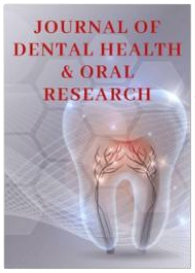

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Review Article

Environmental Impact of Clear Aligner Therapy: Addressing the Hidden Burden of Plastic Waste in Modern Orthodontics

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Abstract

Objective: To critically evaluate the environmental impact of clear aligner therapy, with emphasis on material usage, waste generation and disposal challenges.

Methods: A narrative review of current literature was conducted using electronic databases including PubMed, Scopus and Google Scholar. Relevant studies focusing on aligner materials, manufacturing processes, environmental impact and waste management were included.

Results: Thermoformed aligners demonstrate significant material wastage due to trimming and model-based workflows. Direct 3D printing technologies may reduce solid waste but introduce concerns related to resin handling and disposal. Repeated aligner replacement contributes to substantial biomedical plastic waste, with limited recycling options and inconsistent disposal practices.

Conclusion: Clear aligner therapy represents a growing environmental concern in orthodontics. Sustainable solutions require advancements in biomaterials, optimized manufacturing techniques and implementation of standardized disposal protocols.

Keywords: Clear Aligners; Sustainability; Plastic Waste; Biomedical Waste; Digital Orthodontics; Environmental Impact

Introduction

Clear aligner therapy has significantly transformed orthodontic practice by offering improved esthetics, enhanced patient comfort and integration with digital workflows [1-7]. Its widespread adoption reflects a paradigm shift toward minimally invasive and patient-friendly treatment modalities.

However, alongside these advantages lies an underrecognized concern: the environmental impact associated with aligner use. Increasing attention has been directed toward plastic waste accumulation, microplastic pollution and sustainability challenges in healthcare systems [1,2,4,8].

Unlike conventional orthodontic appliances, aligner therapy requires the sequential use of multiple thermoplastic trays. This repetitive production and disposal cycle contributes to cumulative environmental burden [1,5]. Furthermore, evolving manufacturing techniques such as thermoforming and direct 3D printing introduce distinct ecological challenges [2,3].

The aim of this review is to critically evaluate the environmental implications of clear aligner therapy, focusing on material composition, manufacturing processes, waste generation and disposal challenges, while highlighting strategies for sustainable orthodontic practice.

Materials and Methods

A narrative review of the literature was conducted using PubMed, Scopus and Google Scholar databases. Keywords included "clear aligners," "plastic waste," "sustainability," "orthodontics," and "biomedical waste". Relevant English-language articles addressing aligner materials, production techniques, environmental impact and waste management were included. Due to the narrative nature of this review, strict inclusion and exclusion criteria were not applied.

Material Composition of Clear Aligners

Clear aligners are commonly fabricated using thermoplastic polymers such as Polyethylene Terephthalate Glycol (PET-G), polyurethane and multilayer composite materials. These materials are selected for their mechanical strength, flexibility and transparency.

However, these polymers are largely non-biodegradable and persist in the environment for extended periods, contributing to long-term plastic pollution and ecological burden [2,8].

Sources of Plastic Waste in Aligner Therapy

Thermoformed Aligners

Thermoforming remains the most widely used method for aligner production. It involves molding heated thermoplastic sheets over dental models. This process is associated with significant material wastage due to trimming, as well as additional waste from repeated model fabrication [1,5].

Direct 3D Printed Aligners

Direct 3D printing has emerged as an alternative approach aimed at improving material efficiency [3]. However, it introduces environmental concerns related to photopolymer resins, support structures and post-processing waste, which may pose ecological and health risks [2,3].

Biomedical Waste Generation

Aligners are typically replaced every one to two weeks, resulting in the disposal of numerous plastic appliances over the course of treatment. Despite being intraoral devices, they are frequently discarded in general waste due to lack of awareness and absence of standardized disposal protocols [4,6,9].

Environmental Impact

Microplastic Contamination

Discarded aligners can fragment into microplastics, which may enter soil and aquatic ecosystems and potentially the human food chain [2,4].

Carbon Emissions

Manufacturing, packaging and transportation processes contribute to greenhouse gas emissions associated with aligner therapy [1,5].

Accumulated Waste Burden

The increasing demand for clear aligners has resulted in a significant rise in plastic waste generation globally [1].

Disposal Challenges

The disposal of clear aligners is complicated by their mixed polymer composition and contamination from intraoral use, limiting recycling potential [6].

Studies indicate that orthodontists are more likely to utilize biomedical waste disposal systems, whereas general dentists frequently dispose of aligners in regular garbage [9]. To address this issue, structured disposal protocols have been proposed, including patient return of used aligners, disinfection using ultraviolet light or cleansing agents and disposal in designated biomedical waste containers (Fig. 1) [9].

Comparison Between Thermoformed and 3D Printed Aligners

Parameter	Thermoformed Aligners	3D Printed Aligners
Material wastage	High	Moderate
Model requirement	Required	Not required
Waste type	Plastic sheets	Resin and supports
Sustainability	Lower	Potentially higher

Figure 1: Comparison between thermoformed and 3D printed aligners.

Discussion

This review highlights the multifactorial environmental burden associated with clear aligner therapy [1,5,8]. While thermoforming contributes significantly to material wastage, direct 3D printing introduces concerns related to chemical waste and resin disposal [2,3].

Improper disposal practices and lack of awareness further exacerbate environmental impact. Evidence suggests that knowledge regarding appropriate aligner disposal is inconsistent among dental professionals [9].

Microplastic contamination and carbon emissions further underscore the need for sustainable approaches in orthodontic practice [2,4].

A multidisciplinary approach involving clinicians, manufacturers and policymakers is essential to address these challenges effectively.

Future Directions

Future research should focus on the development of biodegradable or recyclable aligner materials without compromising clinical performance [2,8]. Life cycle assessment studies are required to evaluate environmental impact across all stages of aligner therapy [1,5]. Implementation of circular economy models, including aligner recycling and take-back programs, is recommended [6,9]. Advancements in 3D printing technology should aim to reduce resin waste and improve sustainability [3]. Policy development and educational initiatives are essential to promote environmentally responsible orthodontic practices [4,9].

Conclusion

Clear aligner therapy contributes significantly to plastic waste generation and environmental burden in modern orthodontics. Sustainable material innovation, efficient manufacturing processes and standardized disposal protocols are essential to mitigate this impact.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Statement

The project did not meet the definition of human subject research under the purview of the IRB according to federal regulations and therefore was exempt.

Informed Consent Statement

Not Applicable.

Authors' Contributions

All authors contributed equally to this paper.

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