Journal of Advanced Medical and Dental Sciences Research

@Society of Scientific Research and Studies NLM ID: 101716117

Journal home page: www.jamdsr.com doi: 10.21276/jamdsr Indian Citation Index (ICI) Index Copernicus value = 100

(e) ISSN Online: 2321-9599; (p) ISSN Print: 2348-6805

Review Article

Eco-Orthodontics: Sustainable Materials (Waste Reduction in Modern Orthodontic Practice)

Radha Nivedha R[1], Radha Nirubama R[2], Nivedhita A.T[3]

[1,2]CRI, Thai Moogambigai Dental College & Hospital, Chennai, India;
[3]Lecturer, Department of Orthodontics and Dentofacial Orthopedics, Thai Moogambigai Dental College & Hospital, Chennai, India

ABSTRACT:
Eco-orthodontics represents a rapidly evolving approach aimed at reducing the environmental footprint of orthodontic care through sustainable materials, waste-reduction systems, and energy-efficient technologies. Modern orthodontic practice contributes significantly to healthcare-related emissions due to high plastic consumption, extensive packaging, disposable impression materials, and energy-intensive digital equipment. Emerging sustainable solutions including biodegradable PLA-based aligners, recyclable metals, eco-friendly elastomerics, and low-toxicity adhesives support a shift toward greener clinical materials. Waste-minimization strategies such as digital impressions, reusable instruments, metal recycling, paperless workflows, and resource-efficient sterilization further reduce landfill burden and chemical discharge. Advancements in digital orthodontics, 3D printing, and AI-driven clinic operations enhance efficiency while lowering energy and material use. Future directions emphasize compostable appliances, green resins, carbon-neutral supply chains, and blockchain-enabled lifecycle tracking.
Keywords: Eco-orthodontics, Sustainable materials, Waste reduction, Digital dentistry, Carbon footprint reduction

Received: 10 November, 2025 Accepted: 13 December, 2025 Published: 15 December, 2025

Corresponding Author: Radha Nivedha R, CRI, Thai Moogambigai Dental College & Hospital, Chennai, India

This article may be cited as: R Radha N, R Radha N, AT Nivedhita. Eco-Orthodontics: Sustainable Materials(Waste Reduction in Modern Orthodontic Practice). J AdvMed Dent Scie Res 2025; 13(12):55-58.

INTRODUCTION

The healthcare sector is a major contributor to global climate change, responsible for nearly 4.4–5% of worldwide greenhouse gas emissions an output so large that, if considered a nation, it would rank as the fifth-highest emitter. Dentistry adds substantially to this burden through its heavy reliance on single-use plastics, hazardous chemical disposal, energy-intensive equipment, and waste streams involving materials such as lead foils, mercury-containing capsules, and disinfectants.[1] Within this domain, orthodontics generates significant environmental impact due to the routine use of disposable impression materials, plastic packaging, brackets, arch wires, and digital imaging systems, with up to 97% of its clinical waste ultimately incinerated. Although digitization reduces material consumption, it simultaneously increases energy demand from scanners, computers, and 3D printers, highlighting the need for renewable energy adoption and efficient technologies.[2] This growing ecological footprint underscores the urgent shift toward eco-orthodontics an approach emphasizing sustainable, recyclable, or biodegradable materials; waste reduction through digital impressions, reusable instruments, and metal recycling; and energy-efficient practice models incorporating LED lighting, water-saving devices, and clean-energy sourcing.[3] Sustainability assessments now span fixed, removable, and digital orthodontics, advocating for optimized wire use, recyclable brackets, green adhesives, biodegradable polymers, and low-waste digital workflows. Complemented by innovations such as plant-based clear aligners, recycled-metal alloys, remote monitoring, cloth-based infection control, self-ligating brackets, and low-energy manufacturing techniques, eco-orthodontics integrates responsible resource management with advanced clinical care. Ultimately, it aims to reduce the profession's environmental footprint while safeguarding patient outcomes, positioning orthodontics as a key driver of green transformation in modern healthcare.[4]

Environmental Impact of Orthodontic Practice

Orthodontic practices form a substantial component of healthcare's ecological burden, contributing to carbon emissions, extensive waste generation, and the need for adherence to evolving global sustainability regulations. A significant share of a dental clinic's carbon footprint stems from electricity consumption for lighting, HVAC systems, digital equipment, and chairside devices collectively accounting for nearly 15–25% of total emissions while sterilisation processes, procurement of disposables, and packaging materials further elevate resource usage and greenhouse gas output.[5] Procurement alone can contribute up to 28% of emissions in dental laboratory settings, with energy use adding another 25%, and each orthodontic appliance generating approximately 2.9–3.1 kg CO_2e. Waste in orthodontics arises from multiple sources, including discarded brackets, archwires, elastomerics, and plastic packaging; single-use sterilisation pouches and barrier films; non-recyclable alginate and impression trays; and a variety of biomedical waste such as gloves, gauze, sharps, and chemical residues.[6] Even digital workflows introduce additional waste streams through disposable scanner sleeves and disinfectant materials, though these typically produce lower material volume compared to conventional impressions. To address this impact, international frameworks such as WHO guidelines and FDI sustainability principles encourage safer waste management practices, reduced reliance on single-use plastics, and adoption of recyclable materials, while ISO standards (e.g., ISO 7491, ISO 10993) govern the environmental and biocompatibility testing of dental materials and increasingly promote the development of eco-friendly dental products.[7] Additionally, national biomedical waste regulations mandate colour-coded segregation, proper labeling, and regulated disposal or recycling of dental waste, reinforcing sustainable practices within orthodontic clinics. Through a comprehensive understanding of their carbon footprint and alignment with global and national sustainability standards, orthodontic practices can significantly reduce environmental harm while maintaining high-quality clinical care.[8]

Sustainable Materials in Modern Orthodontics

Category	Sustainable Material/Technology	Description	Environmental Benefit
Biodegradable & Bio-based Materials[10]	**PLA-based aligners**	Made from polylactic acid derived from corn/sugarcane; comparable performance to traditional plastics.	Biodegradable; reduces long-term plastic waste.
	Starch-based thermoplastics	Clear, flexible biopolymers used for aligners.	Decompose faster; 30–45% lower carbon footprint per treatment cycle.
	Bamboo/plant-fibre toothbrushes	Compostable alternatives for orthodontic patients.	Eliminates plastic toothbrush waste.
Eco-friendly Elastomerics[11]	**Biodegradable ligatures/modules**	Latex-free, bio-derived elastomerics.	Reduce petrochemical plastic use; compostable.
	Compostable natural rubber elastics	Under research; maintain elasticity and force levels.	Fully biodegradable; lower toxicity.
Sustainable Bracket Materials[12]	**Recyclable stainless steel/titanium brackets**	Can be collected and recycled after debonding.	Conserves metals; reduces mining emissions.
	Recycled ceramic technologies	Experimental methods to repurpose alumina ceramics.	Diverts ceramic waste from landfill.
	Reusable stainless-steel brackets	Sterilisation protocols allow safe reuse in selected cases.	Significant reduction in material consumption.
Green Arch wire Technologies[12]	**Recyclable Nitiarch wires**	Specialized processes recover nickel and titanium.	Minimizes mining waste; supports circular economy.
	Shape-memory polymer arch wires	Early-stage high-strength polymers for mild movements.	Potential for recyclability or biodegradability.
Adhesives & Bonding Systems[13]	**BPA-free, low-toxicity resins**	Safer bonding materials with reduced chemical hazards.	Lower environmental toxicity during disposal.
	Low-waste precision-dispensing resins	Controlled dispensing reduces excess adhesive use.	Minimizes chemical and plastic waste.
	Bio-adhesives (peptide/enzymatic)	Emerging biodegradable bonding systems.	Eliminates persistent resin residues; eco-safe degradation.

Waste Reduction Strategies in Orthodontic Practice

Reduce–Reuse–Recycle Strategies in Eco-Orthodontic Practice

Implementing the Reduce–Reuse–Recycle framework in orthodontics significantly decreases environmental impact while maintaining high clinical standards. Reduction strategies focus on minimizing single-use plastics by adopting biodegradable or recyclable packaging for aligners, brackets, and consumables, opting for bulk packaging to eliminate excessive wrapping, transitioning to reusable instrument trays and sterilization cassettes, and replacing alginate impressions with digital scanning, which eliminates disposable trays and improves accuracy and comfort.[14] Paperless systems further cut down administrative waste through digital records, e-signatures, and electronic communication. Reuse initiatives include resterilising stainless steel brackets and arch wires when clinically appropriate, utilizing autoclavable metal or high-grade plastic trays and retractors, and replacing disposable suction tips and barriers with sterilizable alternatives.[15] Recycling efforts encompass the reclamation of nickel–titanium and stainless-steel components through specialized metal recovery programs, participation in aligner recycling systems that repurpose plastics or use energy recovery methodseven though current global recycling rates remain low and responsible disposal or recycling of PPE plastics and packaging via certified vendors. [16]

Digital and Resource-Efficient Strategies in Eco-Orthodontics

Digital orthodontic technologies and resource-efficient clinical systems play a pivotal role in reducing the environmental impact of modern orthodontic practice. Intraoral scanners significantly curb waste by eliminating the need for alginate powder, disposable trays, and remakes associated with conventional impressions, while enhancing precision and patient comfort.[17] The integration of 3D printing enables on-demand fabrication of aligners and orthodontic models, cutting material overproduction and reducing transportation-related carbon emissions by allowing localized manufacturing. Digital diagnostic models remove the dependence on plaster casts, thereby decreasing gypsum use, eliminating storage requirements, and streamlining long-term record management with reduced paper consumption.[18] Advances such as plant-based 3D-printed aligners further merge digital precision with biodegradable materials, lowering reliance on petroleum-based plastics.[19] In infection control, eco-friendly disinfectants, biodegradable cleaning agents, and self-etching adhesives reduce chemical toxicity, water usage, and waste discharge, while energy-efficient autoclaves support greener sterilization.[20] Additional sustainability gains come from adopting LED curing units, low-energy clinic lighting systems, and water-conserving dental units that limit unnecessary water flow and incorporate recycling mechanisms. [21]

Future Directions

Future directions in eco-orthodontics emphasize a paradigm shift toward fully sustainable materials, intelligent clinical systems, and transparent supply chains, aiming to significantly reduce the ecological footprint of orthodontic care while maintaining clinical excellence. A major advancement lies in the development of fully compostable aligners made from bio-based thermoplastics such as polylactic acid (PLA) derived from renewable resources like corn starch and sugarcane; these materials degrade nearly 60% faster than conventional plastics in industrial composting settings and can reduce carbon emissions by 30–45% per treatment cycle, all while retaining the mechanical strength and flexibility required for effective tooth movement.[22] Parallel innovations involve green 3D printing resins, where researchers are formulating low-impact, biodegradable, or recyclable photopolymers that provide the precision and biocompatibility necessary for direct 3D-printed aligners, trays, and orthodontic models without the petrochemical burden of traditional materials. Sustainability is also advancing through AI-driven, energy-efficient clinic operations that employ smart scheduling algorithms, adaptive lighting, climate control optimization, and predictive maintenance systems to reduce unnecessary electricity use, minimize downtime, and enhance overall operational efficiency.[23] Beyond individual practices, industry-wide decarbonization efforts are steering orthodontic manufacturers toward carbon-neutral supply chains powered by renewable energy, low-emission transportation networks, responsible raw material sourcing, and carbon offset initiatives that collectively reduce greenhouse gas output from product creation to delivery.[24] Finally, emerging blockchain technologies offer a transformative solution for sustainable practice verification by enabling end-to-end tracking of orthodontic materialsensuring transparent sourcing, monitoring manufacturing processes, documenting usage, and validating that appliances are recycled, repurposed, or disposed of responsibly according to circular economy principles.[25]

CONCLUSION

Eco-orthodontics offers a transformative pathway for aligning high-quality orthodontic care with environmental responsibility. By integrating biodegradable materials, digital workflows, efficient resource management, and greener clinical technologies, orthodontic practices can significantly reduce their ecological impact without compromising treatment outcomes. As innovation acceleratesfrom compostable aligners to carbon-neutral supply chainsthe profession is well-positioned to lead sustainability efforts within dentistry. Ultimately, widespread adoption will depend on greater awareness, stronger regulatory frameworks, and collaborative commitment across clinicians, manufacturers, and policymakers to build a cleaner, more sustainable future for orthodontic care.

REFERENCES

1. Sakchhi S, Elbanna L, Chakor M, Nikferjam AZ, Saeedi N, Badve S, et al. Green Dentistry: Sustainable Practices and Materials for a Healthier Planet. Int J Dent Mater. 2025;7(3):84-92.
2. Shrivastava P, Ganiger C, Pawar R, Phaphe S, Ronad Y, Mane P. Eco-Conscious Orthodontics: A Greener Approach to Dental Care. Cureus. 2025 Feb 10;17(2):e78809. doi: 10.7759/cureus.78809. PMID: 40078266; PMCID: PMC11897922.
3. Ahmed N, YN D, A AY, Niharika E, Kesari R. Green orthodontics - A review article [Internet]. ***IP Indian J Orthod Dentofacial Res***. 2024 [cited 2025 Nov 15];10(1):16-23. Available from: https://doi.org/10.18231/j.ijodr.2024.004
4. Sustainability in orthodontics: what can we do to save our planet? Pithon MM, Faria LC, Tanaka OM, Ruellas AC, Primo LS. https://pubmed.ncbi.nlm.nih.gov/28902257/ Dental Press J Orthod. 2017;22:113–117. doi: 10.1590/2177-6709.22.4.113-117.sar.
5. Force decay of latex and non-latex intermaxillary elastics: a clinical study. Pithon MM, Mendes JL, da Silva CA, Lacerda Dos Santos R, Coqueiro RD. Eur J Orthod. 2016;38:39–43. doi: 10.1093/ejo/cjv005.
6. Elwan AH, Fouda AM. Carbon footprint of private dental laboratories in Egypt: A cross-sectional study. BDJ Open. 2025 Apr 17;11(1):40. doi: 10.1038/s41405-025-00316-w. PMID: 40246855; PMCID: PMC12006433.
7. Effects of recycling on metallic direct-bond orthodontic brackets. Buchman DJ. Am J Orthod. 1980;77:654–668. doi: 10.1016/0002-9416(80)90157-8.
8. Orthodontic bracket recycling. Machen DE. https://pubmed.ncbi.nlm.nih.gov/8249938/ Am J Orthod Dentofacial Orthop. 1993;104:618–619. doi: 10.1016/S0889-5406(05)80447-0.
9. Effects of recycling and bonding agent application on bond strength of stainless steel orthodontic brackets. Bahnasi FI, Abd-Rahman AN, Abu-Hassan MI. J Clin Exp Dent. 2013;5:0–202. doi: 10.4317/jced.51113
10. Towards sustainable orthodontics: environmental implications and strategies for clear aligner therapy. Macrì M, D'Albis V, Marciani R, Nardella M, Festa F. Materials (Basel) 2024;17:4171. doi: 10.3390/ma17174171.
11. Eliades T, Adel SM, Akyalçin S, Atsawasuwan P, Foong KWC, Hiskia A, et al. Environmental footprints in orthodontics: The World Federation of Orthodontists' white paper on sustainable practices, challenges and research imperatives. J World Fed Orthod. 2025;14(4):194-201.
12. Marya, A., Viet, H. Biodegradable clear aligners. *Br Dent J* **236**, 582 (2024). https://doi.org/10.1038/s41415-024-7361-4
13. Freitas MPM. Aligners, environmental contamination, and the role of orthodontics. Angle Orthod. 2022;92:148-149.
14. Camcı H, Büyükbayraktar ZÇ. Aligners from another perspective: could they be a long-term environmental threat? Problems and potential remedies. Am J Orthod Dentofacial Orthop. 2025;167(3):256-260
15. Ahlawat S, Prabhakar M, Nindra J. Aligners in orthodontics and its health and environment hazards. Bull Environ Pharmacol Life Sci, Spl Issue. 2022:519-522.
16. Veseli E, Veseli K, Behluli E. The carbon emissions of clear aligner therapy: a critical review. APOS Trends Orthod. 2024;14:70-1.
17. Pithon MM, Faria LCM, Tanaka OM, et al. Sustainability in orthodontics: what can we do to save our planet? Dental Press J Orthod. 2017;22:113-7.
18. Tan TYD, Duane B, Hussein A, et al. Environmental sustainability of post-orthodontic dental retainers: a comparative life-cycle assessment of Hawley and Essix retainers. Eur J Orthod. 2024;46:cjae012.
19. Watanabe M, Furuya J. The environmental impact of orthodontic materials: a focus on the biocompatibility of materials. Dent Mater J. 2018;34:265-76.
20. Panayi NC, Efstathiou S, Christopoulou I, et al. Digital orthodontics: present and future. AJO-DO Clin Companion. 2023;4:14-25.
21. Khade GS, Agrawal M, Agrawal JA, Fulari S, Shetti S, Vishwalkag. Green Orthodontics: A Sustainable Approach. Int J Dent Med Sci Res. 2021;3(4):811-5.
22. Saxena, G., Rathore, K., & Kumar, V. (2025). Green Dentistry: A Sustainable Approach to Modern Dental Practice. *Indian Journal of Dental Sciences*. https://doi.org/10.4103/ijds.ijds_31_25
23. Prabhu, P., Hemanth, M., Waremani, A. S., Aravind, M., Kavya, B. R., & Raj, R. S. V. (2025). Elastiease: Wasting Less and Smiling More—A Clinical Innovation. *Journal of Pharmacy and Bioallied Sciences*, *17*(Suppl 2), S1952–S1953. https://doi.org/10.4103/jpbs.jpbs_2017_24
24. Agrawal, S. N., &Abedeen, M. Z. (2025). Sustainable Dental Practices: Reducing Waste and Energy. *International Research Journal of Medicine and Surgery (IRJMedS).*, *02*(03), 20–29. https://doi.org/10.47857/irjmeds.2025.v02i03.038
25. Sant, I., Tripathi, P., Chandra, S., & Sinha, S. (2025). Eco-dentistry: Sustainable practices for healthier life and a greener planet. *Asian Journal of Oral Health and Allied Sciences*, *15*, 2. https://doi.org/10.25259/ajohas_16_2024