RESEARCH PAPER

Environmental Sustainability in Orthodontics: Disposal and Recycling of Clear Aligners

Dr. Toshitha G[1], Dr. Siddarth Arya[2], Dr. Sushmitha S[3], Dr. Shwetha G S.[4]

[1]Junior resident (Post graduate student), Department of Orthodontics and dentofacial orthopedics, Rajarajeswari dental college & hospitals, Bengaluru.

[2]Professor, Department of Orthodontics and dentofacial orthopedics, Rajarajeswari dental college & hospitals, Bengaluru.

[3]Junior resident (Post Graduate), Department of Orthodontics and dentofacial orthopedics, Rajarajeswari dental college & hospitals, Bengaluru.

[4]Professor & Head of Department, Department of Orthodontics and dentofacial orthopedics, Rajarajeswari dental college & hospitals, Bengaluru

Emails: [1]dr.toshitha08@gmail.com, [2]sidflanker@gmail.com, [3]sushmitharai8129@gmail.com , [4]drshwethags@gmail.com

Received: 12th May, 2026 | **Revised:** 24th May, 2026 | **Accepted:** 14th June, 2026 | **Available Online:** 23th June, 2026

ABSTRACT

An overview of the environmental consequences of using clear aligners for orthodontic treatment. The article analyzes common aligner materials, potential hazards from improper disposal, and needs for more environmentally friendly practices. Furthermore, the current state of disposal, the applicability of the 4Rs (Reduce, Reuse, Recycle, Recover), and recycling options were provided. The majority of clear aligners contain non-biodegradable materials that create environmental and health hazards when improperly disposed of. Clear aligners exposed to saliva and biofilm are treated as biohazardous material and should not be disposed of in landfills or through incineration as they may become fragmented and release toxic carcinogenic byproducts. Presently, there is a great deal of confusion and lack of environmental awareness among the dental community and patients concerning proper disposal of clear aligners. A move toward sustainable orthodontics requires the development of a standard disposal protocol, greater education for both practitioners and patients, increased responsibility from manufacturers, and development of biodegradable materials to help reduce the waste created from clear aligners.

Keywords: Clear Aligners, Disposal, Hazards, Procedure, Waste management

How to cite this article: Toshitha G, Arya S, Sushmitha S, Shwetha GS. Environmental Sustainability in Orthodontics: Disposal and Recycling of Clear Aligners. Int J Drug Deliv Technol. 2026;16(63s):611-623. DOI: 10.25258/ijddt.16.63s.63

INTRODUCTION

Orthodontics has changed a lot since it became its field of dentistry in the early 20th century. Traditionally orthodontic appliances were made of bands and wires. Now orthodontics has options like ceramics and clear aligners. People desire treatment plans that are not cumbersome, are visually attractive and put comfort first, which has led to the evolution of treatment and technology in orthodontics. Clear aligners in particular revolutionized orthodontics with the introduction of nearly invisible appliances and have now become the treatment of choice for many orthodontists and patients alike. [1,2,3]

Modern clear aligner systems began to develop after the introduction of the clear aligner, which combined 3D digital treatment planning followed by a removable thermoformed plastic appliance. Recent advancements in digital scanning and CAD/CAM have improved the accuracy and predictability of clear aligner treatment. Patients of all ages, adults appreciate the aesthetics and convenience of clear aligners, which has grown the field beyond its traditional focus on adolescents. Due to increased consumer education and readily available technology the global clear aligner market has rapidly expanded. [1]

Clear aligners have raised concerns over waste despite their clinical advantages. Clear aligners are made of grade thermoplastic materials. These materials are made from polyurethane, polyethylene and other synthetic plastics derived from petroleum, which take a time to decompose. Discarded clear aligners may lay in a landfill or in the environment

for a time and contribute to the worsening plastic waste issue. A single clear aligner treatment consists of trays that may be changed every one to two weeks. This means that a complete clear aligner course may involve the use of a number of trays. This commits one person to use an amount of clear aligners and in the case of increased use of orthodontics frequent use of clear aligners will lead to a large volume of orthodontic waste. [1,4,5]

There is a growing demand for aligner therapy and the waste associated with clear aligners is expected to grow with the increase. This has made the need to manage aligners and dispose of them in case of a growing environmental issue. The environmental impacts of aligners do not stop with waste. Clear aligners are made from a material that does not decompose. Discarded clear aligners may accumulate in landfills. Enter natural ecosystems through municipal waste. Also the standard waste management methods for aligners may lead to environmental contamination and expose people to ecological and health concerns. Clear aligners are used as treatment options but there are limited standards for clear aligner waste management. There is knowledge on how to manage clear aligners sustainably. [4,5,6]

The World Health Organization states that effective management of health care waste and adequate government funding for disposal systems is necessary. The management of waste is therefore an important part of the health care system and the dental system. India is one of the countries where expanding clinic operations is resulting in the generation of volumes of health care waste and the need to develop better systems for the segregation, collection and treatment of waste. This is especially true of orthodontic practices which use many different kinds of disposable and single-use items with clear aligners being a fairly new and largely unrecognized contributor. This situation can be remedied to an extent via the 4Rs (Reduce, Reuse, Recycle and Recover) hierarchy. However more research is needed to support the ethical use of clear aligners and clear aligner therapies within orthodontics. [12]

Orthodontists should be collecting used aligners from their patients to dispose of them in a biomedical waste stream. It is vital to evaluate the aligner use in clear aligner therapy the environmental impact of clear aligners and the placement and closure of clear aligners beyond therapy. Analyzing the materials used the quantity consumed and the methods employed for disposal of the materials is essential. Thus this review intends to present the materials utilized in aligners the impact of clear aligners and their disposal on the ecology and the need for sustainability, in orthodontics.

Aligner Materials

Table 2. Summary of the properties of the materials under investigation.

Materials	Properties
TC-85	High flexibility, wider elastic range, slight stress decay, shape memory properties, better adaptation post-usage, viscoelastic properties, geometric stability.
Ca—medium, Essix-copopyester (PETG), Erkodur (PETG)	Smooth surface structure before thermoforming, very rough structure after thermoforming.
Duran (PETG)	Increase in yield stress after thermoforming, elastic modulus increases after thermoforming, smooth surface structure before thermoforming, very rough structure after thermoforming.
Essix ACE (PETG)	High mechanical properties, maintains high force after thermoforming, high transparency, perceptible color change after 14 days in red wine and coffee, exhibits high tensile strength and Young's modulus.
Zendura (PU)	Stiffest flexural modulus among tested materials, significant decrease in yield stress after thermoforming, increase in elastic modulus after thermoforming.
SmartTrack (PU)	Higher hardness and modulus, slightly higher brittleness, lower creep resistance compared to PETG-based products.
Essix C+ (PP-EPR)	Not soluble in any tested solvents, more crystalline characteristics, lower transparency, significant decrease in tensile strength and Young's modulus after heat treatment.

F22 Aligner	Single layer material, high stiffness, rapid stress decay in the first 8 hours, higher absolute stress values.
Erkoloc-Pro	Double layer material, lower stiffness, very constant stress release, but with lower absolute stress values.
Durasoft	Double layer material, lower stiffness, very constant stress release, but with lower absolute stress values.
F22 Evoflex	Maintained high stress rates over a 15-day period, highest final stress level with a constant stress release.
Eon (PU)	Hardness comparable to other PU-based aligners, smooth surface but with some irregularities and impurities.
SureSmile (PU)	Hardness comparable to other PU-based aligners, irregularities and impurities found on surface.
Clarity (PU)	Resistant and practically invisible material, hardness comparable to other PU-based aligners, some impurities and irregularities on surface.

Over time, the materials used for aligners have seen major improvements. At first, aligners were made from single-layer plastics, but they later developed into second-generation polyurethane materials. Now, third-generation multilayered materials are commonly used. These materials usually have both soft and hard layers. The soft layer makes the aligner more flexible and comfortable by allowing it to bend slightly, while the hard layer gives it strength, rigidity, and lasting quality. In the polyester family, polyethylene terephthalate (PET) and polyethylene terephthalate glycol (PETG) are widely used because they have strong mechanical and optical properties. Polyethylene Terephthalate (PET) PET is made by mixing ethylene glycol with terephthalic acid. [14]

It can exist in two forms: amorphous and crystalline, and each form has different characteristics:

• Amorphous PET: Clear and very flexible

• Crystalline PET: Not transparent, appears white, and offers more stiffness, hardness, and strength Depending on how it is processed, PET can be rigid or semi-rigid. It has good toughness, strong mechanical properties, and is resistant to solvents. Polyethylene Terephthalate Glycol (PETG) PETG is a non-crystalline co-polyester made from 1,4-cyclohexanedimethanol (CHDM), ethylene glycol (EG), and terephthalic acid (TPA). Important features of PETG include:

• High transparency and good appearance

• Easy flow during manufacturing

• Resistance to chemicals and environmental damage

• Strong impact resistance and durability PETG is basically a modified version of PET, where the material is treated to prevent crystallization. This gives it an amorphous structure and better clarity. With a glass transition temperature of around 80°C, PETG is easier to work with and more flexible, making it very suitable for creating clear aligners.[]

Properties of Aligners

A clear understanding of aligner material properties is fundamental when establishing appropriate disposal protocols. Since clear aligners are manufactured from durable thermoplastic polymers such as Polyurethane and PETG, their resistance to hydrolysis, chemical degradation, and mechanical wear contributes to prolonged persistence after disposal. These properties increase the likelihood of environmental accumulation and potential fragmentation into microplastics, particularly when discarded with general household plastic waste. [11,14]

Additionally, intraoral exposure subjects used aligners to saliva, microorganisms, biofilm, and organic residues, classifying them as potentially contaminated biomedical waste rather than ordinary plastic. Knowledge of the physical and chemical characteristics of aligner materials is therefore necessary to determine whether disposal by incineration, recycling, or biomedical waste segregation is most appropriate. Improper disposal, especially uncontrolled incineration, may release harmful degradation by-products from materials such as PET-G and polyurethane, further emphasizing the need for evidence-based disposal guidelines.[8,13]

Clear aligner materials should possess adequate optical, mechanical, and biological properties to ensure effective orthodontic tooth movement and patient acceptance. High optical clarity is essential, with materials ideally transmitting around 80% of

visible light to maintain esthetics. For this reason, amorphous thermoplastic polymers are preferred over crystalline polymers due to their superior translucency. Commonly used materials include Polyurethane, Polyester, Polycarbonate, Polyvinyl chloride, and PETG, owing to their favorable transparency and formability. [13,15]

Chemical stability in the oral environment is equally important, as aligners are continuously exposed to saliva, salivary enzymes, moisture, and temperature variations. Certain materials such as polycarbonate and polyamide are susceptible to hydrolytic degradation, which may alter structural integrity over time. Intraoral temperature fluctuations, especially after hot beverages, may transiently rise to approximately 57°C and can affect hardness, thickness, and flexural modulus of thermoplastic materials. Hygroscopic expansion and water absorption may further influence aligner fit and force delivery, with polyurethane-based materials showing comparatively higher water uptake than PETG.[14]

Mechanical durability is essential because aligners are subjected to continuous and intermittent forces during mastication, speech, swallowing, and parafunctional habits. Prolonged clinical use has been associated with surface wear, microcracks, delamination, reduced transparency, and biofilm deposition, which may compromise retention and force application. Surface roughness decreases progressively during wear, reducing frictional adaptation to the tooth surface. [15]

The second factor to consider is the biocompatibility. In vitro testing has found differences in terms of cytotoxic effect between available materials; specifically, Duran proved to have less cytotoxic effect compared to Biolon, Zendura, and SmartTrack, which had relatively higher effects on human gingival fibroblasts. Also, studies conducted on color stability revealed that the majority of materials are not prone to staining during regular wear, except for SmartTrack, which showed substantial staining upon exposure to coffee and red wine.

Principle of the 4rs

According to the reports provided by the United Nations and the World Resources Institute, more than 127 nations across the world have enforced various measures against the usage of single-use plastics. The Indian government enacted the Plastic Waste Management Amendment Rules in 2021, which prohibit the production, sale, and use of specific types of single-use plastic materials, to take effect from July 1, 2022. With the increase in environmental issues and regulatory restrictions concerning plastic waste, the application of the 4R principle, which includes reduce, reuse, recycle, and recover, is now more necessary than ever before. Yet, the use of the 4R waste management technique in the context of orthodontic clear aligner therapy is yet to be studied extensively. Among the 4R principles, reduction seems to be the easiest to implement for clear aligners due to their contamination and intraoral application. [9,16,17].

Hazards of Aligner to Enviornment & Health

Rise in the incidence of adults undergoing orthodontic treatments is prompting patients to opt for more aesthetic orthodontic therapies, especially clear aligners. This trend has spurred the research in developing clear polymer aligners as an alternative to fixed orthodontic devices. Commercially available aligners are made up of thermoplastic materials like polyurethanes and polyethylenes that can be molded by applying pressure or in a vacuum. Thermoplasticity of such polymers allows them to undergo molding during orthodontic treatment. [9]

Though these polymers are beneficial in clinical applications, they pose environmental hazards because they mainly originate from petroleum hydrocarbon chains. Because they cannot be readily degraded, these polymers may lead to environmental pollution in case they are incorrectly disposed of in landfills. Incineration of these materials is another option; however, this may lead to emission of toxic substances into the atmosphere. [10]

Because of the unique nature of aligners and the way they are used, disposing of the used devices requires specific measures as they may be classified both as plastic and biomedical wastes due to being exposed to various microorganisms while worn inside the oral cavity. Thus, proper separation of aligners and their further safe disposal are needed. [11]

Recycling through mechanical means is another option that can be considered as an approach to address the problem. Mechanical recycling involves transforming post-consumer plastics into granulates, which will then be re-used in manufacturing other plastics. Nevertheless, the number of post-consumer plastics currently being recycled on a global scale is insignificant compared to total plastic production. [12]

One more aspect involves the issue of chemical additive leakage from aligners' polymers. Some plastics are known to release various chemicals that may be toxic to humans. These include cyanide analogs and bisphenol A, which is frequently used for the purpose of enhancing visibility and durability. Bisphenol A has been shown to disrupt endocrine activity and contribute to numerous systemic disorders. [13]

It has also been established that long-term utilization of orthodontic appliances could lead to microplastics and nanoplastics leaking into the mouth due to degradation processes and mechanical stress acting upon the materials. The possibility of these small plastic particles entering saliva and subsequently being consumed poses further issues of chronic exposure for patients undergoing orthodontic therapy.

The exposure to microplastics has also been implicated in several other systemic processes. Cardiovascular studies have demonstrated presence of such plastic particles in arterial plaques, pointing out their involvement in processes of vascular inflammation, hypercoagulability, thrombosis, and fibrosis. [12]

Within gastrointestinal system, ingested microplastics are expected to accumulate in gastrointestinal tract and affect microbiota composition.Reported consequences include inflammation, oxidative stress, tissue injury, impaired digestive enzyme activity, and the release of pro-inflammatory mediators. Some studies also suggest translocation of these particles into the bloodstream, allowing distribution to distant organs. [12]

Experimental studies have also indicated reproductive toxicity associated with microplastic exposure. In males, microplastics may impair sperm quality and alter endocrine function, while in females they may affect ovarian structure, uterine tissues, and hormonal regulation. These concerns are particularly relevant because aligners are commonly used in adolescents and young adults. [12]

Airborne microplastics represent an additional health and environmental concern. Inhaled particles may penetrate deep into respiratory tissues, where they can trigger inflammation, oxidative damage, and compromised pulmonary function. At the same time, discarded aligners add to the growing burden of global plastic pollution. [12]

Environmental Health Perspective revealed that, even in small amounts, this chemical can cause diseases such as immune system changes, prostate enlargement, diabetes, hyperactivity, infertility, obesity, precocious puberty, and breast cancer.

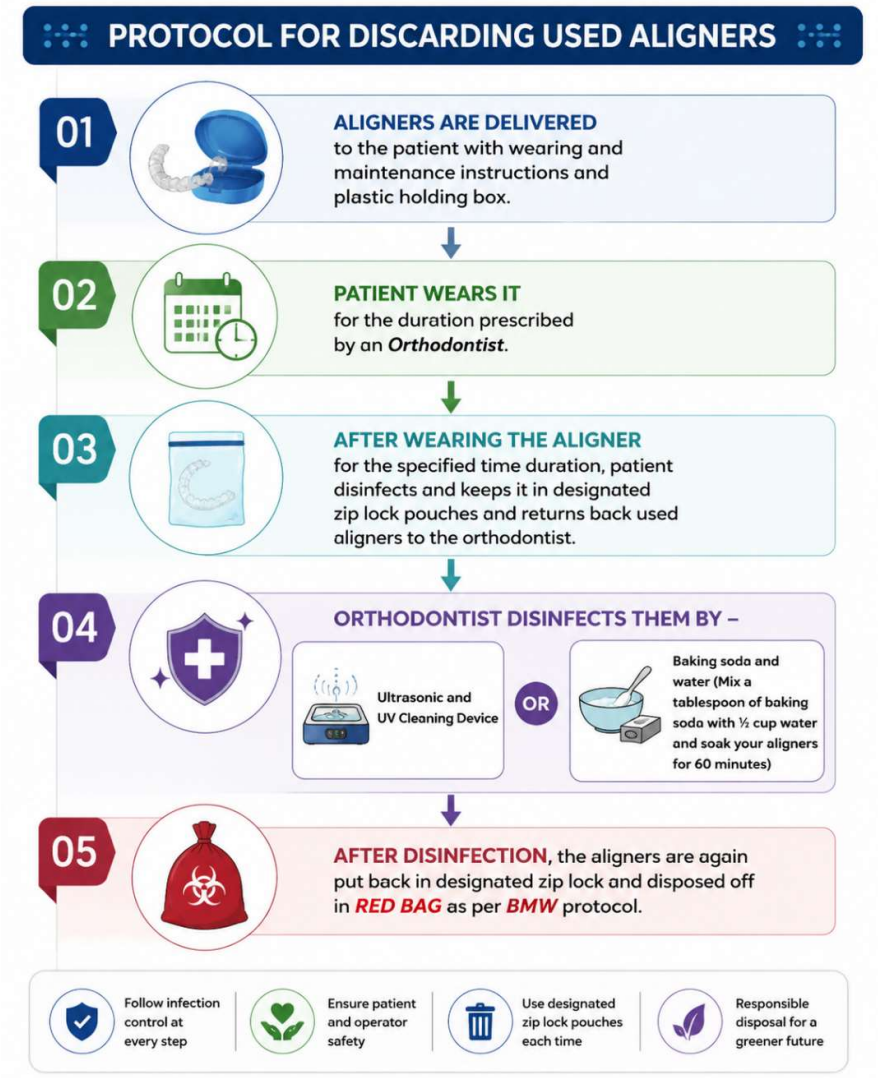
Since orthodontic retainers and aligners may be worn continuously for several years, the authors question whether these plastic particles could leach into the oral cavity and eventually enter the body. The possible health hazards associated with MNP exposure: [14]

- **Cardiovascular effects:**
  Studies have detected microplastics within arterial plaques (atheromas). The article notes that MNPs may contribute to cardiovascular abnormalities such as altered heart rate, thrombosis, fibrosis, coagulation disturbances, and vascular inflammation.
- **Gastrointestinal effects:**
  The authors discuss evidence suggesting that ingested microplastics may accumulate in the digestive tract and negatively affect gut microbiota. Reported effects include inflammation, oxidative stress, cellular damage, reduction in digestive enzyme activity, and increased secretion of inflammatory cytokines. These particles may also pass into the bloodstream and spread to other organs.
- **Reproductive toxicity:**
  Animal studies cited in the article suggest that MNP exposure can impair reproductive function in both males and females. In males, microplastics may reduce sperm vitality and disrupt endocrine regulation. In females, they may damage ovarian and uterine tissues and alter hormonal balance. The authors emphasize

that more human studies are needed, especially because aligners are widely used in adolescents and young adults.

- **Respiratory and environmental concerns:** Airborne microplastics are another concern. The paper explains that inhaled particles can penetrate deeply into lung tissues and may contribute to inflammation, oxidative stress, and impaired lung function. Additionally, discarded aligners contribute to global plastic pollution and environmental burden.

Method of Disposal of Aligners



Clear aligners are manufactured from medical-grade thermoplastic polymers and therefore should not be discarded as ordinary household waste. Invisalign identifies its aligners and Vivera retainers as Class IIa medical devices under the Medical Device Directive 93/42/EEC, indicating that used aligners may be considered contaminated biomedical waste requiring appropriate disposal and recycling procedures. Most aligners are composed of multilayered polymeric materials that combine rigidity and elasticity to facilitate orthodontic tooth movement. However, the combination of different plastics within a single appliance complicates recycling through conventional domestic plastic recycling systems. [18,19]

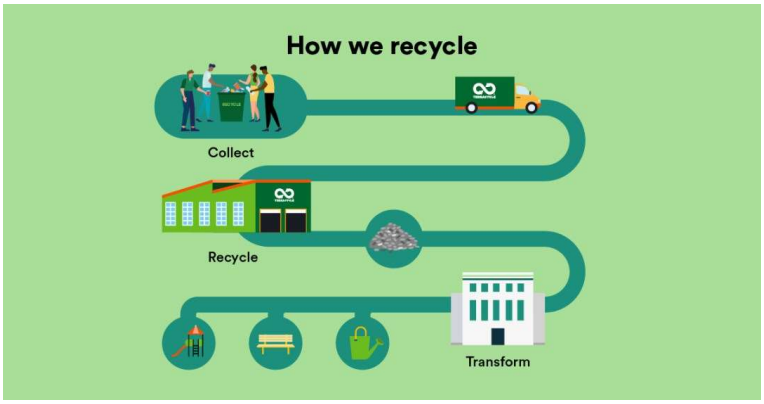
Mechanical or secondary recycling is a sensible choice and consists of turning used plastic waste into pellets that can be reused in the production of other materials. This recycling produces products from one type of plastic or a mixture of different plastics.

It is estimated that only 9% of the world's post-consumer plastic waste is mechanically recycled.Specific protocols should be implemented to collect hepatitis B (HBV) and hepatitis C (HCV) target agents. According to the guidelines of the Centers for Disease Control and Prevention (CDC), ethyl and isopropyl alcohol are effective against HBV.13 According to the literature, HBV is very sensitive to 30% 1-propanol for 1 minute, while 40% ethanol and 2- propanol alcohol is required regardless of time. Another study14 showed that 5 minutes of heat at 80 oC and UV treatment caused irreparable damage to RNA, so loss of viral RNA

Environmental concerns associated with aligner disposal arise primarily because these appliances are fabricated from non-biodegradable thermoplastics such as Polyethylene terephthalate. These materials exhibit high resistance to natural degradation and may persist in the environment for prolonged periods. In addition, combustion of thermoplastic polymers can release hazardous compounds, including dioxins and polychlorinated biphenyls, which may adversely affect ecosystems and human health. Exposure to such substances has been associated with endocrine, metabolic, reproductive, and immunological disturbances. Consequently, there is an urgent need to establish standardized protocols for the collection, segregation, and disposal of used aligners. [19]

Several initiatives have been introduced to promote sustainable recycling of orthodontic plastics. TerraCycle, in collaboration with Spotlight Oral Care, launched a recycling program for aligners of any brand, along with aligner cases and flexible plastic packaging. The collected materials are cleaned, processed, melted, and converted into reusable hard plastic products. Recycling procedures involve multiple stages including sorting, decontamination, and material separation using optical sorters, infrared sensors, air separators, and magnetic separation technologies. Despite these developments, recycling aligners remains more challenging and expensive than recycling conventional PET bottles because aligners consist of multiple plastic layers with varying compositions.[20]

In several countries, including the United States, used aligners may not be accepted in routine recycling streams because they are categorized as contaminated medical waste. To address this issue, orthodontists may play an important role by collecting used aligners from patients after treatment, disinfecting them appropriately, and directing them toward specialized recycling pathways. Such an approach may help reduce environmental contamination while minimizing the risk of cross-infection associated with indiscriminate disposal.[19]



The 4R principle—reduce, reuse, recycle, and recover—has been proposed as a framework for sustainable aligner waste management. However, its implementation in orthodontics remains limited and requires further investigation. Existing evidence suggests that awareness regarding aligner recycling and disposal among dental professionals and patients remains inadequate. Therefore, improving education among orthodontists, general dentists, and patients regarding environmentally responsible disposal practices is essential for sustainable clear aligner therapy. [21]

A survey conducted among 150 dental practitioners in Chennai demonstrated that a majority of clinicians followed at least some recommended disposal measures for used aligners. Approximately 62.7% reported segregating discarded aligners as biomedical waste, recollecting used appliances from patients, disinfecting them prior to disposal, and complying with local biomedical waste regulations. However, patient education regarding proper aligner disposal was less frequently practiced, with only 58.7% of practitioners providing disposal instructions to patients. Similarly, discussions with aligner manufacturing companies regarding disposal protocols were reported by only 54.7% of respondents. Red biomedical waste bags represented the most commonly preferred disposal method, although more than one-third of practitioners returned used aligners directly to patients without recollection. The study also identified significant associations between appropriate disposal practices and factors such as higher educational qualification, type of dental practice, years of clinical experience, and duration of aligner usage in practice. [21]

Another cross-sectional investigation involving orthodontists, general dentists, and aligner patients evaluated differences in knowledge, awareness, and disposal practices related to clear aligner waste management. The study found statistically significant variations among the three groups, with orthodontists demonstrating the highest levels of knowledge, environmental awareness, and adherence to recommended disposal protocols. General dentists showed moderate scores, whereas aligner patients exhibited comparatively limited understanding and poorer disposal practices.[22]

With regard to disposal methods, most orthodontists and general dentists recommended designated biomedical waste disposal services, while fewer patients selected this option. Disposal of aligners as biomedical waste and sterilization prior to disposal were also more commonly practiced among orthodontists compared with general dentists and patients. These findings indicate that specialist training and clinical exposure may positively influence environmentally responsible disposal behavior. [22]

Awareness concerning the environmental impact of improperly discarded aligners was highest among orthodontists, followed by general dentists and patients. Similarly, orthodontists demonstrated greater familiarity with dedicated recycling programs for clear aligners compared with the other groups. Overall, the studies highlighted a substantial gap between knowledge and practical implementation of sustainable disposal practices. The authors emphasized the importance of educational initiatives, standardized clinical guidelines, manufacturer participation, and development of organized recycling systems to reduce the environmental burden associated with clear aligner therapy. [20]

Steps of Disposal [18]

Step 1: Patient Education; At the start of treatment, patients should be informed regarding:

- Environmental burden of aligner waste, Proper collection methods, Avoidance of general trash disposal .Several studies have shown poor awareness among orthodontists and patients regarding aligner disposal practices.

Step 2: Collection of Used Aligners: Patients should be instructed to:

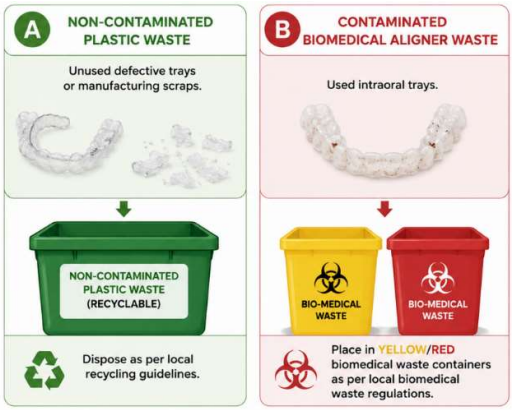
- Store old aligners in provided collection bags, sealed containers, or designated return pouches . Avoid throwing in household waste, flushing into drainage systems, open burning.

Step 3: Segregation in Clinic: The returned aligners should be segregated into:

A. Non-contaminated plastic waste- Unused defective trays or manufacturing scraps.

B. Contaminated biomedical aligner waste- Used intraoral trays.

Used aligners should be placed in yellow/red biomedical waste containers according to local biomedical waste regulations.



Step 4: Disinfection / Sterilization: Before recycling or handling:

Method A – Ultrasonic and UV Disinfection

- Place aligners in an ultrasonic cleaning device for 5–10 minutes.
- Follow with ultraviolet (UV) sterilization according to manufacturer instructions.

Method B – Chemical Cleaning

- Prepare a solution containing:
  - 1 tablespoon baking soda
  - ½ cup water
- Soak the aligners for approximately 60 minutes.

Recycling Protocol [25]

A. Manufacturer Take-Back Programs

Some aligner companies collaborate with recycling firms for:

Collection → sterilization → polymer reclamation.

Example:

- Invisalign–TerraCycle pilot recycling initiative.

B. Shipping and Transportation

After collection, the aligners are packed in designated recycling containers and transported to specialized recycling facilities. Transportation is usually coordinated through mail-back systems or centralized recycling networks. During shipment, biomedical contamination precautions are followed to ensure safe handling of used intraoral appliances.

C. Sorting and Segregation

At the recycling facility, the returned materials undergo manual and automated sorting. Plastics are separated according to polymer composition, density, color, and contamination status. Technologies such as optical sorters, infrared sensors, air separators, and magnetic separation systems are used to distinguish multilayer thermoplastics from other waste materials. Sorting is especially important because aligners contain complex combinations of polymers such as PETG and polyurethane, making recycling more challenging than conventional plastic recycling.

D. Cleaning and Decontamination

Before processing, used aligners undergo industrial cleaning and decontamination to remove saliva, biofilm, organic debris, and microbial contamination. Washing systems use detergents, disinfectants, ultrasonic cleaning, and high-temperature water treatment to prepare the plastic for recycling. This step is essential because used aligners are considered potentially contaminated biomedical waste.

E. Shredding Process

After cleaning, the aligners are mechanically shredded into small plastic fragments or flakes. Shredding reduces material size, facilitates uniform melting, and improves processing efficiency during recycling. The shredded material is further screened to remove impurities and non-recyclable contaminants.

F. Pelletizing

The shredded thermoplastic material is melted and converted into small uniform pellets through extrusion and pelletization processes. These recycled pellets serve as secondary raw materials that can be reused in manufacturing various plastic products. Pelletization helps standardize the recycled polymer for future industrial applications.

G. Raw Material Production and Reuse

The recycled pellets are utilized as raw materials for manufacturing secondary plastic products such as storage containers, outdoor furniture, industrial components, and reusable plastic goods. Although aligner-grade polymers are difficult to reprocess into new medical devices because of strict regulatory and biocompatibility requirements, recycling into non-medical plastic products helps reduce landfill accumulation and environmental pollution [20]

Biomedical Waste Disposal Protocol (When Recycling Is Not Available)

If recycling facilities are unavailable:

Recommended method:

Authorized biomedical waste disposal

Protocol: Send to certified biomedical waste management facility to undergo: controlled incineration, high-temperature destruction.

Incineration of Aligners

Incineration is one of the disposal methods considered for used clear aligners because these appliances are classified as contaminated biomedical plastic waste after intraoral use. Since aligners are continuously exposed to saliva, microorganisms, and biofilm, direct disposal into general household waste may increase the risk of environmental contamination and cross-infection.

Controlled biomedical waste incineration can reduce waste volume and eliminate microbial contamination; however, it also presents important environmental concerns.

Most clear aligners are manufactured from thermoplastic polymers such as Polyethylene terephthalate glycol, Polyurethane, and Polycarbonate. During incineration, these materials may undergo thermal degradation and release potentially hazardous gaseous by-products. Studies evaluating the combustion of aligner materials have detected compounds such as aldehydes, ketones, hydrocarbons, aromatic compounds, and chlorinated substances. Certain toxic emissions, including dioxins and polychlorinated biphenyls (PCBs), may contribute to environmental pollution and adverse biological effects.

Gas chromatography–mass spectrometry (GC-MS) investigations on incinerated aligners demonstrated that thermal decomposition of PETG-based materials generates volatile organic compounds and microparticles that may negatively affect air quality. Incomplete combustion of polymeric materials may further increase the release of toxic substances into the atmosphere. Consequently, uncontrolled burning of aligners is strongly discouraged. [19]

Although high-temperature biomedical incinerators equipped with emission-control systems may reduce microbial contamination and minimize toxic emissions, incineration is still considered less environmentally sustainable than recycling approaches. Recycling programs and structured collection systems are therefore increasingly recommended as preferable alternatives for managing clear aligner waste.

Advantages of Incineration (based on WHO Disposal Guidelines) [23,24]

- Reduces biomedical waste volume
- Eliminates microbial contamination
- Prevents spread of infection
- Useful where recycling facilities are unavailabl

Incineration Concerns [14,23,24]

Studies evaluating incineration of PET-G and polyurethane aligners demonstrated release of multiple toxic compounds during burning.

Reported emissions include:

- aromatic hydrocarbons,
- aldehydes,
- volatile organic compounds,
- potentially carcinogenic substances.

Therefore open burning is contraindicated, uncontrolled incineration should be avoided. Only regulated biomedical incinerators with emission controls are recommended.

CONCLUSION

The increasing popularity of clear aligner therapy has significantly improved esthetics and patient acceptance in orthodontic treatment; however, it has also contributed to the growing burden of non-biodegradable plastic waste. Since aligners are fabricated from complex thermoplastic polymers and are exposed intraorally to saliva, microorganisms, and biofilm, their disposal presents both environmental and biomedical concerns. Improper disposal through routine household waste or uncontrolled incineration may contribute to environmental pollution, release of toxic by-products, and potential microplastic contamination.

Current evidence emphasizes the importance of implementing standardized disposal protocols involving segregation, disinfection, biomedical waste management, and organized recycling strategies. Recycling initiatives such as those developed by TerraCycle demonstrate the potential for sustainable management of aligner waste, although challenges related to multilayer polymer composition and contamination continue to limit large-scale recycling efficiency. In addition, studies have identified deficiencies in awareness and disposal practices among both dental professionals and patients, highlighting the need for improved education and clinical guidelines.

Adoption of environmentally responsible approaches based on the principles of reduce, recycle, and recover may help minimize the ecological impact of clear aligner therapy. Greater collaboration among orthodontists, manufacturers, waste-management agencies, and policymakers is essential to develop safe, practical, and sustainable disposal systems. Future research should focus on biodegradable aligner materials, improved recycling technologies, and evidence-based waste management protocols to support environmentally sustainable orthodontic practice.

While increasing attention has been directed toward the environmental implications and disposal of clear aligners, existing evidence remains insufficient to formulate a definitive disposal protocol. Future research should focus on validating sustainable

waste-management strategies and establishing standardized guidelines for clinical practice.

REFRENCES

1. Weir T. Orthodontic Aligners: Current Perspectives for the Modern Orthodontic Office. *Dent J (Basel).* 2023;11(10):233. doi:10.3390/dj11100233.
2. Lou T, Mair A. An Historical Overview of Clear Aligner Therapy: The Evolution of Clear Aligners. *Oral Health*. 2020 Sep 14.
3. Nagni M, Balbi B, Galati CM, Boschi G, Mangino G, Brucoli O. Evolution of orthodontics: from fixed appliances to clear aligners. An enhanced narrative review. *Annali di Stomatologia*. 2026;17(1):228-232. doi:10.59987/ads/2026.1.228-232
4. Richa, Bansal M, et al. Environmental sustainability in orthodontics: challenges and opportunities. *J Orthod Sci.* 2024.
5. Ahamed S, Kumar P, Priya S. Plastic Waste Generated by Clear Aligner Therapy: An Emerging Environmental Challenge. *Int Orthod.* 2023.
6. Al Mortadi N, Kapsalas A, et al. Sustainability in Orthodontics: A Narrative Review. *European Journal of Orthodontics*. 2023.
7. Nemisri K, Balasubramanian KR, Diwakar MP. Assessment of Clear Aligner Disposal Practices among Dentists in Chennai: A Questionnaire-based Survey. J Oral Health Comm Dent 2025;19(2):44–50
8. Khamatkar A, Sawant V, Kadam V, Garde T, Jadhav P, Shroff K. Knowledge awareness and practices of aligner disposal among orthodontist, general dentist and patients undergoing aligner orthodontic therapy: a cross sectional study. *International Journal of Environmental Sciences*. 2025;11(21s):1874-1884. doi:10.64252/4mnvn229
9. Macrì, M.; D'Albis, V.; Marciani, R.; Nardella, M.; Festa, F. Towards Sustainable Orthodontics: Environmental Implications and Strategies for Clear Aligner Therapy. Materials 2024, 17, 4171
10. Raj DR, Sowmya J, Verma S, Raj GP, Chitra P. Awareness regarding clear aligner disposal among orthodontists and general dentists: A cross-sectional survey-based study. *Journal of Indian Orthodontic Society*. 2024;58(4):353-362. doi:10.1177/03015742241264372.
11. Orthodontics Lombardo L, Martines E, Mazzanti V, Arreghini A, Mollica F, Siciliani G. **Stress relaxation properties of four orthodontic aligner materials: a 24-hour in vitro study.** *Angle Orthod.* 2017
12. World Health Organization (WHO). Safe Management of Wastes from Health-Care Activities. 2nd ed. Geneva: WHO; 2014.
13. Ahrari et al. **The surface roughness, mechanical properties, and cytotoxicity of clear aligner materials.** *Am J Orthod Dentofacial Orthop.* 2020.
14. Gupta S, Ahluwalia R, Gupta N, Rana S. Aligners- Their Properties and Disposal. *Journal of Pharmaceutical Negative Results*. 2022;13(Special Issue 6):186-188. doi:10.47750/pnr.2022.13.S06.027
15. Agarwal C, Rai D, Sharma S, Tiwari A, Anamika, Nidhi, Malviya U. Properties Overview of Aligners. *International Journal of Dental and Medical Sciences Research*. 2024;6(4):173-178.
16. United Nations Environment Programme, World Resources Institute. Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations. Nairobi: UNEP; 2018.
17. Government of India, Ministry of Environment, Forest and Climate Change. Plastic Waste Management Amendment Rules, 2021. New Delhi: Gazette of India; 2021.
18. Mounitha S, Basheer S, Rajan S, Priya RPSM, Devadoss P. Disposal of orthodontic aligners: A review. *International Journal of Creative Research Thoughts (IJCRT).* 2023;11(11):d393-d399.
19. Peter E, Monisha J, George SA. **Are clear aligners environment friendly?** American Journal of Orthodontics and Dentofacial Orthopedics. 2022;161(5):619–620. doi:10.1016/j.ajodo.2021.12.012.
20. TerraCycle Recycling Program Reports and Sustainability Initiatives
21. Gautam A, Mithun K, Saini P, et al. *Knowledge and awareness regarding disposal and recycling practices of clear aligners among dental professionals.* Journal of Orthodontic Research. 2023

22. Saini P, Gautam A, Mithun K, et al. *Knowledge, awareness, and practices regarding disposal and recycling of clear aligners among orthodontists, general dentists, and patients: A cross-sectional survey.* Journal of Orthodontic Research. 2023
23. World Health Organization. *Health-care waste*. Geneva: WHO; 2024. Available from: WHO Health-care Waste Guidelines
24. World Health Organization. *Safe management of wastes from health-care activities*. 2nd ed. Geneva: WHO; 2014. Available from: WHO Safe Management of Healthcare Waste
25. TerraCycle. *Dental Aligners Zero Waste Box™* [Internet]. Trenton (NJ): TerraCycle; cited 2026 Jun 14. Available from: TerraCycle Dental Aligners Zero Waste Box