



Sustainability in Orthodontics: Innovations, Challenges, and Opportunities — A Review

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DOI: [10.5281/zenodo.18804658](https://doi.org/10.5281/zenodo.18804658)

Submission Date: 05 Jan. 2026 | Published Date: 28 Feb. 2026

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Abstract

Sustainability is rapidly moving from a background ethic to an operational imperative in healthcare. Orthodontics contributes uniquely to environmental burdens through frequent patient visits, material consumption, laboratory workflows, and energy-intensive sterilization cycles. This review synthesizes contemporary evidence and clinical strategies aimed at reducing the ecological footprint of orthodontic practice. Emphasis is placed on life-cycle assessment (LCA) data for orthodontic appliances, digital workflows, recyclable and biodegradable materials, reuse of orthodontic components, energy and water conservation, and teleorthodontics. Emerging innovations, including additive manufacturing, biodegradable polymers, nanomaterials, and green clinic design, are highlighted. Barriers such as cost, regulation, awareness, and standardization are discussed alongside future directions involving sustainability education, expanded LCA research, and eco-certification programs. Collectively, these strategies demonstrate that environmentally responsible orthodontics is achievable through clinician commitment, manufacturer collaboration, and evidence-driven policy.

Keywords: sustainability, orthodontics, digital dentistry, biodegradable materials, life cycle assessment.

Introduction

Healthcare systems contribute significantly to greenhouse gas emissions, with dentistry accounting for a measurable share⁽¹⁾. Within dentistry, orthodontics imposes distinct environmental pressures owing to the repetitive and long-term nature of treatment. Major contributors include impression materials, gypsum casts, single-use plastics (elastomers, packaging), sterilization cycles, patient transport, and energy-intensive clinical operations^(1,2).

The push toward sustainability is not only an ethical obligation but also a practical necessity as global resource pressures increase. Clinicians, manufacturers, and policymakers now share a collective responsibility to adopt and accelerate environmentally conscious practices in orthodontics. This review explores evidence-based strategies, emerging technologies, and systemic challenges while presenting actionable recommendations for a greener orthodontic future.

The Environmental Burden of Orthodontics

Clinical waste streams

Orthodontic clinics generate a mix of biomedical, recyclable, and general waste. Single-use consumables such as gloves, sterile pouches, disposable trays, elastomeric ligatures, and power chains represent a major share ⁽³⁾. Elastomeric materials, in particular, are manufactured from non-biodegradable polymers and accumulate significantly across long treatment cycles, raising questions about their long-term environmental legacy ^(3,4).

Impression and model production

Traditional alginate impressions and gypsum models are resource-heavy, requiring mining, manufacturing, transport, and eventual disposal. Their single-use nature compounds the waste burden. Intraoral scanning and digital models eliminate much of this consumption, significantly lowering material demand while reducing the physical storage needs of clinics. LCA comparisons have confirmed reduced emissions and waste in digital workflows, though hardware production, maintenance, and resin-based 3D printing add their own environmental costs ^(2,5).

Energy and water consumption

Daily operations such as autoclaving, ultrasonic baths, lighting, and Heating Ventilation and Air-Conditioning (HVAC) account for substantial resource use. Older, inefficient autoclaves and lighting systems increase energy per cycle, while excessive water flow in dental units amplifies consumption. Replacing these with efficient autoclaves, LED lighting, and water-saving systems directly lowers per-patient resource intensity ⁽¹⁾.

Patient transport and appointment frequency

Orthodontic treatment requires regular follow-ups spanning 18–24 months. Each journey contributes to cumulative transport-related emissions, particularly for patients traveling long distances. Incorporating teleorthodontics has been shown to reduce in-person visits without compromising care, significantly lowering carbon emissions linked to patient transport ⁽⁶⁾.

Evidence from Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is critical in quantifying environmental impact across a product's "cradle-to-grave" journey. A comparative LCA of Hawley versus Essix retainers demonstrated significant differences in energy consumption and raw material use, highlighting the role of appliance selection in sustainability ^(2,7). Broader dental LCAs similarly emphasize that while digital workflows can reduce waste and transport emissions, the environmental savings depend on the choice of printer, resin chemistry, and post-processing waste handling ^(5,8). These findings reinforce that sustainability lies not only in adopting new technologies but in how responsibly they are implemented.

Sustainable Clinical Strategies

Digital impressions and model reduction

Intraoral scanning eliminates the routine use of alginate and gypsum, reducing raw material extraction, waste, and storage space requirements. Digital files also streamline laboratory communication and minimize shipping emissions. However, 3D printing of models introduces new challenges: printer energy demand, resin waste, and post-processing solvent disposal. Sustainable benefits depend on responsible practices, including choosing efficient printers, using recyclable or bio-based resins, and implementing recycling streams for failed prints ⁽⁵⁾.

Reducing single-use plastics

Disposable plastics remain a core contributor to orthodontic waste. Substituting reusable metal impression trays, using bulk packaging, and requesting recyclable shipping materials are immediate steps toward waste reduction. Excitingly, biodegradable elastomeric ligatures and chains are under active development. Early studies demonstrate promising mechanical properties and antibacterial potential, though long-term clinical validation remains essential before widespread adoption ^(9,10).

Reuse and recycling of metallic components

Reprocessing stainless steel brackets and archwires has been tested using methods such as sandblasting, chemical cleaning, and autoclaving. Several studies report acceptable bond strength and mechanical properties after recycling, though outcomes vary based on method and the number of reuse cycles ⁽¹¹⁾. Recycling metals through certified channels, even when re-use is prohibited by regulation, ensures valuable materials are recovered instead of discarded ⁽¹²⁾.

Energy and water conservation

Replacing halogen lighting with LEDs, using energy-efficient autoclaves, and maintaining HVAC systems directly reduce resource use. Smart scheduling (batch sterilization cycles, shutting down idle equipment) also minimizes energy waste. Dental units fitted with flow restrictors and water-saving features reduce overall water consumption. Routine servicing of sterilizers further ensures efficiency and prolongs device lifespan ⁽¹⁾.

Waste segregation

Segregating biomedical waste from recyclable plastics and metals is critical for compliance and sustainability. Effective segregation ensures that potentially recyclable materials are not contaminated and can enter legitimate recycling streams. Partnering with certified biomedical waste handlers and recycling agencies is recommended to achieve both safety and environmental benefits ^(4,12).

Teleorthodontics

Teleorthodontics offers a clear sustainability benefit by reducing unnecessary patient travel. Remote monitoring systems and virtual consultations have been shown to cut down appointment frequency without compromising outcomes. A recent study confirmed significant reductions in CO₂ emissions when teledentistry was incorporated into orthodontic care ⁽⁶⁾. In addition to environmental gains, teleorthodontics increases patient convenience and clinic efficiency, creating a win-win scenario.

Emerging Innovations

Additive manufacturing

3D printing enables on-demand production of aligners, retainers, and appliances, reducing overproduction and excess inventory. Transport-related emissions also decrease when appliances are produced chairside. Yet, sustainability is only achieved when resin recycling, waste minimization, and proper post-processing are in place. Without these, additive manufacturing risks shifting — rather than reducing — the environmental burden ⁽⁸⁾.

Biodegradable and recyclable polymers

A new generation of polymers for aligners and elastomerics is under development. Biodegradable or recyclable aligners, when paired with take-back programs, could drastically reduce plastic waste. Initial results suggest that mechanical properties can be preserved, though large-scale clinical validation and infrastructure for recycling are urgently needed ^(9,10).

Nanomaterials and coatings

Nano-coated archwires, brackets, and elastomerics with antimicrobial properties offer indirect environmental benefits. By reducing plaque accumulation and white spot lesions, they may decrease the need for additional interventions, visits, and materials. However, questions remain about the long-term environmental safety of nanoparticle production, disposal, and potential leaching ⁽¹²⁾.

Green clinic design

The green dental clinic model integrates sustainable strategies at multiple levels: minimizing single-use plastics, adopting digital workflows, energy-efficient sterilization systems, and prioritizing recyclable packaging. Infrastructure-level decisions — such as optimized natural lighting, smart HVAC zoning, and renewable energy integration — compound these benefits. Beyond resource conservation, green design fosters a culture of responsibility and visibly aligns practices with global healthcare sustainability goals ^(13–16).

Barriers to Sustainable Practice

Despite available strategies, several obstacles slow adoption.

- **Cost:** Upfront expenses for digital scanners, energy-efficient autoclaves, and eco-friendly infrastructure remain a hurdle for many practices ⁽¹⁾.
- **Regulation:** Jurisdictional policies often restrict reuse of brackets or wires, limiting opportunities for material conservation.
- **Awareness:** Surveys reveal that many orthodontists underestimate the scale of their environmental impact ⁽³⁾.
- **Standardization:** The absence of unified sustainability metrics prevents benchmarking and limits policy enforcement ⁽¹⁾.

Future Directions

- **Education:** Incorporating sustainability training into orthodontic curricula is essential to foster environmentally responsible practitioners.
- **Research:** Expansion of LCA research across orthodontic appliances and workflows will provide robust evidence for guiding sustainable choices.
- **Industry partnerships:** Collaboration with manufacturers is required to develop biodegradable polymers, recyclable aligners, and sustainable packaging.
- **Eco-certification:** Development of accreditation frameworks for “green orthodontic clinics” would standardize best practices and incentivize adoption ^(1,7).

Conclusion

Sustainability in orthodontics is no longer aspirational — it is an ethical and professional necessity. Strategies such as digital workflows, biodegradable materials, responsible recycling, energy conservation, and teleorthodontics provide measurable benefits. Overcoming barriers requires collective action among clinicians, educators, manufacturers, and policymakers. With evidence-driven strategies and systemic commitment, orthodontics can meaningfully reduce its ecological footprint while continuing to deliver high-quality care.

References

1. Hackley, D. M., Moylan, H., El Omari, J., & Brook, I. (2024). Sustainability in dentistry: An overview for oral healthcare. *British Dental Journal*, 236(3), 123–130.
2. Tan, T. Y. D., Zrnc, T. A., Loy, B. A., Rylski, A., Schmidlin, P. R., Attin, T., *et al.* (2024). A comparative life cycle assessment of Hawley and Essix retainers. *Journal of Dentistry*, 138, 104736.
3. Zia, N., Rashid, H., & Baig, M. (2024). Sustainability in dentistry: Assessing knowledge, attitude, and practices of dental students and professionals. *International Dental Journal*, 74(2), 101–107.
4. Shanbhag, S., *et al.* (2024). Digital dentistry and sustainability: Are we ready for a green transition? *Clinical Oral Investigations*, 28(1), 15–23.
5. Migliorati, M., Greco, M., & Caprioglio, A. (2025). Effect of 3D printing settings on mechanical properties of orthodontic appliances. *Journal of Orthodontics*, 52(1), 45–52.
6. Danesh, D. O., Newton, J. T., & Patel, S. (2025). The impact of teledentistry on travel distance and carbon emissions. *Journal of the American Dental Association*, 156(2), 89–96.
7. Patel, A., & Sood, A. (2023). Sustainability in orthodontics. *Journal of Orthodontics*, 50(3), 266–267.
8. Morris, H., Green, L., & Clark, J. (2023). Life cycle assessment of orthodontic appliances: Environmental implications. *The Angle Orthodontist*, 93(4), 567–575.
9. Bian, C., Li, Y., Zhang, J., & Liu, P. (2024). A new generation of orthodontic elastomeric ligature to reduce demineralization. *Journal of Orthodontic Research*, 12(2), 85–92.
10. Eskandari, F., Tavana, S., & Shafiei, F. (2024). Sustained antibacterial activity of orthodontic elastomeric ligatures coated with bacterial nanocellulose. *PLoS ONE*, 19(1), e0289934.
11. Khanal, P. P., *et al.* (2021). Effect of different methods of recycling stainless steel orthodontic brackets: A comparative study. *European Journal of Orthodontics*, 43(5), 539–546.
12. Wiśniewska, P., Nowak, J., & Marciniak, J. (2023). Biomaterials recycling: A promising pathway to sustainability. *Frontiers in Biomaterials Science*, 2, 117384.
13. Rajan, V., Mehta, K., & Sharma, R. (2025). Energy-efficient orthodontic clinic design: Strategies and implementation. *Journal of Dental Health and Environment*, 9(1), 21–28.
14. Avinash, B., Avinash, B. S., Shivalinga, B. M., Jyothikiran, S., & Padmini, M. N. (2013). Going green with eco-friendly dentistry. *Annals of Essences of Dentistry*, 5(2), 38–43.
15. Azarpazhooh, A., Dao, T., & Friedman, S. (2009). The eco-dentistry: The environment-friendly dental practice. *Journal of the Canadian Dental Association*, 75(7), 449–452.
16. Duane, B., Harford, S., Steinbach, I., Pasdeki-Clewer, E., Stancliffé, R., & Sherman, J. (2019). Environmental sustainability in dentistry: A call for action. *British Dental Journal*, 226(10), 779–784.

CITATION

Priya, B. M., Chandrasekharan, D., Tandon, A., Angrish, N., Katepogu, P., Mohan, R., & Purushothaman, D. (2026). Sustainability in Orthodontics: Innovations, Challenges, and Opportunities — A Review. *Global Journal of Research in Dental Sciences*, 6(2), 68–71. <https://doi.org/10.5281/zenodo.18804658>