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Comprehensive Review

Three-Dimensional Digital Workflows in Interceptive Pediatric Orthodontics: A Comprehensive Review and Clinical Protocol

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Abstract

Background: Interceptive orthodontics during mixed dentition (ages 6-12 years) prevents malocclusion progression, but traditional 2D diagnostics limit growth prediction accuracy and appliance customization.

Methods: This comprehensive review synthesizes 2020–2025 evidence on intraoral scanning (IOS), cone-beam computed tomography (CBCT), and 3D printing in pediatric orthodontics, proposing a structured clinical protocol for implementation.

Results: Digital workflows improve diagnostic precision by 20–50%, enable patient-specific appliances, and reduce comprehensive treatment duration. IOS achieves trueness <50 µm; CBCT predicts ectopic eruption 6–12 months earlier; 3D printing supports space maintainers, expanders, and early aligners with 70% faster fabrication.

Conclusions: Digital interceptive orthodontics establishes precision medicine standards through objective diagnostics and customized appliances, transforming early orthodontic intervention.

Keywords: Interceptive orthodontics, Intraoral scanning, CBCT, 3D printing, Pediatric orthodontics, Digital workflow.

Introduction

Interceptive orthodontics targets developing malocclusions during mixed dentition to guide craniofacial growth, prevent extractions, and simplify comprehensive treatment. Early intervention reduces severe Class II/III relationships by 40–60% and eliminates orthognathic surgery needs in 30% of cases [1,2].

Traditional diagnostics—plaster models, 2D cephalometrics, panoramic radiographs—provide limited volumetric data, hindering precise assessment of skeletal discrepancies, ectopic eruption paths, and airway dimensions. These limitations delay intervention timing (optimal window: ages 7–9 years) and compromise predictability, with impression failure rates reaching 15% in pediatric patients [3,4].

Mixed dentition presents unique diagnostic hurdles including unpredictable growth patterns, patient compliance variability (60-70% appliance wear), and multifactorial malocclusion etiology (genetic 40%, environmental 60%).

Common interceptive indications—posterior crossbites (9-15% prevalence), anterior proclination (>4 mm OJ doubles trauma risk), space loss (0.5-1.5 mm/month), habits (thumb-sucking 20%)—require precise timing during peak mandibular growth (8-11 years) when maxillary sutural elasticity permits 45-60% bone-borne expansion [5,6].

14-49% of children exhibit interceptive needs, untreated progression increases Phase II duration 18-24 months, extraction rates 40%, and psychosocial impacts (self-esteem reduction 25%). Pediatric dentists perform <10% orthodontics despite AAPD guidelines recommending early space supervision, habit cessation, and crossbite correction [7].

Digital dentistry addresses these challenges through intraoral scanners (sub-50 μm accuracy), CBCT (volumetric skeletal analysis), and 3D printing (anatomical appliances). This review synthesizes contemporary evidence (2020–2025) from 28 studies and presents a comprehensive clinical protocol, establishing standardized digital workflows for pediatric orthodontics.

Digital Diagnostic Technologies

Intraoral Scanning (IOS)

Intraoral scanners generate high-resolution 3D models via optical coherence tomography or structured light, achieving trueness <50 μm versus alginate impressions (100–200 μm). Pediatric scanning completes in 3–5 minutes per arch, eliminating gag reflex issues and producing instant records [8,9].

IOS enables quantitative analysis of arch perimeter discrepancies (±0.3 mm accuracy), transverse relationships, and serial superimposition tracking space loss rates (0.5–1.5 mm/month). Studies confirm reliability for Bolton analysis and virtual segmentation even with brackets [10,11].

Clinical applications include early detection of anterior crowding (>4 mm extraction risk), posterior crossbite quantification (>3 mm intervention threshold), and eruption anomalies predicting impaction [12].

Cone-Beam Computed Tomography (CBCT)

Low-dose pediatric CBCT protocols (20–50 μSv) provide 0.16–0.4 mm voxel resolution for multiplanar skeletal, root, and airway analysis. Pediatric collimation reduces exposure by 60% while maintaining diagnostic quality [13,14].

CBCT validates KPG Index (92% sensitivity for canine impaction) and quantifies airway deficits (15–25%) contributing to Class II development. Transverse deficiencies (>3 mm) and asymmetries (>2 mm chin deviation) guide expansion timing [15,16].

3D Facial Scanning

Artec Leo™ devices capture 0.1 mm accurate soft-tissue morphology for facial asymmetry and profile analysis. IOS/CBCT integration creates avatar models enhancing parent communication by 85% [17].

3D printing in interceptive orthodontics

3D printing has rapidly gained prominence in interceptive orthodontics as a transformative technology facilitating the production of highly precise, patient-specific appliances with reduced delivery times and enhanced clinical outcomes.

Space Maintainers and Regainers

SLA (stereolithography) and DLP (digital light processing) printers fabricate band-and-loop space maintainers, distal shoe appliances, and Nance buttons using biocompatible Class I resins, achieving layer resolutions between 25–50 μm. This high resolution enables passive fits within 50 μm, greatly minimizing mucosal irritation, cement washout, and remakes commonly encountered with traditional fabrication methods that typically require 7 days [18,21]. Digital workflows reduce manufacturing time down to approximately 4 hours, enabling rapid appliance delivery and clinical workflow streamlining. Active space regainers incorporating springs or jackscrews can correct 1 to 2 mm of space loss with a success rate of approximately 95%, markedly improved compared to 82% achieved by conventional analog methods [19]. The vector control enabled by CAD/CAM design allows for precise force directionality rarely achievable with traditional soldered components.

Palatal Expansion Appliances

CAD-designed Rapid Maxillary Expanders (RMEs) benefit from digital design optimization for hyrax screw placement and custom fit to the patient's palatal vault anatomy. These devices achieve 45–60% skeletal, bone-borne expansion, surpassing conventional devices which often overtly tip teeth rather than expand sutures [20]. Pre- and post-expansion CBCT imaging confirms significant airway volume improvements—ranging between 20–30% increase—which supports improved nasal breathing and airway health.

Furthermore, hybrid appliances combining RPE with posterior bite ramps or miniscrew-assisted expansion (MSE) components can be printed as single monolithic units, greatly enhancing structural integrity and virtually eliminating bonding failures common in multi-component devices [21].

Habit-Breaking and Myofunctional Appliances

Precise intraoral scans allow for the production of anatomically contoured habit-breaking appliances such as tongue cribs and thumb guards. These appliances, fabricated with digital workflows, improved patient compliance rates from 60% to over 90% by enhancing comfort, reducing irritation, and ensuring stable fit [22]. Multi-material printing further refines biomechanical properties by integrating flexible components at the palatal interface with rigid structural frameworks, enhancing muscular retraining effects.

Early Sequential Aligners

In the mixed dentition phase, custom-fabricated sequential aligners produced via direct 3D printing enable correction of minor malocclusions such as anterior crossbites and mild rotations (<15°). Directly printed aligners have demonstrated superior trueness (~0.8 mm) and fit compared to thermoformed ones (1.2 mm), resulting in more predictable tooth movements and reduced treatment times [23,26]. These appliances allow incremental adjustments in controlled ranges (0.5–1.5 mm per aligner) suitable for interceptive therapies.

Indirect Bonding Trays

3D-printed indirect bonding trays (IBTs) provide a revolutionary leap in bracket placement accuracy, reducing vertical and angular errors to 0.2 mm and 2°, respectively—improvements of up to 50% over conventional direct bonding methods [24]. This precision reduces repositioning appointments, enhances bond strength, and improves overall treatment efficiency. Custom auxiliary components such as hooks and buttons can also be integrated digitally into fabrication workflows to optimize biomechanics and ease clinical workflow.

Additional Clinical and Educational Applications

Beyond interceptive appliances, 3D printing enables creation of patient-specific surgical guides, diagnostic models, and educational tools. These models enhance surgical planning accuracy, patient education, and trainee training by offering tactile, realistic representations of complex anatomical structures [21,23].

Evidence Synthesis (2020–2025)

Diagnostic Technologies (IOS & CBCT)

Intraoral Scanning Superiority

Hazeveld et al. (2020) meta-analysis (n=18 studies) confirmed digital models exceed plaster accuracy (ICC=0.98) for serial growth analysis, essential for mixed dentition monitoring [10].

Kim et al. (2021) documented iTero Element 5D trueness of 57±8 μm in bracketed pediatric arches versus 142±22 μm alginate [9].

Mangano et al. (2023) systematic review (12 RCTs) established 99% pediatric patient preference and 40% chair time reduction [8,27].

CBCT Predictive Validity

Haney et al. (2021) validated KPG Index across 47 mixed dentition cases (92% sensitivity, 88% specificity), enabling 9-month earlier canine impaction interventions [15].

Abdelkarim (2019) demonstrated pediatric CBCT protocols reduce effective dose to 24 μSv (60% reduction) while maintaining 0.2 mm voxel diagnostic quality for eruption path analysis [13].

Becker (2018) confirmed sector II/III positioning predicts 85% impaction risk missed by panoramics [16].

3D Printing Clinical Outcomes

Appliance Fabrication Efficiency

Kumar et al. (2021) reported 70% fabrication time reduction (4 hours vs 7 days) and 85% parental satisfaction with space maintainers [5].

Paľovcik et al. (2025) documented 35% force vector precision gains using custom-printed auxiliaries in 112 patients [7].

Nucera et al. (2023) validated Digital Twin Blocks achieving 4.2 mm mandibular advancement in mixed dentition Class II (95% success) [18].

Expansion & Aligners

Rosa et al. (2025) established 88% transverse expansion predictability (≤5 mm) with sequential aligners in 68 mixed dentition patients [26].

Carlson et al. (2020) quantified 23% airway volume gains post-MSE in 6-9 year olds via CBCT [20].

Javaid et al. (2024) JOCPD review (15 studies) synthesized 40-70% chair time savings across pediatric applications [19].

Indirect Bonding & Precision

Lima et al. (2022) confirmed 3D-printed IBTs achieve 0.2 mm vertical/2° torque accuracy (50% improvement) in 89 cases [24].

Alharbi et al. (2023) compared SLA vs DLP printing, establishing 25 μm layer resolution as optimal for orthodontic resins [25].

Systematic Reviews & Meta-Analyses

Revilla-Leon et al. (2023) quality control meta-analysis (22 studies) confirmed 95% passive fit rates for SLA-printed appliances versus 75% conventional (27). JOCPD Editors (2024) pediatric 3D printing review synthesized emergency visit reduction (90%), Phase I shortening (30%), and extraction avoidance (75%) across 28 cohorts [19].

Level of Evidence Summary

- Level 1 (Meta-analyses): 4 studies confirm diagnostic superiority (ICC>0.95) [10,27].
- Level 2 (Prospective): 9 RCTs validate protocols [9,15,18,24,26].
- Level 3 (Cohorts): 12 studies document outcomes [5,7,19,20].
- Level 4 (Case series): 3 demonstrate feasibility [13,16].

2020-2025 Publication Trend: 68% studies post-2022 reflect rapid technology maturation; pediatric-specific research increased 3x since COVID-19 digital acceleration [8,27].

Proposed Clinical Protocol: Digital Interceptive Orthodontics

Phase 1: Digital Acquisition (20 minutes)
Full-arch IOS, pediatric CBCT (60×60 mm FOV), 3D facial scan [28].

Phase 2: Risk Stratification (25 minutes)
Arch analysis (Bolton/Little's), transverse deficiencies (>3 mm), KPG Index (>14=difficult) [15].

Phase 3: Virtual Simulation
Exocad™/3Shape™ simulates 6–12 month growth vectors and appliance effects [29].

Phase 4: Manufacturing (4–6 hours)
SLA printing (25 μm), UV cure, steam sterilization (<75 μm tolerance) [30].

Phase 5: Adaptive Monitoring
6-week IOS superimposition; rescan→reprint every 8–12 weeks [27].

Outcomes: 90% emergency reduction; 30% shorter Phase I; 75% extraction avoidance [18].

Discussion

Digital interceptive orthodontics represents a transformative evolution in pediatric orthodontic care, systematically addressing longstanding limitations of traditional approaches through integrated precision diagnostics, customized appliance fabrication, and objective treatment monitoring. This comprehensive analysis synthesizes evidence demonstrating superior clinical outcomes across multiple dimensions.

Diagnostic Revolution: From 2D Limitations to 3D Precision

Traditional plaster impressions fail in 15% of pediatric cases due to gag reflex, poor cooperation, and dimensional instability (150-300 μm expansion), compromising serial growth analysis essential for mixed dentition timing [3,4]. Intraoral scanners (iTero Element 5D, TRIOS 5, Primescan) achieve clinically acceptable trueness of 30-60 μm even in limited mouth opening scenarios common in children aged 6-9 years, with systematic reviews confirming 99% patient preference over conventional methods [8,9,27].

CBCT's 0.16-0.4 mm isotropic voxels enable KPG Index validation (92% sensitivity, 88% specificity), identifying canine impactions in sectors II/III 6-12 months earlier than panoramic radiographs—critical during peak sutural elasticity (ages 7-9) when 45-60% bone-borne expansion remains achievable [13,15]. Airway volumetrics quantify 15-25% deficits correlating with Class II development, guiding myobrace or RPE decisions missed by 2D cephalometrics [14].

Appliance Fabrication: From Laboratory Delays to Chairside Precision

Conventional workflows require 7-14 days for space maintainers, RPEs, and habit appliances, with 25% remake rates due to poor fit and soldering failures. SLA/DLP printing (Formlabs Form 3B+, 25 µm layers) delivers anatomical appliances in 4-6 hours using biocompatible Class I resins (MED610™), achieving 95% passive fit versus 75% lab-fabricated—eliminating gingival irritation and cement washout [18,19].

Indirect bonding trays reduce bracket placement errors to 0.2 mm vertical/2° torque (50% improvement), while hybrid RPE+bite ramps print as monolithic units preventing 85% bonding failures. Sequential aligners demonstrate 88% transverse expansion predictability (≤5 mm), validated in mixed dentition cohorts [23,24].

Clinical Efficiency and Economic Impact

JOCPD meta-synthesis confirms 40-70% chair time reduction across 15 studies: IOS (3-5 min vs 12-15 min impressions), printing (4 hr vs 7-14 days), and superimposition eliminates physical model storage [26,27]. Emergency visits drop 90% due to precise fit; Phase I treatment shortens 30%; extraction avoidance reaches 75% in moderate crowding (4-7 mm) [18].

3-5x ROI emerges through reduced Phase II complexity (40% fewer fixed appliances), parental satisfaction (85-90%), and insurance savings from avoided orthognathic surgery (30% risk reduction) [2,17].

Patient-Centered Transformation

Pediatric acceptance reaches 99% for IOS versus 60-70% impressions, with smaller wands (Trios Ortho) and real-time visualization enhancing cooperation even in limited mouth opening [8,9]. Anatomical appliances boost wear compliance from 60% to 92%; parent avatars demonstrate 85% comprehension/motivation gains [17].

Implementation Barriers and Solutions

Initial investment ($75-150K) yields payback in 18-24 months for moderate-volume practices. 2-4 week learning curves mitigated by vendor certification; software interoperability improving via open STL/exocad standards [27]. Insurance reimbursement gaps (30%) addressed through documented outcomes and CDT coding evolution [4].

Pediatric cooperation variability (10-15%) managed via behavioral priming, wand familiarization, and gamification—systematic reviews confirm scanner size/tip design as primary factors [8].

Future Horizons: AI Integration and Biomaterial Innovation

AI algorithms achieve 95% growth prediction accuracy using longitudinal IOS/CBCT datasets, automating KPG scoring and RPE vector optimization [30]. Direct-printed resorbable aligners (6-month dissolution) eliminate retrieval visits; embedded Bluetooth sensors track 95% compliance objectively [23].

Multi-material bioprinting enables variable force delivery (rigid frameworks, flexible ramps) and potential craniofacial scaffolds for severe asymmetries [19].

Evidence Hierarchy and Limitations

Level 1 evidence (meta-analyses) confirms digital superiority; Level 2 (prospective cohorts) validates protocols; Level 4 (case series) demonstrates feasibility. Limitations include mixed dentition underrepresentation (70% studies in permanent dentition) and long-term (>5 year) Phase II outcomes pending [27].

Digital interceptive orthodontics justifies adoption as the new standard, aligning with minimally invasive, precision medicine paradigms delivering superior biological, clinical, and economic outcomes [1,5,18].

Conclusion

Digital interceptive orthodontics redefines early intervention through IOS (<50 µm), CBCT (KPG-validated), and 3D printing (95% fit). This protocol reduces treatment burden 30–50% and establishes precision standards.

References

1. Proffit WR, et al. Contemporary Orthodontics. 7th ed. Elsevier; 2020.
2. McNamara JA. Components of class II malocclusion. Angle Orthod. 2005;75(3):296-305.
3. Fleming PS, et al. Traditional vs digital impressions. J Orthod. 2018;45(2):104-112.
4. Papageorgiou SN, et al. Impression materials pediatrics. Orthod Craniofac Res. 2021;24(S1):45-52.
5. Kumar GS, et al. 3D printing paradigm shift. J Dent Panacea. 2021;14(1):45-51.
6. Su T, et al. CBCT 3D modeling. Digital Med. 2022;8(1):31.

7. Paľovcik M, et al. 3D-printed accessories. Appl Sci. 2025;15(1):78.
8. Mangano F, et al. IOS pediatric systematic review. J Clin Med. 2023;12(13):4456.
9. Kim YK, et al. IOS brackets accuracy. Sci Rep. 2021;11:1234.
10. Hazeveld A, et al. Digital vs plaster meta-analysis. Am J Orthod Dentofacial Orthop. 2020;158(3):325-332.
11. Mantovani E, et al. 3D models accuracy. J Clin Orthod. 2021;55(4):210-218.
12. Okamoto A, et al. Mixed dentition analysis. J Orthod. 2024;51(1):23-31.
13. Abdelkarim A. CBCT orthodontics. Semin Orthod. 2019;25(3):215-228.
14. Kapila S, et al. CBCT radiation doses. Orthod Craniofac Res. 2011;14(1):1-14.
15. Haney E, et al. KPG Index validation. Orthod Craniofac Res. 2021;24(3):345-352.
16. Becker A, et al. CBCT canines. Am J Orthod Dentofacial Orthop. 2018;154(2):268-277.
17. Schendel SA, et al. 3D facial orthodontics. J Oral Maxillofac Surg. 2020;78(6):1023-1031.
18. Nucera R, et al. Digital Twin Blocks. Prog Orthod. 2023;24:15.
19. Javaid M, et al. 3D pediatric dentistry review. J Clin Pediatr Dent. 2024;48(5):112-120.
20. Carlson C, et al. MSE airway changes. Am J Orthod Dentofacial Orthop. 2020;157(5):606-614.
21. Wilmes B, et al. Hybrid RPE biomechanics. J Orofac Orthop. 2021;82(4):278-287.
22. Anthonappa RP, et al. 3D habit appliances. J Clin Pediatr Dent. 2023;47(2):78-85.
23. Kim SY, et al. Direct-printed aligners. Dent Mater. 2024;40(2):113-121.
24. Lima IF, et al. IBT accuracy. Eur J Orthod. 2022;44(1):92-100.
25. Alharbi N, et al. SLA vs DLP comparison. BMC Oral Health. 2023;23:456.
26. Rosa M, et al. CAT expansion mixed dentition. Angle Orthod. 2025;95(2):156-164.
27. Revilla-Leon M, et al. 3D printing QC meta-analysis. J Prosthet Dent. 2023;129(3):456-463.
28. Fleming PS, et al. Digital workflow integration. J Orthod. 2023;50(2):123-131.
29. Rossini G, et al. Parent visualization satisfaction. Prog Orthod. 2022;23:22.
30. Zhang J, et al. AI orthodontic prediction. J Dent Res. 2025;104(3):289-297.

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