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Long-Term Periodontal and Root Resorption Effects of Direct-to-Consumer and In-House Clear Aligners: A Critical Review of Biomechanical Predictability and Non-Specialist Oversight

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Abstract

Background and Objective: The rapid proliferation of direct-to-consumer (DTC) orthodontics and chairside in-house three-dimensional (3D) aligner printing has decentralized clear aligner therapy (CAT) from specialist orthodontic oversight. Although commercial, specialist-supervised CAT demonstrates favorable short-term periodontal indices and reduced orthodontically induced inflammatory root resorption (OIEARR) compared with fixed appliances, long-term biological sequelae in unsupervised or non-specialist workflows remain inadequately defined. This review evaluates the biomechanical predictability, periodontal tissue response, and OIEARR risks associated with DTC and in-house 3D-printed clear aligners.

Materials and Methods: A structured literature search was conducted across PubMed/MEDLINE, Scopus, Web of Science, the Cochrane Library, and regulatory post-market surveillance reports. Peer-reviewed studies evaluating direct-printed photopolymer mechanics, stress relaxation, gingival margin interactions, OIEARR pathophysiology, and provider training disparities were synthesized.

Results and Discussion: In-house 3D-printed photopolymer resins exhibit substantially higher viscoelastic stress relaxation and sensitivity to post-curing protocols than thermoformed polyurethanes, predisposing teeth to unplanned force decay and round-tripping. Clinical management surveys reveal that non-specialist practitioners attempt complex malocclusions with significantly fewer biomechanical auxiliaries and refinements, whereas DTC platforms routinely omit baseline periodontal probing and radiographic diagnostics. Post-market adverse event databases implicate unsupervised aligners in irreversible attachment loss, gingival recession, and occlusal trauma, while unmonitored force spikes and prolonged treatment durations elevate OIEARR risk.

Conclusion: Despite workflow efficiency, decentralizing aligner fabrication and staging without comprehensive diagnostic screening, validated polymer post-processing, and specialist supervision introduces preventable periodontal and root resorption hazards. Standardized clinical governance and prospective longitudinal trials are urgently warranted.

Keywords: *Clear Aligner Therapy; Direct-to-Consumer Orthodontics; In-House 3D Printing; Orthodontically Induced Inflammatory Root Resorption; Periodontal Health; Biomechanical Predictability.*

I. INTRODUCTION

Over the past two decades, clear aligner therapy (CAT) has evolved from a niche modality restricted to mild anterior crowding into a mainstream orthodontic intervention capable of addressing complex three-dimensional malocclusions **[1,2]**. Concurrently, advances in intraoral optical scanning, open-architecture computer-aided design (CAD) tooth-staging software, and vat-photopolymerization three-dimensional (3D) printers have catalyzed two parallel structural shifts in orthodontic care delivery: direct-to-consumer (DTC) remote aligner services and chairside in-house aligner fabrication within general dental practices **[3–6]**. Both models bypass traditional third-party manufacturer biomechanical review and specialist orthodontic oversight, promising reduced laboratory fees, accelerated appliance turnaround, and lower patient costs **[3,6,7]**.

However, orthodontic tooth movement is fundamentally a sterile inflammatory process mediated by controlled mechanical loading of the periodontal ligament (PDL) and alveolar bone **[12]**. When force magnitudes, moments, or staging velocities exceed biological tolerance—or when appliances are placed over undiagnosed periodontal pathology—iatrogenic sequelae ensue, principally alveolar bone dehiscence, gingival recession, loss of clinical attachment, and orthodontically induced inflammatory root resorption (OIEARR) **[5,12,13]**. While extensive literature has examined periodontal and root resorption outcomes in specialist-managed commercial thermoformed aligners, empirical data evaluating long-term biological outcomes when aligners are designed, 3D-printed in-house, or dispensed without specialist supervision remain notably sparse **[3,5,7]**.

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The objective of this critical review is to synthesize current evidence on the material biomechanics, clinical predictability, periodontal tissue responses, and OIEARR risks associated with DTC and in-house 3D-printed clear aligners, with specific emphasis on diagnostic and therapeutic vulnerabilities arising in non-specialist hands.

II. MATERIALS AND METHODS

This investigation was designed as a structured narrative and critical literature review. Electronic searches were performed across PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library for peer-reviewed English-language articles published through 2025, supplemented by regulatory post-market surveillance analyses from the United States Food and Drug Administration (FDA) Manufacturer and User Facility Device Experience (MAUDE) database **[5]**. Search terms combined Medical Subject Headings (MeSH) and free-text keywords: *("clear aligners" OR "orthodontic aligners") AND ("direct-to-consumer" OR "in-house" OR "3D-printed" OR "general practitioner") AND ("periodontal" OR "root resorption" OR "biomechanics" OR "predictability")*.

Eligible sources included systematic reviews, meta-analyses, randomized controlled trials, prospective and retrospective clinical cohort studies, in vivo appliance retrieval analyses, in vitro mechanical and cytotoxicity investigations, clinician practice-pattern surveys, and regulatory adverse-event reports. Studies focused exclusively on fixed orthodontic appliances without aligner comparators, non-clinical technical opinion pieces lacking empirical data, and duplicate datasets were excluded. Extracted findings were synthesized across four analytical domains: (1) polymer mechanics and biomechanical predictability, (2) periodontal and soft-tissue sequelae, (3) OIEARR pathophysiology and volumetric/linear incidence, and (4) clinical governance disparities between specialist orthodontists, general practitioners, and unsupervised DTC platforms.

Ethical and Regulatory Considerations: Because this manuscript constitutes a secondary synthesis of previously published peer-reviewed literature and anonymized public regulatory data without direct human or animal experimentation, formal institutional ethics committee approval and individual patient informed consent were not applicable. Regulatory and professional standards governing custom medical device fabrication and clinical informed consent are addressed within the clinical discussion.

III. Results And Discussion

3.1.Biomechanical Predictability and Material Decay in In-House 3D-Printed Aligners

Predictable orthodontic tooth movement requires sustained, light continuous forces delivered through precise appliance-to-crown engagement **[1,2]**. Even within specialist-led commercial thermoformed systems utilizing engineered attachments and proprietary multi-layer polyurethanes, prospective clinical superimposition studies demonstrate that mean tooth movement accuracy reaches only 41% to 50%, with rotational control of rounded teeth (canines and premolars), incisor torque, and vertical extrusion exhibiting the lowest predictability **[1,2]**. Achieving clinically acceptable occlusion therefore routinely depends on deliberate overcorrection, optimized attachment geometry, interproximal reduction (IPR), and multiple mid-course refinement phases **[2,9]**.

Transitioning to chairside in-house 3D printing introduces substantial material and manufacturing variables that further challenge biomechanical predictability. Unlike thermoformed polyethylene terephthalate glycol (PETG) or aromatic thermoplastic polyurethanes, direct-printed aligners rely on light-cured aliphatic vinyl ester-urethane or methacrylate-based photopolymer resins (such as Tera Harz TC-85) **[3,4]**. In an in vivo retrieval study evaluating in-house 3D-printed aligners after one week of intraoral service, Can et al. **[3]** demonstrated that although Martens hardness and indentation modulus remained stable over seven days, the indentation relaxation index of in-house 3D-printed aligners was nearly ten times higher than that of commercial thermoformed polyurethane aligners. Rapid viscoelastic stress relaxation translates clinically into steep initial force spikes upon insertion followed by premature force decay below the biological threshold required for sustained osteoclastic bone remodeling **[3]**.

Furthermore, the mechanical properties and biocompatibility of in-house printed aligners are highly sensitive to chairside post-processing fidelity, including centrifugation duration, residual monomer removal, ultraviolet curing wavelength, and oxygen-depleted (nitrogen) curing environments **[3,4]**. While Pratsinis et al. **[4]** found no significant cytotoxicity or estrogenicity in eluates from properly post-cured 3D-printed aligners on human gingival fibroblasts, deviations from strict manufacturer curing protocols in busy general practice laboratories risk incomplete double-bond conversion, altered flexural modulus, localized thickness discrepancies, and elution of uncured monomers capable of inducing mucosal irritation **[3,4]**. When programmed staging increments fail to track due to rapid stress relaxation or uncompensated resin shrinkage, subsequent aligners no longer seat passively, generating uncontrolled tipping, intrusive vectors, and "round-tripping" (jiggling) movements that stress the periodontium and root apex **[1–3]**.

3.2.Periodontal Tissue Response and Unsupervised Aligner Sequelae

In controlled specialist settings, clear aligners are frequently associated with superior short-term plaque control and reduced gingival bleeding compared with fixed edgewise brackets, primarily because the appliance is removable for brushing and flossing **[10,11]**. In a systematic review, Rossini et al. **[10]** reported improved periodontal health indices during CAT relative to fixed appliances, although the authors cautioned that the overall quality of evidence was moderate and long-term follow-up was limited. Similarly, a randomized clinical trial by Chhibber et al. **[11]** demonstrated significantly lower gingival inflammation and papillary bleeding at 9 months with clear aligners compared with elastomeric-ligated brackets, yet by 18 months of active treatment, oral hygiene differences among appliance modalities converged, indicating that behavioral compliance and marginal fit exert greater influence over long-term periodontal status than appliance selection alone.

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Crucially, these favorable periodontal observations presuppose pre-treatment periodontal health, meticulous oral hygiene reinforcement, and smooth, anatomically trimmed aligner margins—conditions frequently absent in DTC and unmonitored in-house workflows **[5–7]**. Aligner trim lines designed with straight-cut extensions overlapping the gingival zenith trap salivary pellicle and cariogenic or periodontopathic biofilms against the gingival sulcus while mechanically impinging upon delicate junctional epithelium during insertion and mastication **[11]**. When aligners are manufactured in-house without automated laser trimming, manual finishing burrs or sharp scalloped edges can chronically traumatize thin periodontal phenotypes, precipitating localized gingival recession and cleft formation.

The periodontal risks escalate dramatically when orthodontic forces are initiated without baseline periodontal charting or radiographic bone-level assessment **[5,7]**. Moving teeth with active, untreated periodontitis accelerates vertical alveolar bone loss and clinical attachment loss . Moreover, non-specialist digital setups that resolve anterior crowding primarily through unconstrained arch expansion and labial incisor proclination—rather than diagnostic IPR or extraction—risk translating roots beyond the cortical plate of the alveolar housing, creating bony dehiscences and fenestrations . Empirical evidence from post-market surveillance substantiates these hazards: in an analysis of 104 FDA MAUDE adverse event reports linked to unsupervised DTC sequential aligners, Belgal et al. found that 86.5% constituted patient injuries, with 41.3% involving malocclusion/bite discrepancies, 29.8% orofacial pain, and 26.6% explicit periodontal sequelae including pathological tooth mobility, gingival recession, and alveolar bone loss. Alarmingly, 69.2% of affected individuals required subsequent intervention from an independent dentist, and 28.8% required corrective orthodontic, periodontal, or endodontic therapy . Complementary survey data by Wexler et al. similarly revealed that 6.6% of 470 DTC aligner users required emergency dental visits due to severe adverse effects, underscoring the clinical burden generated by unmonitored tooth movement.**[12][1,9][5][5][6]**

3.3.Orthodontically Induced Inflammatory Root Resorption (OIEARR) Mechanisms and Risks

Orthodontically induced inflammatory root resorption is an unavoidable, multifactorial iatrogenic consequence of orthodontic force application characterized by irreversible loss of apical cementum and dentin **[12–14]**. As described by Brezniak and Wasserstein **[12,13]**, localized compression of the PDL beyond capillary perfusion pressure induces sterile necrosis (hyalinization); during macrophage and odontoclast clearance of the necrotic hyalinized zone, adjacent cementoid layers are degraded, exposing mineralized cementum to clastic resorption. Volumetric micro-computed tomography studies by Chan and Darendeliler **[16]** established that heavy orthodontic forces produce significantly greater root resorption crater volumes than light forces, while systematic reviews identify prolonged treatment duration, apical displacement distance, root morphology anomalies (pipette-shaped or dilacerated roots), prior dental trauma, and genetic predisposition as primary determinants of severe OIEARR **[13,14]**.

Within specialist-supervised settings, systematic reviews and meta-analyses indicate that commercial CAT generally yields lower incidence and severity of OIEARR than fixed appliances **[15,18]**. Fang et al. **[15]** demonstrated significantly less external apical root resorption in maxillary incisors treated with clear aligners compared with fixed edgewise appliances, a finding corroborated by Singh et al.
[18] in a 2024 meta-analysis attributing reduced resorption to intermittent force decay during aligner removal and prescribed staging limits. Nevertheless, cone-beam computed tomography (CBCT) investigations confirm that clinically significant apical root shortening still occurs during aligner therapy, particularly when intrusive or torquing mechanics are applied to maxillary incisors, and cannot be reliably detected on conventional panoramic radiographs **[17]**.

In DTC and unmonitored in-house aligner workflows, three converging mechanisms erode the protective biomechanical margin observed in specialist CAT:

- **Omission ofPre-Treatment and Progress Radiographs:** Without baseline periapical, panoramic, or CBCT imaging, pre-existing short roots, blunt or pipette-shaped apices, endodontically treated teeth, and idiopathic resorption go undetected prior to force initiation **[7,13,14]**.

- **Uncontrolled Force Magnitude and Jiggling Vectors:** High initial stiffness coupled with rapid stress relaxation in in-house photopolymers, or skipped aligner stages when patients force ill-fitting trays onto non-tracking teeth, subjects the apical PDL to repetitive high-stress hyalinization cycles and round-tripping **[3,13,16]**.

- **Protracted Treatment Duration Through Unsuccessful Refinements:** Because non-specialist setups frequently underestimate biomechanical anchorage requirements, cases stall mid-treatment and undergo repeated refinement cycles, extending total active force duration—one ofthe strongest independent predictors ofsevere OIEARR **[9,14]**.

3.4. Clinical Oversight Disparities: Specialists Versus Non-Specialists and DTC Models

A critical vulnerability highlighted by health-services research is the divergence in diagnostic rigor and biomechanical management between specialist orthodontists and general dental practitioners performing CAT **[8,9]**. In a comparative survey of treatment management practices, Best et al. **[9]** reported that general dentists expressed significantly higher confidence than orthodontists in treating complex malocclusions—including deep bites, severe crowding, and Class II discrepancies—using aligners alone ($P \leq 0.0001$), yet spent significantly less time modifying digital treatment setups, prescribed interarch elastics far less frequently (41% vs. 93%), utilized combination fixed-aligner auxiliaries less often (23% vs. 78%), and performed fewer refinement series than orthodontists.

When this disparity in biomechanical training is compounded by in-house CAD/CAM aligner production—where third-party technician algorithmic checks are eliminated—clinicians assume full responsibility for virtual tooth-movement staging, collision detection, root-torque simulation, and medical-device quality assurance **[3,9]**. Meanwhile, population-based surveys by Olson et al. **[8]** and Bous et al. **[7]** demonstrate that patients selecting DTC or low-cost aligner options are motivated primarily by perceived convenience and lower upfront fees, often remaining unaware of the

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diagnostic necessity of radiographic screening, periodontal stabilization, and lifelong retention. Table 1 synthesizes the structural, biomechanical, and biological contrasts across the three primary clear aligner delivery models, while Table 2 outlines the specific clinical risk pathways requiring mitigation.

Table 1. Comparative Biomechanical, Periodontal, and Root Resorption Profiles Across Clear Aligner Delivery Models

Clinical Parameter	Specialist-Led Commercial CAT	Non-Specialist In-House 3D-Printed CAT	Direct-to-Consumer (DTC) Unsupervised CAT
Diagnostic & Radiographic Workup	Comprehensive clinical exam, periodontal charting, panoramic/cephalometric or CBCT imaging **[9,17]**.	Variable; general dental exam typically performed, but skeletal and root-apex diagnostics may be abbreviated **[9]**.	Absent or limited to remote photographs/at-home impressions; no periodontal probing or radiographs **[5,7]**.
Material & Manufacturing Control	Industrial multi-layer polyurethane/PETG; standardized thermoforming and laser margin trimming **[2,3]**.	Photopolymer resin (e.g., TC-85); high stress relaxation (~1 0× higher) and sensitivity to N_2 post-curing **[3,4]**.	Commercial thermoformed polymers, but manufactured without individualized clinical prescription **[5,6]**.
Biomechanical Auxiliaries & Staging	High utilization of optimized attachments, IPR, interarch elastics (93%), and refinements **[2,9]**.	Lower auxiliary/elastic use (41 %); reliance on automated CAD setups with minimal overengineering **[9]**.	No bonded attachments, no clinical IPR, and no mid-course biomechanical adjustments **[5,7]**.
Periodontal Risk Profile	Low when supervised; improved short-term gingival indices vs. fixed appliances **[10,11]**.	Moderate-to-high if manual margin finishing irritates gingiva or uncontrolled expansion causes dehiscence **[3,11]**.	High; 26.6% of MAUDE injury reports involve mobility, recession, and bone loss **[5]**.
OIEARR Risk Profile	Generally lower volumetric/linear OIEARR than fixed brackets under controlled staging **[15,18]**.	Elevated if rapid force decay causes non-tracking, tray forcing, or protracted refinement cycles **[3,14,16]**.	Unmonitored; pre-existing short roots undetected and occlusal trauma/jiggling unaddressed **[5,13]**.

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Table 2. Mechanistic Risk Pathways and Clinical Mitigation Strategies for Periodontal and Root Resorption Sequelae

Risk Domain	Pathophysiological Mechanism	Primary Clinical Consequence	Evidence-Based Mitigation
Pre-Existing Periodontal Pathology	Orthodontic force applied to biofilm-induced inflamed periodontium accelerates osteoclastic bone loss **[12]**.	Rapid vertical infrabony defects, attachment loss, and tooth mobility **[5]**.	Mandatory full-mouth periodontal probing, bleeding scores, and radiographic bone assessment pre-CAT **[7,10]**.
Unconstrained Arch Expansion	Labial crown tipping and bodily translation beyond thin facial alveolar cortical housing **[1,9]**.	Alveolar bone dehiscence, fenestration, and gingival recession **[5]**.	Diagnostic space analysis utilizing calibrated IPR or extractions rather than excessive expansion **[9]**.
Photopolymer Stress Relaxation & Misfit	Rapid viscoelastic decay reduces orthodontic force; subsequent trays misfire and produce heavy point loads **[3,16]**.	PDL hyalinization, cementoclastic cratering, and apical root blunting **[12,16]**.	Validated resin post-curing (nitrogen chamber), conservative staging (≤0.20 mm), and frequent tracking checks **[3,4]**.
Subgingival Trim-Line & Margin Roughness	Mechanical impingement on junctional epithelium and subgingival plaque stagnation **[11]**.	Chronic marginal gingivitis, papillary bleeding, and soft-tissue clefts **[11]**.	Scalloped juxtagingival trim-line design, smooth polishing, and strict oral hygiene reinforcement **[10,11]**.

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3.5.Limitations of the Existing Literature and Research Priorities

A major finding of this review is the pronounced asymmetry between rapid commercial adoption of in-house 3D-printed aligners and the paucity of long-term prospective clinical trials. Most published investigations on direct-printed aligners remain restricted to short-term (7- to 14-day) in vitro mechanical testing or small-sample retrieval studies **[3,4]**. Similarly, evidence regarding DTC aligner harm derives largely from voluntary regulatory databases (such as MAUDE), which are subject to underreporting and selection bias, and cross-sectional patient surveys **[5,6]**. Future research must prioritize multi-year prospective cohort studies and randomized trials comparing specialist-led and non-specialist in-house 3D-printed aligners using standardized CBCT root-volume quantification and longitudinal periodontal attachment measurements.

IV. CONCLUSION

The decentralization of clear aligner therapy through direct-to-consumer platforms and chairside in-house 3D printing has outpaced the clinical evidence base validating its long-term biological safety. While specialist-supervised commercial CAT demonstrates favorable periodontal maintenance and lower OIEARR incidence than fixed appliances, these outcomes cannot be extrapolated to unsupervised or inadequately validated workflows. In-house 3D-printed photopolymer resins exhibit substantially higher viscoelastic stress relaxation and processing sensitivity than thermoformed polymers, while non-specialist and DTC protocols frequently omit baseline radiographic screening, periodontal stabilization, and essential biomechanical auxiliaries. Clinicians adopting in-house aligner fabrication must enforce rigorous pre-treatment periodontal and radiographic diagnostics, adhere strictly to validated photopolymer post-curing protocols, and maintain structured in-person clinical monitoring to prevent irreversible periodontal attachment loss and apical root resorption.

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Conflict of Interest

The author declares no financial, professional, institutional, or personal conflicts of interest that could potentially influence the work or interpretation reported in this manuscript.

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