time. However, performance varies among landmarks and datasets, and evidence for three-dimensional applications is more heterogeneous.²³ A large multicenter study demonstrated strong automated landmark-localization performance following iterative development and refinement involving orthodontists.²⁴

Treatment-planning applications are less mature because performance is commonly evaluated against clinician-derived decisions or diagnostic reference standards rather than prospective patient outcomes.^{25,26}

Generative AI may assist with general orthodontic patient information, but variability in response quality and reliability limits its suitability for unsupervised individualized counseling.²⁷ Across AI applications, recurring limitations include heterogeneous and potentially unrepresentative datasets, limited external validation, restricted explain ability, risks of bias, data-privacy concerns, and a shortage of prospective clinical evaluation.^{21,22,26} Accordingly, current AI applications are most appropriately used as clinician-supervised adjuncts rather than autonomous substitutes for orthodontic judgment.^{22,26}

Integrated Digital Workflows and Comparative Maturity

Integration of surface, volumetric, and clinical data can create a more comprehensive virtual representation of the patient. IOS and CBCT data can be integrated to support three-dimensional visualization and anatomically informed planning, while virtual setups permit simulation and evaluation of planned tooth movement.^{28,29} Digital plans can subsequently be transferred to CAD/CAM or additive-manufacturing processes for the production of guides or appliances.

Integrated digital workflows have demonstrated feasibility across several applications, including combined orthodontic-orthognathic treatment,³⁰ guided orthodontic mini screw placement,^{31,32} pre surgical orthodontic palatal plates in cleft care,³³ customized mini-implant-assisted rapid palatal expansion,³⁴ and naso alveolar molding in infants with cleft lip and palate.³⁵ Stepwise accuracy studies demonstrate that deviations can arise at multiple stages of a digital workflow during transfer from virtual planning to clinical execution.^{31,32} Workflow performance also depends on reliable data transfer between platforms, software compatibility, operator training, and accurate translation of the virtual plan to the clinical setting.

The comparative synthesis is presented in Table 1. IOS demonstrates high clinical maturity for routine orthodontic record acquisition, whereas CBCT is clinically mature for selected, justified indications. CAD/CAM is established for customized appliance design and fabrication, although evidence of patient-level superiority remains application-specific. The maturity of 3D printing varies by application: printed models are comparatively established for orthodontic model production, whereas directly printed definitive appliances remain transitional. AI has its most consistently supported current role in clinician-supervised image analysis and related decision-support tasks. Integrated digital workflows are feasible across several applications, but their comparative effectiveness and long-term patient-centered benefits remain incompletely established.

Discussion

This review identifies a continuum of clinical maturity rather than a simple dichotomy between digital and conventional care. IOS and indication-based CBCT have

comparatively well-established clinical roles because their indications, performance characteristics, and limitations are comparatively well defined. CAD/CAM is established for selected customized design and manufacturing applications, whereas the maturity of 3D printing remains application-dependent: models and guides are comparatively established for their respective orthodontic applications, but directly printed definitive appliances require further validation. AI and fully integrated digital workflows remain less mature. AI is constrained particularly by heterogeneous datasets, restricted external validation, and limited prospective clinical evaluation, whereas complete digital workflows lack sufficient comparative evidence of long-term patient-centered benefit.

The central finding is that technical performance is an intermediate outcome. An accurate scan, segmentation, virtual treatment setup, or customized appliance does not necessarily translate into better occlusal outcomes, shorter treatment duration, greater stability, fewer adverse effects, greater patient satisfaction, or lower cost. Future investigations should clearly define where each technology influences the clinical pathway and evaluate both device-level performance and patient-level outcomes. Comparative studies should incorporate clinically meaningful outcomes, including treatment quality and duration, retreatment, adverse events, periodontal and root effects, stability, patient-reported experience, quality of life, and economic outcomes.

Successful implementation also requires systems-level evidence beyond individual device performance. Implementation considerations include standardized data formats, validated registration and transfer protocols, transparent software-version reporting, cyber security safeguards, and competency-based training. For AI,

progression toward greater clinical autonomy should be supported by multicenter external validation, assessment of subgroup performance and bias, clinically appropriate explain ability, data-privacy safeguards, prospective clinical evaluation, and continued clinician oversight. Radiation justification remains fundamental to appropriate CBCT use, whereas validated materials, post processing protocols, and manufacturing quality control remain important for 3D-printed appliances.

This review is limited by its narrative design, restriction to English-language literature identified primarily through Pub Med and supplementary reference-list screening, and the absence of formal risk-of-bias assessment or certainty – of - evidence grading. Consequently, relevant evidence indexed exclusively in other bibliographic databases may not have been identified. The qualitative clinical-maturity framework also reflects interpretive synthesis rather than a validated grading instrument. A strength of the review is the application of a common clinical perspective across technologies that are often evaluated separately, thereby distinguishing technical capability from evidence supporting routine clinical use.

Conclusion

- IOS is clinically mature for routine orthodontic record acquisition, whereas CBCT is established for carefully justified, patient-specific indications.
- CAD/CAM is established for selected customized design and manufacturing applications; 3D-printed models and guides are comparatively established for their respective orthodontic applications, whereas directly printed definitive appliances require further clinical and material validation.
- AI is most defensible for clinician-supervised image analysis and decision support; treatment-planning

applications remain less mature and require further prospective clinical validation.

- Integrated digital workflows facilitate 3D visualization, customization, and information transfer, but evidence demonstrating superior long-term patient-

centered outcomes over conventional pathways remains limited.

- Future research should prioritize multicenter prospective studies, standardized clinically meaningful outcomes, interoperability, cost-effectiveness, robust governance, and appropriate clinician oversight.

Legend Tables

Table 1: Comparative clinical maturity of major digital technologies in orthodontics.

Technology	Clinical maturity	Established/current role	Principal evidence limitation	Priority for further research
Intraoral scanners (IOS)	High for routine record acquisition	Digital orthodontic record acquisition with clinically acceptable accuracy and favorable patient acceptance	Accuracy may be influenced by scanning conditions, arch characteristics, and operator-related factors	Standardized accuracy assessment, performance in complex clinical conditions, and patient-level comparative outcomes
Cone-beam computed tomography (CBCT)	High for selected, justified indications	3D assessment when volumetric information is expected to provide clinically relevant information beyond conventional imaging	Ionizing radiation precludes routine use without patient-specific justification; evidence varies by indication	Indication-specific outcome studies, optimized acquisition protocols, and continued radiation governance
CAD/CAM	Established for selected customized design and manufacturing applications	Customized appliance design and fabrication, including brackets and fixed retainers	Patient-level superiority over conventional approaches remains application-specific and inconsistently demonstrated	Prospective comparative studies, long-term outcomes, adverse events, patient-reported outcomes, and cost-effectiveness
3D printing	Application-dependent	Established manufacture of models and guides; expanding direct fabrication of orthodontic appliances	Evidence for directly printed definitive appliances remains limited, with material and post processing factors affecting performance	Clinical validation of definitive appliances, material performance, standardized manufacturing and post processing, and long-term outcomes
Artificial	Uneven;	Automated or assisted	Heterogeneous datasets,	Multicenter external

Technology	Clinical maturity	Established/current role	Principal evidence limitation	Priority for further research
intelligence (AI)	strongest for supervised image-analysis applications	image analysis, particularly well-defined tasks such as cephalometric landmark detection	limited external validation, restricted explain ability, bias and data-privacy concerns, and limited prospective clinical evaluation	validation, subgroup and bias assessment, prospective clinical studies, governance, and continued clinician oversight
Integrated digital workflows	Feasible across several applications; comparative clinical maturity remains incomplete	Integration of acquisition, visualization, virtual planning, and digitally transferred manufacturing or treatment procedures	Limited comparative long-term patient-centered evidence; deviations may occur during transfer from virtual planning to clinical execution	Interoperability, standardized transfer protocols, prospective comparative studies, long-term patient-centered outcomes, and cost-effectiveness

Abbreviations: AI, artificial intelligence; CAD/CAM, computer-aided design and computer-aided manufacturing; CBCT, cone-beam computed tomography; IOS, intraoral scanner; 3D, three-dimensional.

Clinical maturity represents a qualitative interpretive assessment based on consistency of clinical evidence, external validation, reproducibility, safety, implementation readiness, patient-centered benefit, and suitability for routine orthodontic practice; it is not a formally validated evidence-grading system.

References

1. Krymovskyy KG, Zhehulovych ZE, Storozhenko KV, Babaskin YI. Nowadays and the future of the 3D digital technologies in modern orthodontics. *Wiad Lek.* 2024;77(10):2047-2056. doi:10.36740/WLek/195140.
2. Francisco I, Ribeiro MP, Marques F, et al. Application of three-dimensional digital technology in orthodontics: the state of the art. *Bio mimetics (Basel).* 2022;7(1):23. doi:10.3390/biomimetics7010023.
3. Cunha TMAD, Barbosa IDS, Palma KK. Orthodontic digital workflow: devices and clinical applications. *Dental Press J Orthod.* 2021;26(6):e21spe6. doi:10.1590/2177-6709.26.6.e21spe6.
4. Leonardi R. Cone-beam computed tomography and three-dimensional orthodontics: where we are and future perspectives. *J Orthod.* 2019; 46 (suppl 1):45-48. doi:10.1177/1465312519840029.
5. Alassiry AM. Clinical aspects of digital three-dimensional intraoral scanning in orthodontics: a systematic review. *Saudi Dent J.* 2023;35(5):437-442. doi:10.1016/j.sdentj.2023.04.004.
6. Christopoulou I, Kaklamanos EG, Makrygiannakis MA, Bitsanis I, Perlea P, Tsolakis AI. Intraoral scanners in orthodontics: a critical review. *Int J Environ Res Public Health.* 2022;19(3):1407. doi:10.3390/ijerph 1903 1407.

7. Saccomanno S, Saran S, Vanella V, Mastrapasqua RF, Raffaelli L, Levrini L. The potential of digital impression in orthodontics. *Dent J (Basel)*. 2022;10 (8): 147. doi:10.3390/dj10080147.
8. Lin WQ, Pan CY, Chen PH, Liu CT, Hung CC, Lan TH. Trueness of intraoral scanning for different tooth-size arch-length deficiencies. *J Dent Sci*. 2024;19(1):397-403. doi:10.1016/j.jds.2023.08.006.
9. De Grauwe A, Ayaz I, Shujaat S, et al. CBCT in orthodontics: a systematic review on justification of CBCT in a paediatric population prior to orthodontic treatment. *Eur J Orthod*. 2019;41(4):381-389. doi:10. 10 93 /ejo/cjy066.
10. Savoldi F, Dagassan-Berndt D, Patcas R, et al. The use of CBCT in orthodontics with special focus on upper airway analysis in patients with sleep-disordered breathing. *Dento maxillofac Radiol*. 2024;53(3):178-188. doi:10.1093/dmfr/twae001.
11. Samandara A, Papageorgiou SN, Ioannidou-Marathiotou I, Kavvadia-Tsatala S, Papadopoulos MA. Evaluation of orthodontically induced external root resorption following orthodontic treatment using cone beam computed tomography (CBCT): a systematic review and meta-analysis. *Eur J Orthod*. 2019;41(1):67-79. doi:10.1093/ejo/cjy027.
12. Ardila CM, Elorza-Durán A, Arrubla-Escobar D. Efficacy of CAD/CAM technology in interventions implemented in orthodontics: a scoping review of clinical trials. *Biomed Res Int*. 2022;2022:5310555. doi: 10.1155/2022/5310555.
13. Bardideh E, Kerayechian N, Ghorbani M, Younessian F, Shafae H. The efficacy and effectiveness of customized CAD/CAM brackets in fixed orthodontic treatment: a systematic review and meta-analysis. *Eur J Orthod*. 2025;47(1):cjae075. doi:10.1093/ejo/cjae075.
14. Bardideh E, Ghorbani M, Shafae H, Saeedi P, Younessian F. A comparison of CAD/CAM-based fixed retainers versus conventional fixed retainers in orthodontic patients: a systematic review and network meta-analysis. *Eur J Orthod*. 2023;45(5):545-557. doi: 10.1093/ejo/cjad033.
15. Charavet C, Lecloux G, Jackers N, Albert A, Lambert F. Piezocision-assisted orthodontic treatment using CAD/CAM customized orthodontic appliances: a randomized controlled trial in adults. *Eur J Orthod*. 2019;41(5):495-501. doi:10.1093/ejo/cjy082.
16. Dantagnan CA, François P, Le Goff S, Attal JP, Dursun E. Degree of conversion of 3D printing resins used for splints and orthodontic appliances under different post polymerization conditions. *Clin Oral Investig*. 2023; 27 (6):2935-2942. doi:10.1007/s00784-023 -04893-8.
17. ElShebiny T, Matthaios S, Menezes LM, Tsolakis IA, Palomo JM. Effect of printing technology, layer height, and orientation on assessment of 3D-printed models. *J World Fed Orthod*. 2024;13(4):169-174. doi:10.1016/j.ejwf.2024.03.006.
18. Torkomian T, de la Iglesia F, Puigdollers A. 3D-printed clear aligners: an emerging alternative to the conventional thermoformed aligners? A systematic review. *J Dent*. 2025;155:105616. doi:10.1016/j. jdent. 2025.105616.
19. Panayi NC. In-house three-dimensional designing and printing customized brackets. *J World Fed Orthod*. 2022;11(6):190-196. doi:10.1016/j.ejwf.2022.10.004.
20. Dipalma G, Inchingolo AD, Inchingolo AM, et al. Artificial intelligence and its clinical applications in orthodontics: a systematic review. *Diagnostics (Basel)*. 2023;13(24):3677. doi:10.3390/diagnostics13243677.

21. Bichu YM, Hansa I, Bichu AY, Premjani P, Flores-Mir C, Vaid NR. Applications of artificial intelligence and machine learning in orthodontics: a scoping review. *Prog Orthod.* 2021;22(1):18. doi:10.1186/s40510-021-00361-9.
22. Nordblom NF, Büttner M, Schwendicke F. Artificial intelligence in orthodontics: critical review. *J Dent Res.* 2024;103(6):577-584.
23. Hendrickx J, Gracea RS, Vanheers M, et al. Can artificial intelligence-driven cephalometric analysis replace manual tracing? A systematic review and meta-analysis. *Eur J Orthod.* 2024;46(4):cjae029. doi:10.1093/ejo/cjae029.
24. Jiang F, Guo Y, Yang C, et al. Artificial intelligence system for automated landmark localization and analysis of cephalometry. *Dento maxillofac Radiol.* 2023;52(1):20220081. doi:10.1259/dmfr.20220081.
25. Evangelista K, de Freitas Silva BS, Yamamoto-Silva FP, et al. Accuracy of artificial intelligence for tooth extraction decision-making in orthodontics: a systematic review and meta-analysis. *Clin Oral Investig.* 2022; 26 (12): 6893-6905.
26. Gracea RS, Winderickx N, Vanheers M, et al. Artificial intelligence for orthodontic diagnosis and treatment planning: a scoping review. *J Dent.* 2025;152:105442. doi:10.1016/j.jdent.2024.105442.
27. Dursun D, Bilici Geçer R. Can artificial intelligence models serve as patient information consultants in orthodontics? *BMC Med Inform Decis Mak.* 2024;24 (1): 211. doi:10.1186/s12911-024-02619-8.
28. Impellizzeri A, Horodyski M, De Stefano A, et al. CBCT and intra-oral scanner: the advantages of 3D technologies in orthodontic treatment. *Int J Environ Res Public Health.* 2020;17 (24):9428. doi:10.3390/ijerph 17 249428.
29. Baan F, de Waard O, Bruggink R, Xi T, Ongkosuwito EM, Maal TJJ. Virtual setup in orthodontics: planning and evaluation. *Clin Oral Investig.* 2020;24(7):2385-2393.
30. Elnagar MH, Aronovich S, Kusnoto B. Digital workflow for combined orthodontics and orthognathic surgery. *Oral Maxillofac Surg Clin North Am.* 2020;32(1):1-14. doi:10.1016/j.coms.2019.08.004.
31. Ronsivalle V, Venezia P, Bennici O, D'Antò V, Leonardi R, Lo Giudice A. Accuracy of digital workflow for placing orthodontic miniscrews using generic and licensed open systems. A 3D imaging analysis of non-native .stl files for guided protocols. *BMC Oral Health.* 2023;23(1):494. doi:10.1186/s12903-023-03113-9.
32. Pozzan L, Migliorati M, Dinelli L, et al. Accuracy of the digital workflow for guided insertion of orthodontic palatal TADs: a step-by-step 3D analysis. *Prog Orthod.* 2022;23(1):27. doi:10.1186/s40510-022-00423-6.
33. Weismann C, Xepapadeas AB, Bock stedte M, et al. Complete digital workflow for manufacturing presurgical orthodontic palatal plates in newborns and infants with cleft lip and/or palate. *J Funct Biomater.* 2024;15(10):301. doi:10.3390/jfb15100301.
34. Hsu LF, Moon W, Chen SC, Chang KWC. Digital workflow for mini-implant-assisted rapid palatal expander fabrication: a case report. *BMC Oral Health.* 2023;23(1):887. doi:10.1186/s12903-023-03589-5.
35. Gong X, Dang R, Xu T, Yu Q, Zheng J. Full digital workflow of naso alveolar molding treatment in infants with cleft lip and palate. *J Craniofac Surg.* 2020;31(2):367371. doi:10.1097/SCS.0000000000000625 8.