Environmental Sustainability Related to the Materials and Procedures in Endodontics: A Critical Review

Endodontide Kullanılan Materyaller ve Prosedürlerle İlgili Çevresel Sürdürülebilirlik: Eleştirel Bir İnceleme

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ABSTRACT

The aim of this study is to identify strategies for protecting the environment in dental practices, including the materials used in these treatments, and to determine how simple measures can contribute to green dentistry. Articles published between 1996 and 2024 in PubMed, Scopus, Google Scholar, and Web of Science were reviewed. A total of 36 non-duplicate English-language articles containing the keywords 'green dentistry,' 'eco-friendly dentistry,' and 'sustainable dentistry' were included, and studies conducted in this field were analyzed. Green dentistry promotes the use of eco-friendly materials and technologies, such as digital impressions, lasers, restorative materials and irrigation solutions to minimise waste generation and energy consumption. It is easy to transform current dentistry into green dentistry by adopting simple measures and small changes. Dental practices can contribute to sustainability by implementing waste segregation, recycling and using renewable energy sources. Embracing green dentistry principles reduces environmental pollution, enhances patient health and ensures long-term sustainability. More incentives should be introduced for the adoption of green dentistry principles. Furthermore, access to these principles should be made easier and inexpensive.

Keywords: *Eco-friendly dentistry, green dentistry, dental materials, dental procedures, endodontology, sustainable dentistry*

ÖZ

Bu çalışmada amaç diş hekimliği uygulamaları ve bu tedavilerde kullanılan malzemelere kadar çevreyi korumaya yönelik stratejilerin tespit edilmesi ve alınacak basit önlemlerle yeşil diş hekimliğine ne gibi katkılar sağlanabileceğinin belirlenmesidir. 1996-2024 yılları arasında Pub Med, Scopus, Google Scholar ve Web of Science'ta yayımlanan makaleler tarandı. "Yeşil diş hekimliği", "çevre dostu diş hekimliği" ve "sürdürülebilir diş hekimliği" anahtar kelimelerini içeren İngilizce olan ve dublike olmayan toplam 36 makale dahil edildi ve bu alanda yapılan çalışmalar incelendi. Yeşil diş hekimliği, atık üretimini ve enerji tüketimini en aza indirmek için dijital ölçü yöntemleri, lazerler, restoratif materyaller ve irrigasyon solusyonları gibi çevre dostu materyallerin ve teknolojilerin kullanımını teşvik etmektedir. Basit önlemler ve küçük değişikliklerle mevcut diş hekimliğini yeşil diş hekimliğine dönüştürmek kolaydır. Diş hekimliği muayenehaneleri atık ayrıştırma, geri dönüşüm ve yenilenebilir enerji kaynakları kullanarak sürdürülebilirliğe katkıda bulunabilir. Yeşil diş hekimliği ilkelerinin benimsenmesi çevre kirliliğini azaltır, hasta sağlığını iyileştirir ve uzun vadeli sürdürülebilirlik sağlar. Yeşil diş hekimliği ilkelerinin benimsenmesi için daha fazla teşvik sağlanmalıdır. Ayrıca, bu prensiplere erişim daha kolay ve ucuz hale getirilmelidir.

Anahtar Kelimeler: *Çevre dostu diş hekimliği, yeşil diş hekimliği, dental malzemeler, dental prosedürler, endodontoloji, sürdürülebilir diş hekimliği*

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INTRODUCTION

Synchronicity and balance between humans and nature are greatly challenged by the consequences of rapid economic growth that has been triggered by scientific and technological innovations. In 2012, UNESCO stated that sustainability is a paradigm for creating a future in which environmental, social and economic considerations are balanced in the pursuit of development and improved quality of life.[1]

Sustainable development is defined as 'development that meets the needs of today without compromising the ability of future generations to meet their own needs'.[1] Furthermore, the collaborative efforts of countries are essential to protect this earth, which is humanity's home.[2] Therefore, the following possible strategies for global environmental sustainability have been proposed: reducing waste through the implementation of strategies to reduce, reuse and recycle waste materials; reducing toxicity by using non-toxic or less harmful materials and chemicals; conserving resources by minimising the consumption of water, energy and other resources; and implementing responsible waste management while preventing or minimising pollution.

In today's world, the concept of sustainability is gaining importance across various industries, including dentistry. Dental practices, like other healthcare facilities, can significantly impact the environment through their operations. Thus, there's a growing emphasis on adopting sustainable practices in dental offices, which is commonly referred to as 'green dentistry'. Green dentistry includes the concept of 'Reduce, Reuse, Recycle and Rethink'.[3] 'Reduce' is one of the easiest principles to implement. By reducing the number of resources used, the amount of waste produced can be reduced, protecting the environment. A few measures that can be implemented are reducing electricity and water consumption and preventing paper waste. 'Reuse' refers to extending the life of materials being used. Reusing products prevents waste generation and reduces the amount of energy used for producing new materials. Biodegradable disposable instruments and sterilisable stainless-steel instruments can be used to implement this principle. Waste generated in dentistry consists of materials that can be 'recycled' with simple separation techniques. Some of these recyclable materials include aluminium, paper, steel and plastic. 'Rethinking' every treatment step, clinic operation and clinical layout in the dental office can be an important step towards sustainability and environmental protection. This can be achieved with the following strategies: avoiding heavy chemicals to prevent water pollution during sterilisation, using digital methods instead of paper for storing patient data to prevent paper waste, choosing renewable energy sources to power the clinic and choosing conventional radiography instead of digital radiography to prevent water and soil pollution.[3]

By following the principle of 'Reduce, Reuse, Recycle and Rethink', sustainability can be naturally achieved. Sustainability brings about a healthier society, less environmental pollution and healthier use of existing resources. Integration of dentistry innovations in daily practice promotes the efficient use of time and resources, reduces supply costs, curbs waste generation and prevents environmental pollution. Thus, patients benefit from higher quality treatments at lower costs.

The increase in carbon footprint is an important factor in global warming and impacts the environment. In recent years, the carbon footprint of dental clinics has significantly increased. Therefore, using sustainable materials and devices in dentistry is crucial. Furthermore, waste reduction and separation should be emphasised to ensure a sustainable future.[4] A typical dental clinic uses several disposable materials and chemicals daily. Although these disposable materials are useful for maintaining sterility, they should be avoided to limit waste generation. Green dentistry practices often encourage the use of sterilisable materials.[5] From treatments to office supplies, there are numerous easily accessible and affordable ways to help dentists and endodontists be more environmentally conscious.[6]

MATERIAL AND METHODS

This scoping review followed the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). A comprehensive search was conducted across four electronic databases, namely Google Scholar, PubMed, Scopus and Web of Science, using a research query detailed in Figure 1. The terms 'green dentistry', 'eco-friendly dentistry' and 'sustainable dentistry' were searched independently, and 1,332 articles were identified. The search was last conducted on August 18th, 2024, and included papers published between 1996 and 2024. All identified records were screened in two sequential stages. Initially, two independent reviewers scrutinised titles and abstracts to eliminate studies beyond the review scope. Non-English, duplicate and inaccessible full text articles were excluded. The remaining articles were further reviewed under the headings of dental lasers, natural irrigation solutions and medicaments, root canal filling materials, dental filling materials and dental impressions. The individual articles identified under these five headings were scrutinised and articles relevant to the topic but not identified during the literature search were included in the study. Finally, 36 articles were

included in the study. The included articles were categorised according to the areas of expertise (Table 1) and topics (Table 2).

RESULTS

The 36 included studies were categorised according to dentistry sub-branches, and their suitability was examined (Table 1). The studies were also sub-divided into five thematic headings: dental lasers (n = 4), natural intermediate session medications and irrigation solutions (n = 12), root canal filling materials (n = 4), dental filling materials (n = 6) and separation of impression materials (n = 10) (Table 2). These data will allow readers to focus on specific points according to their general areas of interest and expertise, while data related to thematic headings have been examined in detail.

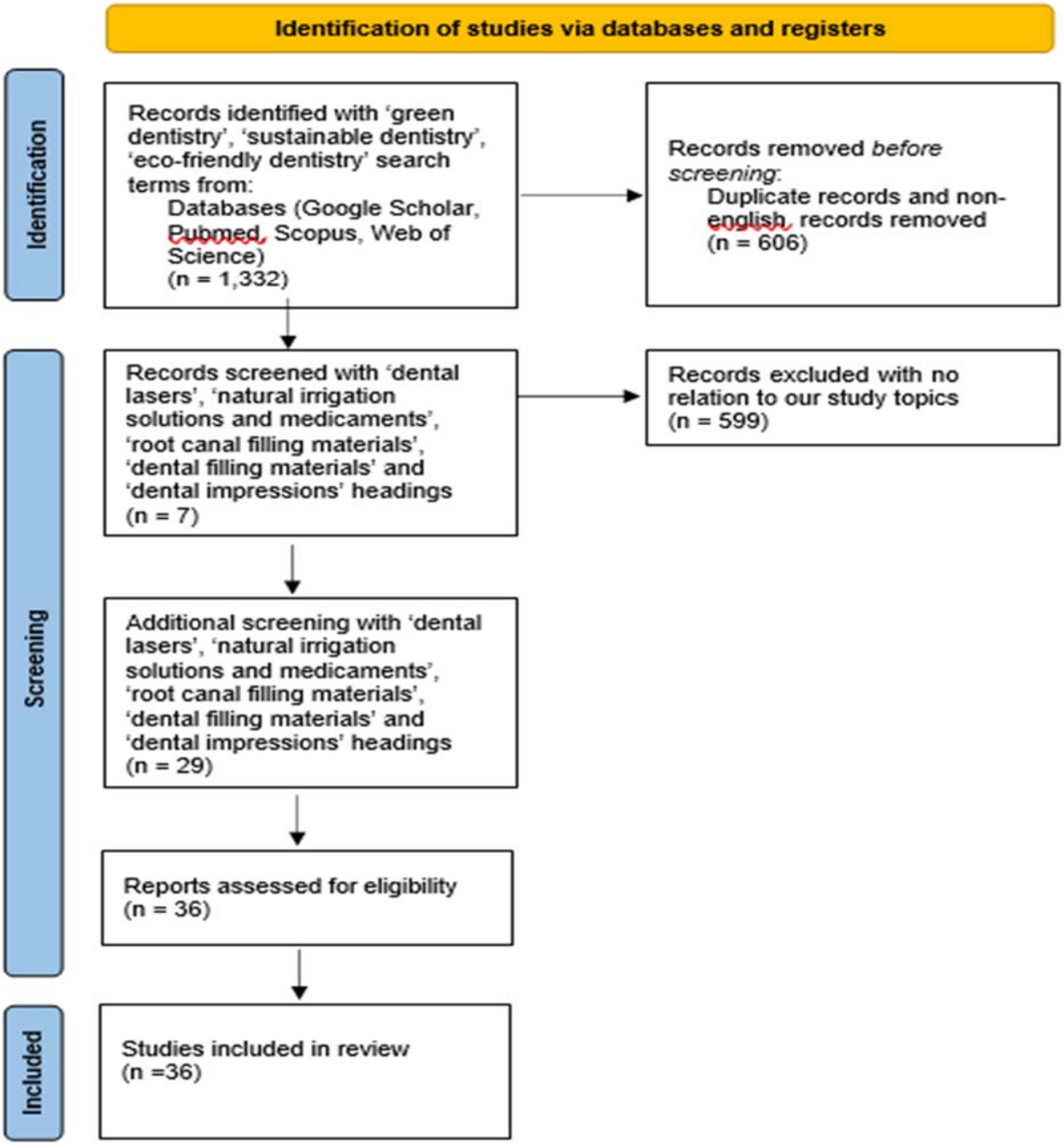

Figure 1. Flow diagram of the literature search and included studies.

Table 1. The included studies according to the sub-branches of dentistry.

Studies	*Endodontics*	Restorative	Prosthetic Dentistry	Periodontology	Radiology	Orthodontics	Oral and Maxillofacial Surgery	General Dentistry
Gupta & Brizuela, 2023								+
Duane & Steinbach 2023								+
Raoof et al. 2023	+							
Ruchi Gupta et al. 2022	+	+			+			+
Kaval et al. 2022	+							+
Wanicharat et al.2022	+							
Martin et al. 2021		+						+
Bota et al. 2021	+							+
Mittal et al 2020								+
Pallavi et al. 2020 (noinfo)								
Tekin&Demirkaya 2020	+							
Dobrzański et al 2020	+	+	+	+				+
Khanna&Dhaimade, 2019								+
Alikhasi et al. 2018a			+					
Alikhasi et al. 2018b			+					
Nedelcu et al 2018			+					
Ahlholm et al., 2018			+					
Rathakrishnan&Priyadarhini 2017								+
Chopra&Raju, 2017								+
Al-Haddad& Che Ab Aziz, 2016	+							
Srinivasan&Chitra 2015		+			+			+
Joda & Brägger 2015			+					
Lee et al 2015			+					
Rupa et al. 2015		+			+			+
Costa et al. 2014				+				
Flügge et al. 2013						+		
Silva et al. 2013	+							
Thopegowda et al 2013			+					
Kumar, 2012		+			+			+
Passi& Bhalla 2012								
Schembri et al. 2010	+	+						
Matsunaga et al. 2010	+							
Murray et al. 2008	+							
Bramante et al. 2008	+				+		+	
Oncag et al. 2006	+							
Wynn, 2005				+	+		+	
Estrela et al. 2004	+							
Ozbek&Sanin, 2004								+
Batchu et al. 2004		+						
Hepşen et al. 1996	+							

Table 2. The included studies according to the dental applications.

Studies	*Dental Lasers*	*Natural Medicaments and Irrigation Solutions*	*Root canal filling materials-*	*Dental filling materials*	*Dental impressions*
Raoof et al. 2023		+			
Kaval et al. 2022		+			
Gupta&Brizuela, 2023					+
Juman et al, 2022					+
Wanicharat et al.2022		+			
Martin et al 2021				+	
Bota et al. 2021		+			
Tekin&Demirkaya 2020		+			
Dobrzański et al 2020				+	
Mittal et al, 2020					+
Pallavi et al. 2020	+				
Khanna&Dhaimade, 2019	+			+	
Alikhasi et al. 2018a					+
Alikhasi et al. 2018b					+
Nedelcu et al 2018					+
Ahlholm et al., 2018					+
Rathakrishnan&Priyadarhini 2017				+	
Chopra&Raju, 2017	+				
Al-Haddad& Che Ab Aziz, 2016			+		
Lee et al 2015					+
Rupa et al. 2015				+	
Joda & Brägger 2015					+
Costa EM et al. 2014		+			
Flügge et al. 2013					+
Silva et al. 2013		+			
Kumar 2012	+				
Schembri et al. 2010			+		
Matsunaga et al. 2010			+		
Murray et al. 2008		+			
Bramante et al. 2008			+		
Oncag et al. 2006		+			
Wynn RL, 2005		+			
Estrela C et al. 2004		+			
Ozbek&Sanin, 2004				+	
Batchu et al.2004				+	
Hepşen et al. 1996		+			

Dental lasers

Lasers play a crucial role in various dental procedures, offering several benefits in the field of oral health. Lasers are used to remove tooth decay and prepare the surrounding enamel for a replacement filling.[7] Additionally, soft tissue lasers are utilised to reshape gums and eliminate bacteria during root canal procedures during the treatment of gum disease.[3] Furthermore, lasers expedite office teeth whitening processes by serving as a

heat source and activating a peroxide bleaching solution on the tooth surface.[8] Lasers have also been used in conducting biopsies and removing oral cavity lesions. They enable the extraction of small tissue samples for cancer screening and assist in alleviating the discomfort associated with canker sores.[9]

The adoption of lasers in dentistry is associated with several advantages and aligns with the concept of sustainable dentistry. Lasers have replaced traditional drills and the self-sterilising nature of the active laser tip eliminates the need for autoclaving and the associated sterilisation costs. Longevity is another feature of lasers. The inserted fibre ends, when used appropriately, can last for an extended period. The use of lasers to reduce intraoperatively bleeding can save time and minimise the need for materials to staunch the bleeding. Furthermore, the diminished pain experienced during cavity preparation is associated with reduced anaesthesia consumption. Finally, the absence of scalpel use negates the generation of hazardous medical waste, aligning with environmentally conscious practices in healthcare. A single laser device encompasses multiple dental applications, eliminating the necessity for numerous individual devices. Furthermore, the extended lifespan of laser devices contributes to its cost-effectiveness.

Natural irrigation solutions and medicaments

Effective irrigation is an important procedure to disinfect the root canal in endodontic treatments. Traditional irrigation methods, such as sodium hypochlorite, Ethylenediaminetetraacetic acid and chlorhexidine, have been used for a long time. Although these solutions are effective disinfectants, they are associated with the risks of cytotoxicity, allergic reactions and environmental concerns. These limitations and patients' growing environmental concerns and sensitivities there is an increasing need and desire for sustainable and natural solutions. Natural irrigation solutions have emerged as an alternative to address these needs.[10]

Natural irrigation solutions offer promising benefits in endodontic practice. Natural irrigation solutions utilise the therapeutic properties of plants and organic compounds to achieve effective disinfection. These solutions offer biocompatibility, reduced toxicity and potential synergistic effects with conventional treatment methods.[10]

Bouea macrophylla kernel extract

Bouea macrophylla kernel extract is used as an intracanal medicament between root canal treatment appointments. It disrupts the fungal and bacterial cell membranes and inhibits root canal biofilm formation. Its exhibits antimicrobial effects against *Enterococcus faecalis, Streptococcus gordonii* and *Candida albicans*.[11]

Vinegar

Consisting mainly of acetic acid, vinegar has natural antimicrobial properties that make it effective against bacteria within the root canal. Furthermore, its acidic structure facilitates the dissolution of organic tissue and ensures thorough cleaning of the root canal system. Unlike some traditional irrigation solutions, vinegar is biocompatible and rarely causes adverse reactions, making it a safer option.[10]

Vinegar can eliminate the smear layer, which consists of organic and inorganic components that block the dentinal tubule entrances. Furthermore, it exhibits a bactericidal effect against microorganisms frequently associated with endodontic infections, such as *Staphylococcus aureus* and *Enterococcus faecalis*. The high malic acid content in vinegar also contributes to the repair process in the periapical region.[12]

Although vinegar offers several advantages, it also has its disadvantages. Its acidic nature may cause tissue irritation if not diluted properly and long-term exposure could impact dental materials. Furthermore, the patient's acceptance of vinegar irrigation may vary due to its taste and smell, requiring communication and education regarding its benefits and safety.[10]

Propolis

Propolis is a sticky resinous mixture produced by the *Apis mellifera* bees from materials collected from different plants to protect the honeycomb structure.[10] Propolis exhibits potent antimicrobial and anti-inflammatory properties. Its inclusion in irrigation protocols has demonstrated a reduction in bacterial load and promotion of tissue healing, making it a valuable adjunct in endodontic therapy.[13] Propolis has demonstrated good in vitro antibacterial activity against *E. faecalis* in root canals and has been suggested as an alternative intracanal medicament.[14]

Chitosan

Chitosan, a derivative of chitin found in the exoskeletons of crustaceans, has garnered attention for its versatile properties across various industries. It has been included in research studies in dentistry due to its biocompatibility, adhesive capability, lack of toxicological activity and genotoxic effect.[15] Thus, chitosan is a promising irrigation solution in endodontics. In 2013, Silva et al. used scanning electron microscopy (SEM) to evaluate the effectiveness of the final irrigation agents used after root canal instrumentation in removing the smear layer. SEM analysis demonstrated that 0.2% chitosan solution could remove the smear layer and similar results were obtained only with high concentration solutions such as 15% ethylenediaminetetraacetic acid (EDTA) and 10% acetic acid.[16]

Chitosan is a hydrophilic biopolymer prepared by the alkaline deacetylation of chitin. It exhibits high biocompatibility, biodegradability, antimicrobial and anti-inflammatory activities. Furthermore, it positively affects wound-healing, hemostasis and tissue regeneration. A study examining the anti-inflammatory activity of chitosan revealed that at a concentration of 50 μg/mL, it lowered the expression levels of IL-1β, IL-6 and TNF-α.[17]

Morinda Citrifolia

Morinda citrifolia (Rubiaceae), known as noni, is indigenous to Southeast Asia and the Pacific and has a longstanding history of medical use.[10] The combination of antimicrobial, anti-inflammatory and tissue healing properties make the *Morinda citrifolia* juice (CMJ) a versatile solution for the complexities of endodontic infections and inflammation and a promising alternative irrigation solution.

Murray et al. (2008) compared the effectiveness of CMJ, sodium hypochlorite (NaOCl) and chlorhexidine solutions in removing the smear layer from root canal walls and their antimicrobial properties. The growth of *E. faecalis* was inhibited by CMJ at a concentration of 6%. Furthermore, 6% CMJ, 6% NaOCl and 17% EDTA were required to effectively remove the smear layer during the final irrigation.[18]

Aloe vera

Aloe vera gel (*Aloe barbadensis* Miller), renowned for its anti-inflammatory and wound-healing properties, is a viable irrigation solution in endodontics. Its soothing effect on periapical tissues and ability to enhance dentin remineralisation make it a viable option for clinicians seeking natural alternatives.[10] Aloe vera demonstrates antimicrobial activity against various species such as *Streptococcus pyogenes, S. aureus, E. faecalis* and *Candida albicans*.[19]

Triphala

Triphala, composed of three medicinal herbs (*Emblica officinalis* [Amalaki], *Terminalia bellerica* [Bibhitaki] and *Terminalia chebula* [Haritaki]), is revered in Ayurveda for its therapeutic properties.[10] Rich in antioxidants and bioactive compounds, Triphala exhibits antimicrobial, anti-inflammatory and wound-healing properties, making it a promising alternative for endodontic irrigation. Its multifaceted mechanism of action ensures thorough cleansing while promoting tissue healing and addressing the dual challenges of infection control and tissue preservation in endodontic therapy.

Herbal extracts

Herbal extracts such as neem, tea tree oil and thyme have demonstrated antimicrobial activity against endodontic pathogens. Their natural origin and broad-spectrum efficacy make them promising candidates for irrigation solutions, particularly against antibiotic-resistant strains.[20]

Essential oils

Essential oils such as clove, eucalyptus and cinnamon possess potent antibacterial and anti-inflammatory properties. Thus, incorporating these oils into irrigation solutions can enhance microbial control and promote periapical healing, offering a holistic approach to endodontic therapy.[21]

Root canal filling materials

Using more biocompatible materials in dentistry is crucial for the health of patients, dentists and the environment. To ensure that the health of patients, dentists and the environment is not threatened by the dental materials used, we should aim to improve the clinical practices of dentistry, the maintenance of the products and the use of dental materials. Thus, the mineral trioxide aggregate (MTA) and its bioceramic properties have been modified.

The MTA is composed of Portland cement[22], which contains primarily aluminium and trace amounts of arsenic, lead and chromium elements. Studies have demonstrated that the Portland cement generates negative effects.[23-27] Thus, second generation materials such as pure tricalcium silicate cement have been developed. Additionally, bioceramic-based materials have been introduced. Bioceramic root canal sealers, composed of second-generation materials, do not allow the leakage of these trace elements and aluminium into the surrounding tissues.[22] They have become very popular recently, and contain a dental material that continues to be developed and modified. Bioceramic root canal sealers are highly biocompatible materials that do not irritate the periapical tissue, making them popular. Furthermore, they allow the formation of tooth and bone-like tissue via a series of chemical reactions during the hardening process. The other theories for tooth formation include the diffusion of second-generation materials into dentin tubules, infiltration of the area with collagen fibres released due to dentin contact and hydroxyapatite formation due to absorption of moisture from the dentin.[28] Furthermore, the antimicrobial activity gained by bioceramic root canal sealers due to calcium ion release increases the success rate of endodontic treatments by eliminating the possibility of intraradicular infection.[28]

Dental filling materials

Although dentists are careful during treatments, waste material can be released into the environment. The most important of these are the chemicals released from the frequently used amalgam fillings. Dental amalgam is preferred over other fillings because it is inexpensive,

durable and easy to use. However, mercury is the most abundant metal in amalgam fillings, which contributes to the high worldwide mercury consumption. Mercury can bioaccumulate in the environment, plants, animals and humans, producing a toxic effect. Mercury is a neurotoxic and teratogenic heavy metal. Due to reactions at the site of accumulation, mercury can turn into methylmercury, which can also accumulate in the food chain.[29] Dentistry accounts for approximately 6% of the global mercury consumption and 14% of the mercury waste. Excess mercury in waterways can cause various health complications in humans and severely affect the local ecosystem.[30] Apart from this, dentistry contributes to cotton, plastic, paper and other 'disposable' waste.[31] Using sustainable resources reduces the burden on dentistry and produces less waste. The adoption of green dentistry offers numerous benefits, both for dental practitioners and the environment. Some of these benefits are as follows: reduced treatment costs due to reduction in resource consumption and waste generation; enhanced reputation of the dental practice via its commitment to sustainability, which can attract environmentally conscious patients; and reduced exposure of patients and physicians to harmful chemicals due to the use of eco-technology. Green dentistry can promote and contribute to the conservation of natural resources and ecosystems by minimising the harmful effects on the environment and ensuring better oral and general health.

Recently, researchers have focused on the polluting effect of amalgam.[3,9,32-34] Several measures have been proposed to eliminate or reduce this polluting effect. The most important target of these measures is dental aspiration units. Dental suction units evacuate numerous products that are generated during dental treatment, including restoration by-products and milling waste. The improper disposal of mercury, especially during the removal of amalgam fillings, can harm the environment. In dental clinics, low-cost amalgam separators should be used to recycle mercury and prevent the mercury residue from entering water sources and therefore the environment. Several ISO 11,143-certified amalgam separators are capable of significantly reducing amalgam particles and by-products in the wastewater of dental clinics [29]. Amalgam separators are inexpensive, easily available and very easy to maintain.[29]

Dental separators are designed to capture waste. However, they are not universally used due to the lack of equipment, legal obligations and updated regulations. Oxidising agents used to disinfect the dental unit after dental treatments also reportedly increase mercury release.[29] The mercury level in dental clinics is much higher than acceptable due to difficulties in controlling mercury release, insufficient equipment support, inadequate ventilation systems and wrong practices such as mixing amalgam by hand instead of using amalgam capsules.[29]

Dental impressions

Dental impressions are moulds or copies of a patient's teeth and oral tissue that are used by dentists to create accurate dental restorations such as crowns, bridges, dentures and orthodontic devices. Traditional and digital impression techniques differ in terms of their features and applications. Traditional impressions involve the use of impression materials, such as alginate, polyvinyl siloxane or polyether, to capture a detailed replica of the patient's teeth and surrounding tissue.[35] Dental waxes are not required after being shaped by heat and used in the patient's mouth. Moreover, 80–90% of the wax can be collected and purified by removing sticky impurities using simple techniques. Thus, the wax can be effectively reused and recycled several times without any deterioration in its properties.[36]

Traditional impression materials become unusable after they have been used in the patient's mouth and thus generate waste. To prevent this waste generation, digital measurement methods can be employed, which is beneficial for the patient, dentist and environment. Digital impressions serve as virtual models of the patient's mouth structure, eliminating the need for traditional impression materials that negatively affect the environment. This in turn preserves the energy resources used in the production of traditional impression materials. Digital impressions offer numerous advantages over traditional methods, including greater efficiency, better accuracy, improved patient comfort, reduced time consumption, remote collaboration and less environmental impact.[37,38] Furthermore, digital impressions can be easily shared electronically between dental laboratories or specialists, enabling remote collaboration and communication for treatment planning and fabrication of dental restorations.[37]

Digital impressions have demonstrated environmental benefits such as reduction in material waste, energy efficiency, long-term sustainability, elimination of disposable trays, conservation of natural resources, reduction in water use, reduction in carbon emissions, reduction in hazardous waste and promotion of green practices.[39] Digital impressions eliminate the need for traditional impression materials, which are often single-use and contribute to waste generation. By replacing these materials with digital scanning technology, the amount of disposable waste generated during dental procedures is significantly reduced.[38]

Digital impression technology is continuously evolving and becoming more sustainable over time. With advancements in materials, equipment and software, digital impressions could become more environmentally friendly and contribute to long-term sustainability in dental practice.[40]

Digital impressions contribute to the conservation of natural resources by reducing the demand for raw materials used in traditional impression materials, trays

and packaging. By minimising the extraction and processing of these resources, digital impressions support the sustainable practices in dental care.[41] Furthermore, digital impressions eliminate the need for increased water consumption associated with rinsing trays and cleaning traditional impression materials. Thus, it contributes to water conservation efforts.[40,42]

Digital impressions can reduce carbon emissions associated with the transportation and shipping of traditional impressions to dental laboratories. Thus, it helps decrease the carbon footprint of dental practices and contributes to environmental sustainability.[41]

Traditional impression materials often contain hazardous chemicals, such as mercury in dental amalgam or polymethyl methacrylate in acrylic resins, which can pose risks to human health and the environment if not disposed of properly. Digital impressions eliminate the need for these hazardous materials, resulting in a reduction in hazardous waste generation.[41]

Technological advancements in obtaining digital impressions are intraoral scanning, computer-aided design/computer-aided manufacturing (CAD/CAM) integration and cloud-based solutions. Modern intraoral scanners capture detailed digital impressions of patients' teeth and oral structures with high accuracy and precision. These scanners eliminate the need for messy impression materials, offering a more comfortable experience for patients while producing digital models that can be stored electronically.[37] Digital impressions seamlessly integrate with CAD/CAM systems, allowing for the efficient fabrication of dental restorations such as crowns, bridges and veneers. This integration streamlines the production process, which reduces waste generation and enhances the precision of dental restorations.[43] Several digital impression systems offer cloud-based storage solutions for securely storing and sharing digital models. This eliminates the need for physical storage space and facilitates the collaboration between dental professionals, contributing to a more sustainable and interconnected dental community.[44]

RESULTS

In this comprehensive review, we identified 36 studies that contribute to our understanding of environmentally sustainable oral health. The analysis highlights five dentistry themes: dental lasers, natural root canal medicaments and irrigation solutions, root canal filling materials, dental filling materials, and dental impressions. The 36 studies were also categorised according to the sub-branches of dentistry such as endodontics, restorative, prosthetics, periodontics, orthodontics, oral and maxillofacial radiology and general dentistry. This contributed to the creation of a road map for dental practices to achieve a more sustainable world.

The analysis revealed that attention should be paid to the separation, recycling and disposal of waste.[45] Reusable tools and equipment should be used instead of disposable ones.[46] By switching to the use of digital radiography, the amount of waste lead foil and chemicals, such as fixatives and developers, which can cause serious soil and water pollution, can be reduced.[47] One can switch to sustainable and renewable energy sources, such as solar energy, to power the dental offices.[48] Recycling reduces the amount of waste thrown into landfills while also limiting resource consumption.[45] Green dentistry promotes the use of biodegradable and non-toxic cleaning products as well as environmentally friendly dental materials to minimise chemical exposure and environmental pollution.[49,50] Green dentistry also promotes the adoption of digital technology, such as digital radiography, electronic health records and digital impressions, to reduce the use of paper and chemical processing associated with traditional film-based radiography and record-keeping.[51] By embracing digital impressions, dental practices demonstrate their commitment to sustainability and contribute to a greener future for dental healthcare. Adopting digital technology aligns with the growing trend of green dentistry, which emphasises environmentally friendly practices in dental care. The importance of sustainability in dentistry has not been fully understood until recent years, leading to a lack of sufficient research on the topic. This limitation may have constrained our review.

CONCLUSIONS

In conclusion, sustainability in dental practice, via the adoption of green dentistry principles, is essential for mitigating the environmental impact, promoting patient health and ensuring long-term viability. By incorporating sustainable practices into dental operations, practitioners can contribute to a healthier planet while maintaining high-quality oral healthcare services. As the global community increasingly prioritises environmental stewardship, green dentistry will play a vital role in shaping the future of the dental industry.

Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article.

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REFERENCES

1. Brundtland G. Report of the World Commission on Environment and Development. 1987.
2. Somani M, Srivastava AN, Gummadivalli SK, Sharma A. Indirect implications of COVID-19 towards sustainable environment: An investigation in Indian context. *Bioresour Technol Rep* 2020; **11**.
3. Khanna SS, Dhaimade PA. Green dentistry: a systematic review of ecological dental practices. *Environ Dev Sustain* 2019; **21**: 2599–2618.
4. Duane B, Steinbach I. What is the environmental footprint of a dental practice? A life cycle analysis (Part 1). *Br Dent J* 2024.
5. Gupta R, Tomer AK, Krishnakumar K. Green Dentistry: An Eco-friendly Approach. *IOSR J Dent Med* 2022; **21**: 45–49.
6. Passi S, Bhalla S. Go green dentistry. *J Educ Ethics Dent* 2012; **2**: 10.
7. Bharath KG. Green Dentistry; Ecofriendly Dentistry: Beneficial for Patients, Beneficial for The Environment. *Ann Ess Dent* 2012; **4**:72-4.
8. Pallavi C, Moses J, Chrishantha Joybell C, Sekhar KP. Assessment of knowledge, attitude, and implementation of green dentistry among dental practitioners in Chennai 2020.
9. Chopra A, Raju K. Green Dentistry: Practices and Perceived Barriers Among Dental Practitioners of Chandigarh, Panchkula, and Mohali (Tricity), India. *J Indian Assoc Public Health Dent* 2017; **15**:53-6.
10. Tekin B, Demirkaya K. Natural irrigation solutions in endodontics. *Gulhane Medl J* 2020; **62**: 133–138.
11. Wanicharat W, Wanachantararak P, Poomanee W, Leelapornpisid P, Leelapornpisid W. Potential of Bouea macrophylla kernel extract as an intracanal medicament against mixed-species bacterial-fungal biofilm. An in vitro and ex vivo study. *Arch Oral Biol* 2022; **143**.
12. Estrela C, Holland R, Bernabé PFE, De Souza V, Estrela CRA. Antimicrobial potential of medicaments used in healing process in dogs' teeth with apical periodontitis. *Braz Dent J* 2004; **15**: 181–185.
13. Hepsen İF, Tilgen F, Er H. Propolis: medical properties and ophthalmologic use. *Ann Med Res* 1996; 3(4): 386-391.
14. Oncag O, Cogulu D, Uzel A, Sorkun K. Efficacy of Propolis as an intracanal medicament against Enterococcus faecalis. *Gen Dent* 2006; **54**: 319–322.
15. Costa EM, Silva S, Costa MR, Pereira M, Campos DA, Odila J, Madureira AR, Cardelle-Cobas A, Tavaria FK, Rodrigues AS, Pintado MM. (2014). Chitosan mouthwash: toxicity and in vivo validation. *Carbohydr Polym* 2014; **111**: 385–392.
16. Silva PV, Guedes DFC, Nakadi FV, Pécora JD, Cruz-Filho AM. Chitosan: a new solution for removal of smear layer after root canal instrumentation. *Int Endod J* 2013; **46**: 332–338.
17. Kaval ME, Cakir B, Polatli E, Rençber S, Karavana SY, Nalbantsoy A, Güneri P. IL-1ß, IL-6 and TNF-α expression levels of macrophage cells induced by benzydamine hydrochloride, benzydamine hydrochloride with chitosan, calcium hydroxide and chlorhexidine medicaments: An ELISA study. *Dent Mater J* 2022; **41**: 545–551.
18. Murray PE, Farber RM, Namerow KN, Kuttler S, Garcia-Godoy F. Evaluation of Morinda citrifolia as an endodontic irrigant. *J Endod* 2008; **34**: 66–70.
19. Wynn RL. Aloe vera gel: Update for dentistry. *Gen Dent* 2005; **53**: 6–9.
20. Raoof M, Zadeh M, Nejad Z, Sharififar F, Khodashenas M, Fereidooni R. Antimicrobial efficacy of different herbal extracts against root canal pathogens - An in vitro study. *Indian J Dent Res* 2023; **34**: 204–208.
21. Nagy-Bota MC, Man A, Santacroce L, Brinzaniuc K, Pap Z, Pacurar M, Pribac M, Ciurea CN, Pintea-Simon IA, Kovacs M. Essential oils as alternatives for root-canal treatment and infection control against enterococcus faecalis— A preliminary study. *Appl Sci* 2021; **11**: 1–13.
22. Camilleri J. Will Bioceramics be the Future Root Canal Filling Materials? *Curr Oral Health Rep* 2017; **4**: 228–238.
23. Duarte MAH, De Oliveira Demarchi ACC, Yamashita JC, Kuga MC, De Campos Fraga S. Arsenic release provided by MTA and Portland cement. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005; **99**: 648–650.
24. Monteiro Bramante C, Demarchi ACCO, de Moraes IG, Garcia RB, Duarte MAH. Presence of arsenic in different types of MTA and white and gray Portland cement. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; **106**: 909–913.
25. Schembri M, Peplow G, Camilleri J. Analyses of heavy metals in mineral trioxide aggregate and Portland cement. *J Endod* 2010; **36**: 1210–1215.
26. Matsunaga T, Tsujimoto M, Kawashima T, Tsujimoto Y, Fujiwara M, Ookubo A, Hayashi Y. Analysis of arsenic in gray and white mineral trioxide aggregates by using atomic absorption spectrometry. *J Endod* 2010; **36**: 1988–1990.

27. Camilleri J, Kralj P, Veber M, Sinagra E. Characterization and analyses of acid-extractable and leached trace elements in dental cements. *Int Endod J* 2012; **45**: 737–743.
28. Al-Haddad A, Che Ab ZA. Bioceramic-Based Root Canal Sealers: A Review. *Int J Biomater* 2016; **2016**:9753210.
29. Martin N, Sheppard M, Gorasia GP, Arora P, Cooper M, Mulligan S. Awareness and barriers to sustainability in dentistry: A scoping review. *J Dent* 2021; **112**: 103735.
30. Dobrzański LA, Dobrzański LB, Dobrzańska-Danikiewicz AD, Dobrzańska J. The Concept of Sustainable Development of Modern Dentistry. *Processes* 2020; **8**:160
31. Rathakrishnan M, Priyadarhini A. Green dentistry: The future. *J Int Clin Dent Res Organ* 2017; **9**:59.
32. Batchu H, Chou HN, Rakowski D, Fan PL. The effect of disinfectants and line cleaners on the release of mercury from amalgam. *J Am Dent Assoc* 2006; **137**: 1419–1425.
33. Ozbek M, Sanin FD. A study of the dental solid waste produced in a school of dentistry in Turkey. *Waste Manag* 2004; **24**: 339–345.
34. Rupa KR, Chatra L, Shenai P, Km V, Rao PK, Prabhu R. Taking a step towards greener future: A practical guideline for eco-friendly dentistry. *AKT Derg* 2014; **24**:135-148.
35. Gupta R, Brizuela M. Dental Impression Materials. *Stat Pearls;* 2023.
36. Thopegowda NB, Shenoy K, Shankarnarayana RK, Kukkila J, Vaddya SB, Gingipalli K. Recycling of Materials used in Dentistry with Reference to its Economical and Environmental Aspects. *Int J Health Rehabil* Sci 2013; **2**: 140–140.
37. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. *Am J Orthod Dentofacial Orthop* 2013; **144**: 471–478.
38. Joda T, Brägger U. Digital vs. conventional implant prosthetic workflows: a cost/time analysis. *Clin Oral Implants Res* 2015; **26**: 1430–1435.
39. Nedelcu R, Olsson P, Nyström I, Rydén J, Thor A. Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: A novel in vivo analysis method. *J Dent* 2018; **69**: 110–118.
40. Alikhasi M, Siadat H, Nasirpour A, Hasanzade M. Three-Dimensional Accuracy of Digital Impression versus Conventional Method: Effect of Implant Angulation and Connection Type. *Int J Dent* 2018; **2018**. doi:10.1155/2018/3761750.
41. Lee SJ, Betensky RA, Gianneschi GE, Gallucci GO. Accuracy of digital versus conventional implant impressions. *Clin Oral Implants Res* 2015; **26**: 715–719.
42. Mittal R, Maheshwari R, Tripathi S, Pandey S. Eco-friendly dentistry: Preventing pollution to promoting sustainability. *Indian J Dent Sci* 2020; **12**: 251.
43. Alikhasi M, Rohanian A, Ghodsi S, Kolde AM. Digital versus conventional techniques for pattern fabrication of implant-supported frameworks. *Eur J Dent* 2018; **12**: 71.
44. Ahlholm P, Sipilä K, Vallittu P, Jakonen M, Kotiranta U. Digital Versus Conventional Impressions in Fixed Prosthodontics: A Review. *J Prosthodont* 2018; **27**: 35–41.
45. Berg LR, Hager MC. Visualizing environmental science. *New Jersey: Wiley* 2007.
46. Anderson K. Creating an environmentally friendly dental practice. *CDS Rev* 1999; 12–18.
47. Adappa D, Chatra L, Shenai P, Veena K, Rao P, Prabhu R, Kushraj T, Shetty P, Hameed S. Being Environmental Friendly in Dental Radiology - 'Be the Change'. *Balkan Mil Med Rev* 2015; **18**: 81.
48. Srinivasan K, Chitra S. Green dentistry: A metamorphosis towards an eco-friendly dentistry: A review. *Int J Inf Res Rev* 2015; **2**: 1521–1525.
49. Furlini E, Desantis V, Nastri L. A Review of the Ecological Impacts of Green Dentistry. *Int J Dent* 2017.
50. Wu L, Gao S, Cao Y. Dental unit wastewater: an underestimated source of environmental pollution and public health risk. *Environ Sci Pollut Res Int* 2018; **25**.
51. Rozier RG, Horowitz AM, Podschun G. Dentist-patient communication techniques used in the United States: the results of a national survey. *J Am Dent Assoc* 2011; **142**: 518–530.