



Aligner Recycling: - Exploring the Processes and Methods – A Narrative Review

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DOI: [10.5281/zenodo.17132821](https://doi.org/10.5281/zenodo.17132821)

Submission Date: 02 Aug. 2025 | Published Date: 16 Sept. 2025

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Abstract

Clear aligner therapy (CAT) generates substantial volumes of single use plastics, yet frameworks to recover, reprocess, and reintegrate these materials into circular value chains remain nascent. We conducted a narrative review of peer reviewed articles (2019–August 2025) and policy/guidance documents to synthesize the evidence on materials used in aligners, their environmental footprint, leachables and biocompatibility, and emerging pathways for collection, disinfection, and recycling (mechanical, chemical, thermal, and advanced/bio catalytic). We also summarize clinical, regulatory, and supply chain enablers for implementing circular solutions. Evidence indicates that most thermoformed aligners are polyethylene terephthalate glycol (PETG) or thermoplastic polyurethane (TPU), where mechanical reprocessing is feasible for clean process scrap, while chemical depolymerization offers a route for post-consumer items with mixed contamination. Directly printed aligners (DPA) are emerging; early reports show encouraging dimensional accuracy but raise questions about residual monomers and long-term biocompatibility. A practical program should combine chairside segregation in puncture resistant containers, validated disinfection, mass balance documentation, and certified recyclers, aligned to national biomedical waste rules. Priority research gaps include robust life cycle assessments, longitudinal leachables data, and scalable reverse logistics models. A phased roadmap and extended producer responsibility (EPR) could accelerate adoption while safeguarding patients and staff.

Keywords: Clear Aligners, PETG, TPU, Direct 3D Printed Aligners, Recycling, Life cycle assessment.

1. INTRODUCTION

Clear aligners have transformed orthodontics, but each patient may use dozens of appliances and multiple auxiliaries, creating a visible plastic footprint. Unlike metals, most aligner plastics lack mature end of life streams. Emerging reviews map the environmental implications of clear aligner therapy and propose mitigation strategies, while technical literature is rapidly expanding on directly printed aligners (DPA), novel polymers, and recycling technologies. This narrative review integrates these strands to support clinicians, manufacturers, and policy makers planning practical and compliant recycling programs.¹

From an environmental perspective, the dominant contributors to orthodontic care emissions are travel and energy use, but device materials add measurable life cycle burdens that clinics can mitigate with scheduling, digital records, and local workflows. Used aligners and trimming offcuts are considered health care waste and require segregation, validated disinfection, and traceable handling before any form of material recovery. For end of life, mechanical reprocessing is suitable for clean PETG and TPU streams, while chemical depolymerisation routes such as glycolysis and hydrolysis can handle mixed or contaminated PET family plastics. Microplastic generation and leachable residuals from intraoral polymer devices are active research areas; current evidence indicates low level releases that depend on material formulation and post processing, underscoring the need for longitudinal data.²

Clear aligner therapy integrates digital workflows from intraoral scanning to computer aided setup and appliance fabrication, enabling iterative refinements and remote monitoring. Most commercially available thermoformed appliances are manufactured from polyethylene terephthalate glycol or thermoplastic polyurethane sheets in the 0.5–1.0 mm range, with thermoforming and trimming influencing fit and force delivery. Directly printed aligners produced via DLP or LCD processes have emerged as an alternative to thermoforming, but material selection, printer–resin compatibility, and post curing protocols critically affect accuracy and safety. Regulatory oversight is maturing, with an aligner indicated photopolymer receiving FDA 510(k) clearance in 2024, though the portfolio of approved resins remains limited.³ (Figure 1)



Figure 1: Clear Aligner with Model

2. MATERIALS AND METHODS

Sources: We searched PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar for publications from January 2019 to August 2025 using combinations of the terms: clear aligners, aligner, PETG, TPU, direct printed aligners, DLP, LCD, biocompatibility, leachables, microplastics, recycling, glycolysis, methanolysis, pyrolysis, circular economy, extended producer responsibility, biomedical waste, and lifecycle assessment. **Inclusion:** works addressing aligner materials, manufacturing, environmental impacts, disinfection, or recycling. We prioritized peer reviewed reviews, invitro/clinical studies, standards/guidance, and regulatory documents. **Exclusion:** non scholarly commentaries without sources and papers unrelated to orthodontic appliances or polymer end of life. Given the heterogeneity of study designs, we synthesized findings narratively and summarized technologies in tables.²

3. ALIGNER MATERIALS AND MANUFACTURING

3.1. Thermoformed PETG and TPU

Most commercial thermoformed aligners are PETG sheets or TPU films of varying thickness. PETG offers clarity and crack resistance; TPU provides elasticity and stress relaxation behavior. Mechanical properties depend on polymer grade, sheet thickness, thermoforming parameters, and post forming trimming/polishing. Comparative testing shows that stiffness and strength rise with thickness, but force delivery also depends on fit and geometry.⁴ (Figure 2 & Table 1).

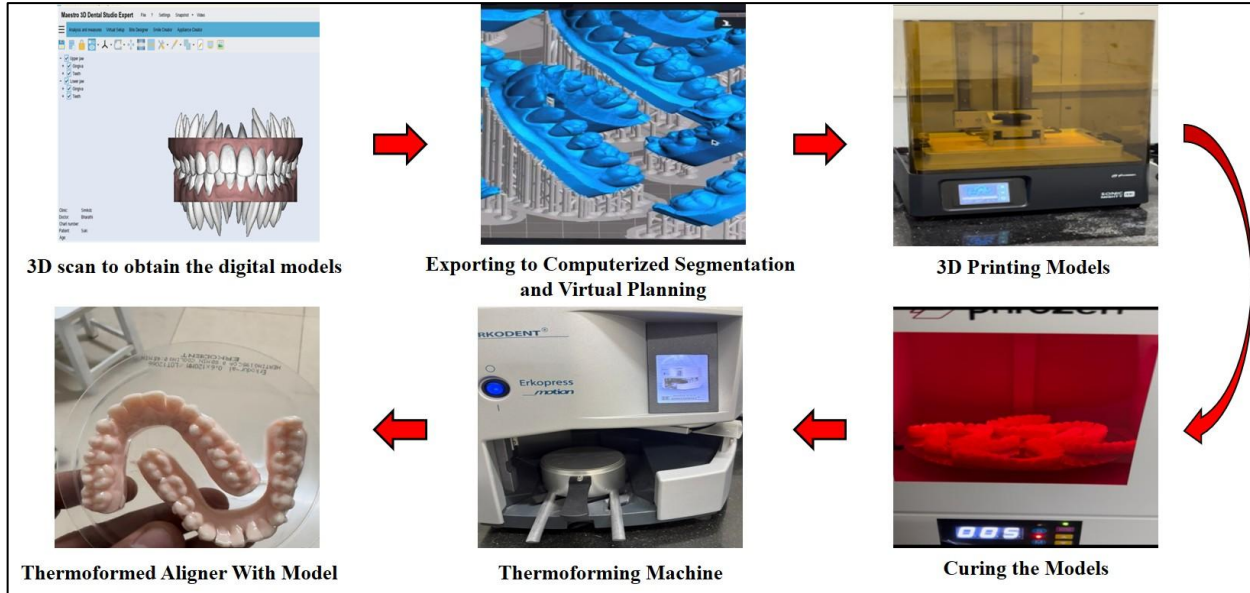


Figure 2: The key stages of laboratory procedure in the manufacturing of thermoformed clear aligner

3.2. Directly Printed Aligners (DPA)

An FDA 510(k) clearance (2024) exists for one aligner indicated resin, signaling maturing oversight. DPA manufacture appliances by photopolymerization (e.g., DLP/LCD), avoiding thermoforming over printed models. Scoping and narrative reviews report improved workflow efficiency and potential for thinner, accurate appliances. However, accuracy depends on printer/resin interactions and post processing, and regulatory grade resins are still limited (Table 1).^{1,3-6}

Table 1. Common aligner materials, typical properties, and recycling implications

Material	Key Properties	Notes for Recycling	Typical Issues
PETG	Clear, tough; thermoformable	Mechanical reprocessing; chemical depolymerisation by glycolysis/methanolysis possible	IV loss after multiple cycles; contamination sensitivity
TPU	Elastic, flexible; stress-relaxation	Mechanical reprocessing; chemical routes (glycolysis/hydrolysis) to polyols	Property drift with heat history; additive variance
DPA Photopolymers	Direct 3D printed; cross-linked networks	Mechanical re-melt not applicable; energy recovery or advanced chemolysis emerging	Residual monomers if under-cured; regulatory constraints

4. ENVIRONMENTAL AND OCCUPATIONAL CONSIDERATIONS

4.1. Life Cycle and Carbon Impacts

The largest contributors to emissions in orthodontics are patient/clinician travel and energy use; device plastics add material impacts. Reviews recommend digital records, appointment optimization, and local workflows to reduce travel related emissions. Comprehensive LCAs specific to aligners remain scarce; more data are needed to quantify benefits of in-house printing vs outsourced manufacturing.⁵

4.2. Microplastics, Leachables, and Biocompatibility

For DPA, early in vitro work has detected low level carbonyl containing leachates that decrease with extended post curing; longitudinal in mouth data are a priority.

Wear, thermal cycling, and saliva exposure can modify polymer surfaces and release microscopic particles or leach residuals. Systematic reviews of 3D printed dental resins caution that incomplete curing and post processing may increase elutable monomers, though reported concentrations generally remain below regulatory thresholds. For thermoformed PETG/TPU aligners, leachables are typically low but depend on material formulation and hygiene practices.⁵

5. WASTE CLASSIFICATION, SEGREGATION AND DISINFECTION

Policies treat used intraoral appliances as health care waste requiring segregation to prevent sharps injuries and cross contamination. The WHO Blue Book outlines safe handling, on site containment, and transport to authorized treatment. Disinfection prior to material recovery should follow validated protocols (e.g., immersion in intermediate level disinfectants compatible with the polymer, or low temperature steam for hardware). Clear documentation and chain of custody are essential where recyclers process post-consumer medical plastics.²

6. RECYCLING PATHWAYS FOR ALIGNER PLASTICS

6.1. Mechanical Recycling (Reprocessing)

Mechanical recycling is the simplest route but sensitive to contamination. Suitable for clean production scrap and—after validated disinfection selected post-consumer items. Steps include collection, washing/disinfection, size reduction, melt filtration, and extrusion into pellets or filament. PETG and TPU can tolerate several reprocessing cycles with manageable declines in molar mass; stabilizers/chain extenders can restore viscosity and properties.⁶

6.2. Chemical Recycling of PET Family Polymers

Depolymerisation (glycolysis, methanolysis, hydrolysis) breaks PETG into monomers or oligomers (e.g., BHET, MHET), which can be purified and repolymerised. Chemical routes are advantageous for heterogeneous or contaminated streams but require energy and catalysts; emerging processes target lower temperatures and closed loop quality.⁷

6.3. Recycling of Thermoplastic Polyurethanes (TPU)

Recent reviews highlight growing interest in dynamic/repairable TPU chemistries to enable easier end of life processing. TPU waste can be mechanically reprocessed; chemical routes include glycolysis, hydrolysis, and amino lysis to recover polyols and chain-extendors.⁸

6.4. Thermal Recovery and Advanced Options

For mixed medical plastics where material recovery is impractical, energy recovery via controlled combustion may be used under stringent emissions standards. Research into enzymatic PET depolymerisation and vitrimeric/biobased polyurethanes may open future circular options for aligner class polymers.⁵ (Table 2)^{7,8,9,10}

Table 2. Recycling routes for aligner plastics: process, steps, Advantages and Disadvantages

Route	Core Steps	Advantages	Disadvantages
Mechanical reprocessing	Disinfect → shred → melt-filter → extrude	Low capex; fast; scalable	Requires clean, sorted streams; property loss without stabilization
Glycolysis (PETG)	Depolymerize to BHET/MHET → purify → repolymerise	Handles contamination; near-virgin quality	Energy/catalyst needs; solvent handling
Hydrolysis/Methanolysis (PETG)	Depolymerize to TPA/EG or DMT/EG	Monomer recovery for closed loop	Higher pressure/temperature; purification burden
TPU chemolysis	Glycolysis/hydrolysis/aminolysis to polyols	Recovers valuable polyols	Mixed TPU chemistries complicate control
Energy recovery	Controlled combustion with emissions control	Volume reduction; recovers energy	End-of-pipe; not circular; regulatory constraints

7. IMPLEMENTATION: CLINIC TO RECYCLER WORKFLOW

1. Chairside segregation: Provide puncture resistant, labelled containers for used aligners and trimmings.¹
2. Disinfection: Validate a protocol compatible with PETG/TPU/DPA materials (e.g., 70–80% ethanol or approved agents; avoid strong oxidizers).⁹
3. Storage & documentation: Log patient batches, dates, and disinfection batch numbers; maintain chain of custody.¹
4. Logistics: Partner with licensed medical waste hauliers or manufacturer take back programs; minimize transport emissions.¹
5. Preprocessing: Shredding and melt filtration for mechanical routes; solvent/chemical pretreatment for depolymerisation.¹
6. Quality control: Test melt flow index, IV (PETG), or hardness/elongation (TPU) of recyclate; add stabilizers/chain extenders as needed.¹⁰
7. End use markets: Non-medical products (e.g., lab tools, packaging, printing filament) unless closed loop quality is demonstrated.¹
8. Governance: Include EPR clauses in supplier contracts; publish annual diversion metrics and LCA updates.¹¹

8. CLINICAL BEST PRACTICE TO REDUCE WASTE

Optimize treatment planning to reduce refinements; maintain strict hygiene to extend in mouth life when clinically acceptable; use digital workflows and chairside repairs over reprints where feasible; schedule bundled appointments; and educate patients on returning used appliances.^{5,12}

9. RESEARCH GAPS AND FUTURE DIRECTIONS

Key gaps include (i) robust LCAs specific to aligners and competing workflows; (ii) standardized test methods for long term elution/micro wear in simulated oral environments; (iii) scalability studies of chemical recycling of PETG with aligner grade additives; (iv) clinical trials comparing DPA and thermoformed devices on force constancy and biodegradation; and (v) policy models for EPR, data reporting, and cross border shipments of medical plastics.^{1,13}

10. CONCLUSION

A pragmatic recycling program for aligners is feasible today using validated segregation, disinfection, and mechanical reprocessing for clean fractions, with chemical depolymerisation offering a path for contaminated PET family streams. As DPA matures and regulatory grade materials expand, integrating circular design with EPR and transparent metrics will help orthodontics shrink its plastic footprint without compromising safety or care.²

ACKNOWLEDGEMENT

Nil.

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CITATION

Vigneshwaran, K., Selvaganesh, L., Chandrasekaran, D., Purushothaman, D., Tandon, A., Angrish, N., Mohan, R., Priya, K., & Katepogu, P. (2025). Aligner Recycling: - Exploring the Processes and Methods – A Narrative Review. In *Global Journal of Research in Dental Sciences* (Vol. 5, Number 5, pp. 11–15). <https://doi.org/10.5281/zenodo.17132821>