REVIEW ARTICLE

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Green Dentistry: Sustainable Practices and Materials for a Healthier Planet

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Abstract

Climate change and environmental degradation have heightened the urgency for sustainable practices across healthcare sectors, including dentistry. Green dentistry, also known as eco-friendly dentistry, aims to integrate dental care with principles of sustainability by utilising resources responsibly, reducing waste, employing eco-friendly materials, and designing clinics with an environmentally conscious approach. This narrative review examines the key domains of sustainable dental practice, including the adoption of bio-based and biodegradable dental materials, low-carbon ceramics and composites, and innovative waste-to-resource approaches, such as hydroxyapatite derived from by-products. Effective waste management strategies, such as reducing single-use plastics, using amalgam separators, and ensuring safe disposal of chemical and infectious waste, are highlighted as essential measures. Digital technologies, including CAD/CAM systems, teledentistry, and electronic health records, further contribute to reducing material waste, paper use, and travel-related emissions. Energy and water saving measures, such as energy-efficient equipment, solar-powered clinics, and water recycling systems, offer additional opportunities to minimise environmental impact. By embracing eco-friendly innovations, dentistry can reduce its ecological footprint while maintaining high standards of patient care, contributing meaningfully to global sustainability goals.

Keywords: Green dentistry, Dental waste management, Eco-friendly dental materials, Sustainable dentistry.

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1. Introduction

Climate change, driven largely by human activity and excessive fossil fuel use, has emerged as one of the greatest challenges of the twenty-first century. Rising greenhouse gas emissions, deforestation, and unsustainable consumption have weakened natural ecosystems, intensifying global warming and extreme weather events. While healthcare sectors worldwide are beginning to integrate sustainability into practice, dentistry still lacks sufficient evidence-based approaches and research in this area. Existing initiatives remain limited and largely based on general recommendations [1,2].

Green dentistry, also referred to as eco-friendly dentistry, emphasises aligning dental care with sustainable practices. It promotes responsible use of resources, reduction of waste, and minimisation of chemical exposure within the clinical setting to safeguard both human health and the environment. The concept was further advanced through the development of eco-friendly dental clinics that integrate green design and operations, aiming to protect patients, dental teams, surrounding communities, and global ecosystems. Fundamentally, these approaches reflect the broader principle of sustainable development, which seeks to meet current needs without compromising the ability of future generations to do the same [2,3].

Despite growing awareness of environmental challenges, the application of sustainable principles within dentistry remains underexplored. Most available literature provides only broad recommendations rather than detailed strategies supported by empirical evidence. For instance, a review by Damle SG outlines key concepts of green dental practice, including conservation of water and energy, use of non-toxic products, reduction of waste, and elimination of hazardous toxins [4]. Additionally, Liu discusses the implementation of virtual reality dental simulators and digital impression techniques as sustainable alternatives to traditional methods [5]. With increasing attention on eco-friendly materials, digital workflows, waste reduction, and energy-efficient technologies, there is a pressing need to consolidate current knowledge and highlight areas for future innovation. This narrative review, therefore, aims to explore the environmental impact of dental practice, examine recent developments in green dentistry, and identify opportunities for integrating sustainability into everyday clinical care.

2. Chemical exposure in dentistry: Impacts on health and the environment

Dental practices involve the use of various chemicals that can pose risks to both human health and the environment. Mercury, a component of dental amalgam, is a neurotoxin that can vaporise during placement or removal, leading to potential exposure for dental professionals and patients. Improper disposal of amalgam waste can result in mercury contamination of water systems, affecting aquatic life and entering the food chain [6]. Glutaraldehyde and formaldehyde, commonly used as disinfectants and sterilising agents, are associated with respiratory issues, skin irritation, and allergic reactions among dental personnel. These chemicals can also contribute to air and water pollution if not disposed of properly [7]. X-ray processing chemicals, including hydroquinone and silver compounds, used in traditional film-based radiography, may generate hazardous waste if not treated before disposal. Even resin-based materials can release residual monomers, such as bisphenol A derivatives, which are endocrine-disrupting compounds, during polymerisation or degradation [8]. Additionally, pesticides or rodenticides sometimes used for clinic maintenance can contribute to environmental toxicity. Implementing eco-friendly approaches, such as replacing conventional radiographic film with digital systems to avoid chemical use, employing biodegradable disinfectants, and managing hazardous waste responsibly, helps reduce environmental risks and supports a healthier environment.

3. Principles of green dentistry

The philosophy of green dentistry is rooted in sustainability and responsible use of resources. Its guiding principles can be summarised through the "Four Rs": Reduce, Reuse, Recycle, and Rethink. Reduce emphasises minimising resource consumption and waste generation within dental practices, such as decreasing reliance on single-use plastics and optimising energy and water use. Reuse involves selecting products and equipment that are durable, sterilizable, and capable of multiple uses to reduce environmental burden. Recycling highlights the importance of proper segregation and recycling of paper, plastics, metals, and even dental materials wherever feasible. Finally, Rethink calls for a shift in mindset among dental professionals, encouraging environmentally conscious decisions in patient care, procurement, and clinic design. Together, these principles serve as a framework for integrating eco-friendly practices into routine dentistry (Figures 1 and 2) [9].

Globally, the healthcare sector is increasingly recognising the importance of sustainability in reducing its ecological footprint. Initiatives such as the World Health Organisation's commitment to climate-resilient health systems and the development of sustainable healthcare facility guidelines provide models for dentistry to follow. Similarly, national policies promoting waste reduction, renewable energy use, and green procurement in healthcare can inspire dental practices to align with broader sustainability goals. By adopting these principles, dentistry can actively contribute to global movements aimed at mitigating climate change while safeguarding public health and conserving resources for future generations [10].

4. Sustainable dental materials

The selection of dental materials plays a crucial role in advancing the goals of green dentistry. Traditional restorative and impression materials often involve energy-intensive manufacturing, synthetic chemicals, and limited recyclability, contributing to environmental burdens. Sustainable alternatives are being developed that aim to reduce toxicity, lower carbon emissions, and minimise long-term ecological impact, while maintaining clinical effectiveness (Tables 1 and 2).

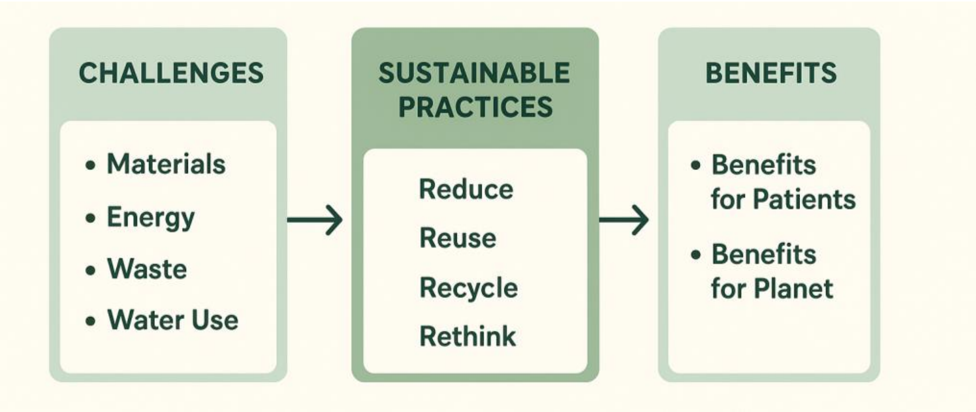

Figure 1. Conceptual framework of green dentistry

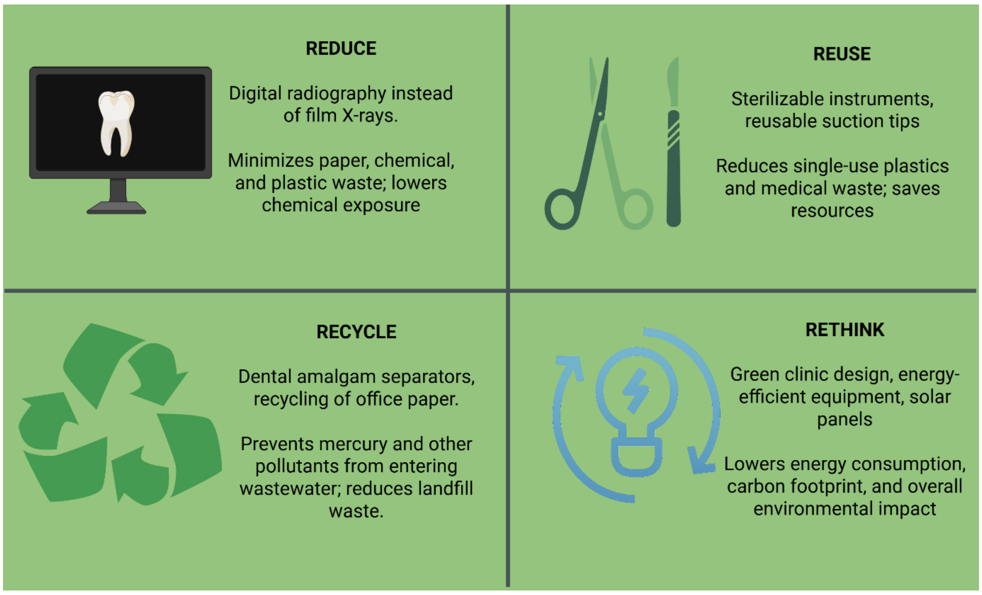

Figure 2. Four R's in dentistry.

4.1 Bio-based and biodegradable materials

Bio-based and biodegradable materials represent a promising avenue for sustainable dentistry. Plant-derived resins, biopolymers, and natural alternatives to alginate for impressions have been developed to minimise reliance on petroleum-based products. These materials not only reduce chemical exposure but also degrade more safely, lessening the load on landfills [11]. Beyond clinical materials, everyday dental items have also shifted toward eco-conscious design. For instance, bamboo toothbrushes, often the lowest-impact option available, stand out for their comparative environmental advantages over plastic counterparts. Studies show that bamboo manual toothbrushes and plastic toothbrushes with replaceable heads have significantly lower life-cycle ecological impacts than traditional plastic or electric toothbrushes [12]. Additionally, bamboo interdental brushes and bamboo floss display reduced environmental footprints across multiple life-cycle impact categories, including carbon emissions and ozone depletion [13].

Further innovations have introduced a range of biodegradable alternatives with direct clinical and auxiliary applications. Polylactic acid (PLA) and polyhydroxyalkanoates (PHA), derived from renewable resources such as corn starch and microbial fermentation, are increasingly applied in dental packaging, impression trays, and 3D-printed dental models due to their moldability and safe biodegradation [14]. Chitosan, a natural polysaccharide from crustacean shells, offers both biodegradability and antimicrobial activity, making it valuable for periodontal dressings, guided tissue regeneration membranes, and bio-adhesive formulations [15]. Similarly, starch-based biomaterials are being developed as temporary trays and packaging alternatives, providing both cost-effectiveness and reduced environmental burden [16]. Natural protein-based materials such as silk fibroin, derived from silkworm cocoons, are gaining traction as sustainable matrices for guided tissue regeneration, drug delivery systems, and scaffolds due to their biocompatibility and degradability [17].

4.2 Low-Carbon footprint ceramics and composites

Low-carbon footprint ceramics and composites are innovations designed to reduce the environmental impact of restorative dentistry. Advances in material science are producing ceramics and composites that require less energy-intensive processing and generate lower emissions during production [18-20]. These materials combine strength and aesthetics with improved sustainability profiles, aligning restorative care with environmental goals [21].

4.3 Materials derived from waste sources

Researchers are also exploring the potential of materials derived from waste sources, such as hydroxyapatite synthesised from biological or industrial by-products like fish bones and eggshells [22]. Eggshells, composed primarily of calcium carbonate, can be thermally converted into hydroxyapatite and used as fillers in composites, bone graft substitutes, and remineralising agents [23]. Similarly, fish scales and bones provide both collagen and hydroxyapatite, enabling their use in scaffolds, periodontal membranes, and restorative applications [24]. Animal bone waste from meat-processing industries also contributes to the development of xenografts and synthetic hydroxyapatite for bone augmentation procedures [25].

Additionally, fruit and vegetable peels, including orange, banana, and pomegranate husks, provide polyphenols and antioxidants with potential applications as natural antimicrobial or remineralising agents in dental materials [26]. These waste-to-resource approaches align with circular economy principles by transforming discarded materials into clinically useful products, thereby reducing both ecological and economic costs.

Table 1. Sustainable dental materials

Material type	Examples	Environmental benefits
Bio-Based & Biodegradable	Plant-derived resins, biopolymers, and alginate alternatives	Reduced reliance on petroleum-based products; biodegradable; lower chemical exposure
Low-Carbon Footprint Ceramics & Composites	Energy-efficient ceramics, eco-friendly composites	Less energy-intensive production; reduced greenhouse gas emissions; durable and recyclable
Materials from Waste Sources	Eggshell-derived hydroxyapatite, fish bone hydroxyapatite	Valorises waste; supports circular economy; reduces landfill load; biocompatible

Table 2. Department-wise dental materials and sustainable alternatives.

Dental Specialty	Common Materials / Biomaterials	Sustainable / Green Alternatives	Notes on Environmental Impact
Restorative Dentistry	Amalgam, Composite resins, Glass ionomer cements	Plant-based resins, Biodegradable composites, Bioactive glass	Biodegradable or bio-based alternatives reduce chemical and plastic waste
Endodontics	Gutta-percha, Sealers (epoxy, bioceramic), MTA	Bioceramic sealers with a lower carbon footprint, Natural resin-based sealers	Reduces toxic monomer release and promotes biocompatibility
Prosthodontics	PMMA, Zirconia, Porcelain, Metal alloys	Recyclable metals, Low-energy processed ceramics, Reusable custom trays	Lower energy consumption and material waste
Orthodontics	Stainless steel wires, Ceramic brackets, Resin adhesives	Reusable brackets, Biodegradable elastics	Minimises single-use plastic/elastomer waste
Periodontics	Bone grafts (autografts, allografts, xenografts), Collagen membranes	Synthetic or natural biodegradable scaffolds	Reduces reliance on animal-derived or high-impact materials
Oral & Maxillofacial Surgery	Titanium plates/screws, Biodegradable fixation materials	Resorbable polymer plates	Eliminates the need for secondary surgery and reduces metal waste
Pediatric Dentistry	Stainless steel crowns, Resin-modified GIC	Bio-based crowns, Biodegradable sealants	Reduces chemical and metal waste, safer for children
Implantology	Titanium implants, Zirconia implants	Recyclable implant materials, Low-energy ceramics	Sustainable manufacturing and potential recycling

5. Waste management strategies

Effective waste management is a cornerstone of green dentistry, aiming to minimise the environmental impact of dental practices while ensuring patient and staff safety. Dental clinics generate a variety of waste streams, including infectious waste, chemical residues, amalgam, plastics, and general office waste. Implementing targeted strategies for waste reduction is critical for sustainability.

5.1 Reducing single-use plastics in clinics

Single-use plastics, including disposable cups, gloves, suction tips, and packaging, contribute significantly to environmental pollution and healthcare waste. Replacing these items with reusable or biodegradable alternatives is a key step toward greener clinical practice. For instance, gloves, which represent a major component of dental waste, are now available in biodegradable nitrile formulations that decompose more rapidly in landfill conditions while maintaining barrier protection [27]. Alternatively, some manufacturers offer biodegradable suction tips made from PLA (polylactic acid) or other plant-derived polymers, which degrade faster than conventional polypropylene tips. Other plastic disposables, such as saliva ejectors, air–water syringe tips, and impression trays, are increasingly available in metallic or silicone reusable versions, which can be disinfected or autoclaved between patients without compromising infection control [28]. For disposable items that cannot be replaced (e.g., barrier wraps), switching to paper-based or compostable films where appropriate can reduce long-term microplastic pollution [29].

A quality improvement project across 12 dental practices in North London found that three practices reduced or eliminated their use of single-use plastics, resulting in an equivalent saving of 46.87 kg CO_2e per week [31]. In addition, several consumer and clinical dental products are moving toward more sustainable alternatives. For example, many toothpaste manufacturers now use recyclable cardboard or aluminum packaging instead of plastic tubes, while chewable toothpaste tablets provide a plastic-free option for patients. The removal of microplastics from toothpaste formulations further reduces environmental harm.

Similarly, silk dental floss has emerged as an effective biodegradable substitute for conventional nylon-based floss. Collectively, these innovations demonstrate how both clinical and consumer-level changes can help dentistry reduce its reliance on single-use plastic [31].

5.2 Mercury and amalgam separator use

Amalgam, used in restorative dentistry, contains mercury, a hazardous material with potential environmental and health risks. The use of amalgam separators in dental clinics ensures that mercury particles are captured before wastewater enters the sewage system. In the United States, the Environmental Protection Agency (EPA) requires most dental practices that place or remove amalgam to install and properly maintain amalgam separators that meet the ISO 11143 standard, ensuring effective capture of mercury-containing waste. Proper handling, recycling, or disposal of amalgam waste in compliance with EPA guidelines prevents contamination of water bodies and reduces ecological harm, supporting dentistry's shift toward sustainable and environmentally responsible practices [32].

5.3. Safe disposal of chemical and infectious waste

Dental practices use various chemicals, disinfectants, and pharmaceuticals that must be disposed of carefully to prevent soil and water contamination. Infectious waste, including sharps, blood-soaked materials, and contaminated instruments, requires strict segregation, sterilisation, and disposal according to local regulations. Staff training and adherence to waste management protocols are essential for minimising risks to humans and the environment [33].

5.4 Digital dentistry as a green tool

Digital technologies are transforming dentistry while providing significant environmental benefits. By integrating computer-aided design and manufacturing (CAD/CAM), teledentistry, and electronic health records, dental clinics can reduce paper use, material waste, and carbon emissions. Additional tools such as digital radiography and 3D imaging eliminate chemical-based film processing, 3D printing and additive manufacturing minimise material waste in crowns, dentures, and surgical guides, and digital shade matching and smile design software reduce trial-and-error adjustments.

Furthermore, artificial intelligence in diagnostics improves accuracy, lowering unnecessary procedures, while virtual treatment planning and simulation reduce the need for physical models and repeat impressions. Digital patient communication platforms replace paper forms and educational materials, collectively enabling efficient, high-quality care with a reduced ecological footprint [34,35].

5.5 Teledentistry to minimise travel-related emissions

Travel and transportation account for nearly 13% of the carbon footprint in healthcare, a figure that can be lowered by adopting more sustainable alternatives. Teledentistry facilitates remote consultations and follow-ups, and reduces the need for patients and staff to travel frequently. This not only improves access to care but also contributes to lower greenhouse gas emissions by reducing vehicle use [35,36].

5.6 Digital patient records for paper reduction

Electronic health records (EHRs) and digital imaging have revolutionised record keeping in dentistry, offering significant environmental and clinical advantages. By eliminating paper charts, handwritten treatment notes, and film-based radiographs, EHR systems dramatically reduce paper consumption and the need for chemical processing solutions, which are common sources of hazardous waste. Digital imaging, including intraoral radiographs, panoramic radiography, and cone-beam computed tomography (CBCT), enables instant image capture, storage, and retrieval without physical films, developers, or fixers, further lowering chemical discharge and water use. Moreover, digital records facilitate secure data sharing between providers, reducing the need for printed referrals and mailed documentation. Integration with practice management software also enhances appointment scheduling, billing, and insurance claims electronically, minimising paper-based communication. Collectively, these digital solutions streamline workflows, improve accuracy, and reduce the clinic's ecological footprint, aligning dental care delivery with modern sustainability goals [34,37].

6. Energy and water conservation

Energy and water conservation are critical pillars of sustainable dental practice. Dental clinics are resource-intensive, requiring electricity for lighting, equipment, Heating, Ventilation, and Air Conditioning (HVAC) systems, and sterilisation, as well as large volumes of water for patient care, instrument cleaning, and hygiene. By implementing energy- and water-efficient strategies, clinics can reduce their environmental footprint, lower operational costs, and set an example for sustainable healthcare.

6.1 Energy-efficient equipment

Dental practices can significantly reduce energy consumption by upgrading to modern, energy-efficient equipment. Energy-efficient dental chairs, compressors, and autoclaves consume less electricity while maintaining or even improving clinical performance. For example, advanced autoclaves with eco-modes use lower energy for sterilisation cycles without compromising safety, while efficient compressors reduce both electricity usage and noise pollution. Over time, these upgrades translate into lower greenhouse gas emissions and operational costs, while promoting a more environmentally conscious practice [38].

6.2 Solar-powered clinics

Integrating renewable energy, such as solar panels, allows dental clinics to generate electricity sustainably. Solar-powered systems can offset a significant portion of a clinic's electricity needs, reducing reliance on fossil-fuel-based power grids. Clinics that adopt solar energy not only benefit financially through lower electricity bills but also contribute to global efforts to reduce carbon emissions. Additionally, solar-powered practices can serve as a visible commitment to sustainability, educating patients and staff about the importance of renewable energy in healthcare. Belmont Dentistry in Portland, Oregon, installed more than 85 solar panels, enabling the clinic to achieve zero-net-energy status and avoid over 100,000 pounds of CO_2 emissions each year [39].

6.3 Water recycling systems

Water is essential in dentistry for patient care, instrument sterilisation, and sanitation. Implementing water recycling systems, such as filtration and reuse technologies for dental unit waterlines and autoclaves, can substantially decrease freshwater consumption. Some dental clinics collect condensate water from sterilisers, safely repurposing it for non-clinical tasks such as equipment flushing, sink irrigation, or cleaning, thereby reducing overall water consumption. Beyond conserving water, these systems reduce the volume of wastewater discharged into municipal systems, lowering treatment costs and environmental impact. Water conservation practices not only preserve resources but also align dentistry with broader Sustainable Development Goals (SDGs) established by the United Nations. For example, SDG 6 (Clean Water and Sanitation) emphasises sustainable water management and improved water quality, while SDG 12 (Responsible Consumption and Production) promotes efficient resource use and waste reduction. By adopting water-saving measures, dental practices contribute to these global objectives, supporting environmental stewardship, resource efficiency, and the health of surrounding communities [40].

7. Infection control with minimal environmental impact

Infection prevention is a cornerstone of dental practice, ensuring patient and provider safety. However, conventional infection control methods often rely on chemical disinfectants and sterilisation processes that carry environmental costs, such as the release of toxic residues, high energy consumption, and excessive use of disposable products. Green dentistry emphasises adopting eco-friendly alternatives that maintain rigorous infection control while minimising harm to the environment [41,41].

Traditional chemical disinfectants, such as glutaraldehyde and chlorine-based agents, pose risks to both human health and ecosystems due to their toxic by-products. Sustainable alternatives include hydrogen peroxide and peracetic acid-based solutions, which degrade into water and oxygen, leaving a minimal ecological footprint [42]. Additionally, UV-C light and ozone sterilisation systems have emerged as effective non-chemical methods for surface and instrument disinfection, reducing reliance on harmful chemicals. For instrument sterilisation, modern autoclaves with energy and water-saving cycles offer a more sustainable solution without compromising sterility assurance levels [42].

8. Barriers to implementation

Despite the growing recognition of green dentistry, several barriers hinder its widespread adoption. Cost is one of the most significant challenges; eco-friendly materials, digital systems, and energy-efficient equipment often require substantial upfront investment, which may deter smaller practices from adopting them [43]. Lack of awareness and education among dental professionals also remains a major limitation. Many clinicians are unfamiliar with sustainable alternatives or underestimate the environmental footprint of their daily practices [44]. Furthermore, material availability presents difficulties, as bio-based or recyclable dental products are not yet widely accessible in all regions, particularly in developing countries.

Finally, regulatory issues create inconsistencies in practice. While some regions mandate amalgam separators or medical waste segregation, others lack clear guidelines, leaving sustainability efforts voluntary and fragmented [45]. These barriers highlight the need for systemic efforts at the educational, industrial, and policy levels to ensure progress.

9. Future perspectives

Looking forward, there are several critical areas for advancing green dentistry. First, research gaps need to be addressed, particularly in conducting comprehensive life-cycle analyses of dental products and procedures to assess their true environmental impact [46]. Such data would guide evidence-based policy and product innovation. Second, integration of sustainability into dental education is essential. By incorporating eco-conscious practices into dental curricula, future practitioners can develop habits and decision-making frameworks that prioritise environmental health alongside patient outcomes [47].

Lastly, policy-level initiatives hold great potential. National and international health authorities can establish eco-friendly dental standards, incentivise the adoption of green technologies, and promote waste reduction strategies across healthcare sectors. Such policy measures would accelerate the transition to environmentally responsible dentistry, which refers to the practice of delivering oral healthcare in a manner that minimises negative environmental impacts while maintaining patient safety and quality of care [48].

10. Conclusion

Green dentistry represents a paradigm shift in oral healthcare, aligning clinical excellence with environmental stewardship. Sustainable practices from eco-friendly materials and waste management to digital dentistry and energy conservation demonstrate that dentistry can evolve without compromising the quality of care.

Adopting green approaches not only benefits patient safety and comfort but also reduces the ecological footprint of dental services, contributing to broader climate and sustainability goals. The dental professionals must embrace these strategies proactively, as the profession faces the dual responsibility of delivering care and protecting the planet. A collaborative effort involving practitioners, educators, researchers, industry, and policymakers is essential to overcome current barriers. By adopting a culture of sustainability today, dentistry can secure a healthier future for patients and the planet alike.

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