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Green Dentistry: Sustainable and Environmentally Responsible Oral Care

[1]Dr Anusha Pulluri, BDS, Sri Sai College of Dental Surgery, Vikarabad, Telangana, India

Corresponding Author: Dr Anusha Pulluri, BDS, Sri Sai College of Dental Surgery, Vikarabad, Telangana, India.

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Abstract

Dentistry is crucial in maintaining the oral and overall health of an individual. Conventional dental practices consume excessive energy resources, use non-biodegradable materials and produce hazardous waste which altogether significantly contributes to environmental pollution. Green dentistry, also known as eco-dentistry, is an emerging sustainable framework that integrates clinical excellence with environmental responsibility, ethics, and public health responsibilities.

The key contributors to pollution from dentistry are single use plastic and non-biodegradable dental materials. Emphasis should be on the adaptation of eco-friendly alternatives along with cost-cutting. Barriers for implementation should be identified and strategies to compensate for them are the need of the hour. With collective initiatives and responsible execution green dentistry is possible to the full extent.

This literature review explores concepts, feasibility and importance of eco-friendly dental practices and ways to adapt them effectively. This paper proposes methods of green dentistry adoption such as education, phased adoption, policy support, and sustainable procurement. By including sustainability into dental education curriculum, and daily practice, dental professionals can achieve environmental conservation and economic efficiency.

Keywords: Green Dentistry, Eco-Dentistry, Sustainability, Environmental Pollution, Single-Use Plastics

Introduction

The American Dental Association describes dentistry as the evaluation and management whether non-surgical, surgical, or related of diseases and conditions affecting the oral cavity, maxillofacial region, and associated structures, along with their influence on overall human health.[1]

Providing good dental care is the prime objective for any clinician.[2] Good dental care means giving the best to the patient and this includes creating a comfortable and patient friendly atmosphere.[2]Dentistry has evolved in terms of materials and techniques. The recent materials and treatment promise to provide the best for the patient.[2] However, the treatment methods have their own adverse effects.

According to United States Environmental Protection Administration, pollution is defined as "Any substance in water, soil, or air that degrades the natural quality of the environment, offend the sense of sight, taste, smell, or cause a health hazard."[1]

Eco-friendly dentistry term is coined by Dr. Gorankralj and Dr. Stevenkoos[3,8] They defined it as a newly evolving practice of dentistry, which encompasses a simultaneous devotion to sustainability, prevention, precaution, and a minimally invasive patient-centric as well as global-centric treatment philosophy.[3] This offers protection in a broad sense including the dentists, patients, the community and preserves the natural resources.[3]

Dental practices significantly impact the environment due to high energy consumption, excessive water usage and hazardous waste generation.[4] The use of disposables, amalgam fillings and radiographs that have adverse effects contributes to pollution.[4] Additionally, electricity and water consumption also amounts to energy depletion.[4] An average practice uses 360 gallons of water per day accounting to 9 million annually in the US alone.[4]

Green dentistry, also called eco-dentistry, aims to reduce waste, lower energy consumption, and promote biodegradable and non-toxic alternatives.[4] This encourages water and energy conservation, adoption of non-toxic products, proper waste management, and eco-friendly practice. By adopting green dentistry, practitioners uphold their commitment to reducing environmental harm.[4] Although a single dentist or a single dental clinic set up does not contribute to global warming, the profession has a major role in contributing to environmental pollution.

Hence it is important to shift from the conventional form of dentistry to a more sustainable, holistic, safer, and much newer form of dentistry known as green dentistry or eco-dentistry.

This literature review indicates that there is a significant gap between the idea of green dentistry and its implementation. This analyses the existing literature on green dentistry, evaluates the factors important for sustainability, the state of professional awareness and the systemic barriers that hinder the adoption of green dentistry.

Green dentistry can help in minimizing waste generation, conservation of natural resources, usage of non-toxic and biocompatible materials, adoption of digital technologies, ensure safe disposal of hazardous waste, redesign eco-friendly dental clinics, promote green behavior among staff and patients. This can be achieved by the reduction of single-use plastics, implementation of waste segregation programs, usage of reusable and sterilizable instruments. The dry-vacuum systems, LED smart lighting can conserve significant energy. Reduction of mercury usage, BPA-free biodegradable and non-toxic dental materials can contribute markedly to limit pollution. Usage of green-certified cleaning agents and office supplies are one of a few eco-friendly options. Utilization of CAD/CAM, digital radiographs, transition to paperless systems for billings and records maintenance can be other options. Training staff on sustainable practices and encouraging patients to adopt eco-friendly oral hygiene habits can also significantly benefit not only the individuals but also the environment.

Materials and Methodology

To review the literature, studies were selected from PubMed, Scopus, Web of Science, and Google Scholar with restrictions on publication year, to provide a comprehensive overview of current knowledge on Green Dentistry. This review focused on evaluating the adverse effects of pollution due to dentistry and suggested ways

to adapt eco-friendly practices. The search terms included: "Sustainability", "Eco-dentistry", "Green Dentistry", "Single-use plastics", "Pollution". The research encompassed, Case reports, Clinical studies, and Systemic reviews.

Pollution in dentistry due to dental materials:

Conventional Radiographs: Dental radiography is vital for diagnosis and treatment. However, these procedures produce tons of waste products which are disposed of into soil and water.[1] The lead foils are disposed of in soil which leaches harmful heavy metals into the soil affecting human health. The developer and fixer solutions cause water pollution when disposed. Although digital dentistry has evolved tremendously, traditional radiographic methods are still practiced in most of the developing countries which burdens the environment significantly.

Adapting digital dentistry aids to eliminate pollution and decrease of manufacturing these can have best benefits overall. The radiation exposure to patients is also reduced with these eco-friendly options.

Dental Impression materials

Dental impression materials play an indispensable role in better delivery of prosthesis. However, these also contribute to hazardous pollution. The disposal of conventional impression materials typically results in significant waste, including non-recyclable plastics and chemical-laden materials.[7] Alginate, which is widely used, contains silica fillers which increase the particulate load. The best detail replicating silicone materials are non-biodegradable and causes plastic load in the soil. Incineration of these materials results in release of toxic gases which cause air pollution. Use of sectional impression trays and wooden trays can help to minimize pollution.

Dental Wax

Waxes are used widely in almost all the specialties of dental care. These are mostly paraffin wax, which is petroleum derived, beeswax, carnauba wax. While heated, these release low molecular weight hydrocarbons which can damage the respiratory system in low-ventilated places. Wax contaminated investment materials produced during casting can also increase biomedical waste. Although individually small, cumulative release from all the dental laboratories is a serious concern to the environment. A simple laboratory procedure of removing the impurities can be used to recycle the wax and about 80–90% of the wax can be recycled using this method.[7]

Eco-friendly alternatives to Conventional Dental Materials and Procurement of Sustainable Dental Supplies

Eco-friendly alternatives can best help in the prevention of plastic waste. Successful procurement also plays a role. This includes purchasing materials in bulk to reduce packaging waste, choosing manufacturers that supply eco-friendly products, and investing in durable equipment. The following changes can be made to reduce environmental pollution:

Lighting

Energy-saving lights such as compact fluorescent lamps (CFL) should be used instead of traditional incandescent bulbs.[2] CFLs consume less electricity and are more durable. In addition, they produce comparatively less heat than the usual lights.[2,3]

Paper and Printing

Paper use can add to the maintenance costs.[2] Limiting unnecessary paper use can help prevent storage issues. Software applications such as Eco-print and Toner saver can help prevent excessive ink usage.[2]

Digital X-rays

Traditional radiographs cause environmental pollution and high radiation exposure.[2] Digital radiography reduces waste such as film packets, lead foils, plastics and chemical developers.[2] It also prevents disposal of these solutions into water thereby preventing water pollution.[2] CAD/CAM systems reduce greenhouse gases produced from patient and staff travel for the multiple appointments, and the shipping of impressions and final restorations, sometimes as far as overseas.[2,4]

Paperless Office

Dental offices can adapt paperless systems by using dental software. These can better manage patient data storage, scheduling, billing, and communication. E-mails and text messages can replace the traditional bill receipts.[2]

Green Building

A green building is designed to be environmentally sustainable and resource- efficient from its design, construction, maintenance and demolition.[3] The goal is to be environmentally friendly while being energy efficient.[3]

Computer and Electronic Equipment

Devices which consume less power such as LED screens should be used. Keeping the computers turned off at night and when not in use can also save electricity.[2]

Hi-tech Dentistry

Advanced dental technologies contribute to sustainability by improving efficiency and reducing waste.[3] These include digital imaging, CAD/CAM and complete digitalization of paperwork.[3] Maintaining a website for promotion and primary communication can also promote sustainability in modern dental practice.

Wellness Practices

In recent times, dentistry along with other medical branches adopted wellness practices like disease prevention, early diagnosis, and minimally invasive treatment. This supports the patients as well as the environment.[3] These include the use of laser diagnostic devices for early detection of dental caries which are not visible to the naked eye as well as advanced tools for oral cancer screening.[3] Laser periodontal therapy is effective with minimal damage to the tissue. Incorporation of indoor plants enhances oxygen levels, and air purifiers can improve the indoor air quality and remove contaminants.[3]

Future of Green dentistry and its practicality

Green dentistry adoption can be achieved by following the four 'R' and 'A' models:

R model: Rethink, Reduce, Reuse, Recycle.[2,5,9,10]

Rethink: This emphasizes the change in the mindset of the clinicians and the awareness of the long-term effects on the environment by the resources used in dentistry. This includes reducing paper utilization by adapting digital systems for maintenance of patient's records and documentation. Digital radiography can also benefit by reducing radiation exposure, by providing easy accessibility and storage. In addition, both these preserve the confidentiality of the patients.

Reduce: This includes reduction of the use of natural resources like light, water, and other resources which can directly decrease the carbon footprint of a dental clinic. This includes the increased usage of natural light, or solar-based light sources, reduction of water unnecessary water usage, proper handling of the dental materials.

Reuse: This includes the adaptation of reusable materials, but only materials which can be autoclaved. These include the introduction of reusable cotton towels and drapes instead of plastic covers, use of stainless-steel suction tips instead of plastic tips, micro brushes and tip applicators with a wooden handle, and reusable glass syringes. For example, opting for reusable face shields

reduces the need for single-use plastics, while providing glass or ceramic rinse cups minimizes waste and eliminates the constant disposal of plastic alternatives. These practices not only conserve resources but also contribute to a more environmentally friendly approach.[10] Resource reduction can be achieved through water conservation methods such as use of hand-sanitizers when appropriate, turning off the taps when applying soap to hands, operating autoclaves only with full loads, and regularly inspecting leaks.

Recycle: It includes the conversion of waste materials into new products. This includes collection, regeneration and resale. This includes the recycling of the metals used in traditional radiographic films, and other dental materials.

Although the four 'R' model provides an approach to sustainability, the practical execution is limited due to the lack of infrastructure and guidelines for adoption. However, staff training, environmental awareness and cultural changes can seed improvement. Barriers such as lack of technology, resistance to follow advanced methods, lack of recycling can be addressed with effective communication and planning.

A model: Ask, Access, Advice, Assist. [4,5,8] A structured management model which was proposed for tobacco cessation can be implied to green dentistry adoption.[5]

Ask: Gather detailed information about the routine dental procedures.[4,5,8]

Assess: Identify the procedures that can support eco-friendly dentistry.[4,5,8]

Advice: Develop clear, practical and achievable guidelines.[4,5,8]

Assist: Design frameworks considering the local environment in the clinics.[4,5,8]

Patients also play a major role in the success of green dentistry. Their preference of dentists who follow sustainable practices can also motivate the dentists to adapt eco-friendly options.

Education and training are essential for long-term success. Introduction of green dentistry into undergraduate and post-graduate training will prepare future dentists to adapt to green dentistry from the beginning of their career. Continuous education programs can help the existing practitioners. A key finding from the 2014 HEA and NUS report on student attitudes toward sustainability revealed that approximately two-thirds of surveyed students believe sustainable development should be included in university curricula, a trend consistently observed since the first survey conducted in 2010–2011.[6] Significant investments have been made by universities in the USA and UK to construct buildings with sustainability features such as University of Rhode Island and Tufts University. [6] Green Impact initiative at the University of Manchester is another prime example of adoption of green dentistry.[6]

A comparable framework was established in the United States through the Association for the Advancement of Sustainability in Higher Education (AASHE), which introduced its Campus Sustainability Leadership Award in 2006.[6] Hundreds of institutions now use Sustainability Tracking, Assessment and Rating System (STARS) to measure and showcase sustainability performance.[6]

Although initial investment is high, long-term results include decreased expenses, improved efficiency, and enhanced public perception. With appropriate policy support and professional commitment green dentistry is practical and essential for the future of dentistry.

Research and development in biocompatible dental materials, less energy consuming dental equipment, laser dentistry adoption can make green dentistry possible to the full extent. Collaboration between dental

associations, environmental scientists, and policy makers can drive the development of realistic sustainability.

Pollution in Dentistry Due to Single-Use Plastics

Modern dental practices rely mostly on single-use plastics for infection control and operational efficiency. Disposable gloves, masks, suction tips, saliva ejectors, plastic impression trays, barrier films, headrest covers and sterilization pouches are routinely used in the clinics. Although these help in the prevention of cross-infection, they cause significant environmental pollution. 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.[11,15]

Most plastics used in dentistry are non-biodegradable and persist in the environment for decades. Land-filling leads to soil and water contamination through chemical leaches. Incineration leads to release of greenhouse gases and other harmful byproducts which cause air pollution. The waste produced from a single clinic might appear small, but the cumulative effect from all the dental offices in the world results in substantial burden on the environment.

Improper waste segregation, excessive packaging, and lack of recycling plants further complicates pollution. Therefore, single use plastics poses a major environmental challenge and emphasizes the urgent need for eco-friendly alternatives. To reduce pollution, regular audits of the plastic waste produced can be beneficial. Introducing alternatives such as reusable barriers and autoclavable suction tips can play a major role in reducing the accumulation of plastic waste.

Manufacturers can be encouraged to use recyclable polymers. Dental associations can collaborate with recycling programmers for effective recycling. Establishment of strict waste segregation protocols and staff accountability can further contribute to eco-friendly practices.

Table 1: Differences in the Maintenance of Infection Control Protocols and Environmental Sustainability in Developed and Developing Countries

Aspect	Developed countries	Developing countries
Infection control guidelines	Strict, standardized and regularly updated protocols supported by national and international regulatory bodies	Guidelines are not consistently implemented due to resource limitations
Regulatory framework	Routine monitoring and compliance audits	Inconsistent regulatory monitoring
Use of disposable materials	High use, balanced with recycling strategies	Low to moderate; Increasing gradually with increased importance of infection control protocols.
Waste segregation and management	Well-established systems for segregation, recycling and disposal of biomedical waste	Improper segregation is common; lack of accessibility to recycling and safe disposal facilities
Recycling infrastructure	Advanced recycling facilities and environmentally responsible disposal systems	Minimal or no recycling infrastructure causing environmental pollution
Energy efficiency	Using energy efficient equipment and digital records	Limited energy efficient systems due to high costs

Feasibility of Green Dentistry Adoption: Ethical and Professional responsibility of the Dentists

Dentists hold ethical and professional responsibility towards environmental and public health protection. 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.[11] The principle of 'non-maleficence' applies not only to the patients but also to society and the environment. Excessive waste generation, inefficient resource use, and environmental pollution conflict with the ethics of dentists. By adopting eco-friendly practices, dentists stand as role models and contribute positively to the environment and society. Adopting sustainable practice also aligns with 'non-maleficence' that is doing no harm. Professional responsibility also includes advocacy and education. As dental healthcare providers, they can promote preventive dentistry and influence patients positively, eliminating significant waste production while maintaining patient's health.

Biodegradable dental materials

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.[11,12] Similarly, starch-based biomaterials are being developed as temporary trays and packaging alternatives, providing both cost effectiveness and reduced environmental burden.[11,13] 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.[11,14]

Advantages and Disadvantages of Green dentistry

The advantages include a reduction in environmental pollution, workplace safety and indoor air quality, long-term cost efficiency, improved patient trust and alignment with global sustainability goals. However, there are a few disadvantages including high initial investments, limited access to technologies in low economic settings, need for training and behavioral change, and inadequate recycling infrastructure in some regions.

To maximize advantages clinics should integrate sustainability into long-term planning rather than an initial goal. Overcoming the financial barriers through phased investments, cost benefit analysis showing long-term benefits. To overcome infrastructure limitations, regional recycling plants and shared disposal facilities can be developed. By proactively addressing these challenges, green dentistry can have broader acceptance along with environmental, economic and professional benefits simultaneously.

Table 2: Strategies to introduce green practices into dentistry

Strategy	Approach	Contribution to bridge the gap
Infection control	Simplified, resource appropriate protocols	Maintains patient safety while supporting environmental sustainability in low-income settings
Education and Training	Online and distance learning programs	Expands awareness and skills in green dentistry at very low cost
Local manufacturing	Production of reusable dental materials and instruments	Reduces dependance on costly imports and enhances sustainability
Government and global support	Investments in waste disposal and recycling infrastructure	Improves environmental protection and safe disposal
Equity in Implementation	Context specific sustainable strategies	Guarantees green dentistry adoption and respects different healthcare realities

Conclusion

Green dentistry is an essential development of dental practice to prevent growing environmental, ethical and public health concerns. While infection control remains non-negotiable, oral healthcare delivery must balance patient safety with environmental responsibility. The excess use of single-use plastics, high energy and water consumption, and generation of biomedical waste places dentistry as a resource intensive profession. The principles of green dentistry state that sustainability and clinical excellence are not separate but complimentary.

The adoption of eco-friendly alternatives, digital dentistry, and sustainable procurement of dental materials has shown significant potential to reduce the carbon footprint of the dental practices. Reusable instruments, digital radiography, paperless records, and energy-efficient infrastructure contribute to waste reduction, cost-saving and improved operational efficiency over time. Although initial investments remain higher, long term economic benefits, and enhanced professional image make the adoption of green dentistry worthy. In addition, ethical principles like beneficence and non-maleficence requires dental professionals to do no harm not only to the patients but also to the environment.

However, differences between developed and developing countries pose challenges related to cost, infrastructure, awareness and regulations. Addressing these differences is important for equal and widespread implementation of green dentistry.

Recommendation for Green dentistry adoption:

1. **Phased implementation:** Begin with low-cost measures such as waste segregation, paper reduction, water and energy conservation and slow introduction of reusable materials.
2. **Education and training**: Introduction of green dentistry into dental curriculum in undergraduate and post-graduate levels and provide continuous professional development courses on green dentistry.
3. **Policy and Incentives**: Government and regulatory bodies should provide guidelines, incentives and subsidies to support sustainable dentistry, especially in low-income settings.
4. **Sustainable procurement:** Encourage purchasing dental materials in bulk with minimal packaging, along with selection of eco-certified suppliers.[5]
5. **Professional advocacy:** Dentists should advocate responsibility and accountability to environment, which can influence the patients, colleagues, and policy makers.

To conclude, green dentistry is essential and practical to the future of oral healthcare. With collective professional commitment, supportive policies, and education sustainable dental practice can become the standard for future.

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