Journal of Dentistry 112 (2021) 103735

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Review Article

Awareness and barriers to sustainability in dentistry: A scoping review

Nicolas Martin *, Madison Sheppard, GaneshParth Gorasia, Pranav Arora, Matthew Cooper, Steven Mulligan

School of Clinical Dentistry, The University of Sheffield, S10 2TA, UK

ARTICLE INFO

Keywords:
Sustainability
Dentistry
Awareness
Barriers
Scoping review

ABSTRACT

Objectives: (i) To undertake a comprehensive scoping review of the literature that addresses the research question 'What is the current state of environmental sustainability in general dental practice?' (ii) To provide an effective baseline of data that will consider general awareness, barriers and challenges for the implementation of sustainable practice.

Data & sources: The scoping review was conducted for all published literature in the English language that addresses this topic up to the 31st April 2021. The method of the PRISMA-ScR (PRISMA extension for Scoping Reviews) was followed. 128 papers included in this scoping review consisted of: Commentary [Letters, editorials, communication and opinion] ($n = 39$); Research ($n = 60$); Literature reviews ($n = 25$); Reports [Policy and legislation] ($n = 4$). Each included record was analysed for emerging themes that were further classified according to their general relevance. The scoping review is considered over two manuscripts, with this first paper focusing on awareness of the problem and barriers or challenges to the implementation of sustainable care.

Conclusions: Eight diverse but closely interlinked themes that influence the sustainability of oral health provision were identified: Environmental impacts (CO_2e, air and water); Reduce, reuse, recycle and rethink; Policy and guidelines; Biomedical waste management; Plastics (SUPs); Procurement; Research & Education; Materials. Barriers to implementation were identified as: Lack of professional and public awareness; carbon emissions arising from patient and staff commute; challenges associated with the recovery and recycling of biomedical waste with a focus on SUPs; lack of knowledge and education into sustainable healthcare provision and; the challenges from the manufacturing, use and disposal of dental materials.

1. Introduction

Evidence that climate change is anthropogenic in nature is established [1,2]. Four out of nine planetary boundaries (safe operating limits of planetary health) have been crossed, including climate change, loss of biosphere integrity, land-system change and altered biogeochemical cycles (phosphorus and nitrogen) [3]. Global average temperatures are now significantly higher than pre-industrial levels, an effect that cannot be explained without human activity and greenhouse gas emissions [4]. The impacts of climate change include increased ocean and atmospheric temperatures, the associated impacts of altered precipitation patterns, rising sea levels, acidification of the oceans, increase in the frequency and intensity of extreme weather events and severe flora and fauna species-level extinction. Climate change has also been described as 'one of the biggest global threats to human health of the 21st century' [5]. Human health is intrinsically linked to the environment. It is estimated that climatic change currently causes over 150,000 deaths globally per year and between 2030 and 2050 this will increase to 250,000 additional deaths per year [6,7].

Health care delivery is currently not environmentally, socially or financially sustainable due to high amounts of CO_2e (carbon dioxide equivalent) and waste generation [8]. It is paradoxical that healthcare, with a central tenet to support and protect health and life, contributes to climate change with consequent increased deaths and reduced quality of life through unsustainable practices. Oral healthcare in particular, has previously focused on solely providing optimal patient care, without consideration of environmental impact. This is changing with an increasing awareness of the need for sustainability at all levels of society, government and industry. For example, the signing of the Paris Agreement of 2016, national legislation such as the U.K.'s Climate Change Act of 2008 and global climate change activism. Accordingly, there is a call for Dentistry as a profession, to integrate sustainable development goals

* Corresponding author.
E-mail addresses: n.martin@sheffield.ac.uk (N. Martin), s.mulligan@sheffield.ac.uk (S. Mulligan).

https://doi.org/10.1016/j.jdent.2021.103735
Received 4 May 2021; Received in revised form 6 June 2021; Accepted 18 June 2021
Available online 25 June 2021
0300-5712/

into daily practice and support a shift to a green economy in the pursuit of healthy lives and well-being for all through all stages of life [9]. As we strive to implement more sustainable practices, there is a need to understand the current knowledge base, to increase awareness, identify barriers and opportunities to implementation; alongside examples of best practice that can be implemented and translated into wider contexts.

Sustainability within oral healthcare is an emerging topic with a significant volume of literature outputs covering multiple facets of this domain. It is therefore important to review and compile this existing knowledge in a structured manner to establish a baseline, that will inform and support further research, fill knowledge gaps, drive engagement and establish parameters of best practice.

A scoping review of the current literature base is considered the most appropriate tool to accomplish this by asking the research question, 'What is the current state of environmental sustainability in general dental practice?' The aim of this study is to undertake a comprehensive scoping review of the literature to address the research question. Through this process we have undertaken a thematic analysis that describes the general professional and societal awareness of the problem; identifies the barriers or challenges to the implementation of sustainable care; considers the drivers and opportunities to develop and engage with sustainable practice and reviews recommendations and examples of best practice.

2. Method

The methodology established by Arksey & O'Malley and the PRISMA-ScR (PRISMA extension for Scoping Reviews) was used [10,11].

A thematic analysis as described by Braun & Clarke (2006, 2014) was employed to analyze the emerging themes in accordance with the six-point phases described [12,13]. Through a thematic analysis we have organized, described and interpreted our data set. Themes were identified from common patterns in the included papers. A patterned response relates to 'prevalence', in terms of space within each data item and of prevalence across the entire data set. Items of low prevalence, or that captured something important in relation to the overall research question, were also included. In this scoping review, we have gone beyond an inductive process of thematic coding and analysis (Frith and Gleeson, 2004) to a more detailed semantic approach (Knafl and Patton, 1990) [14,15]. In this way, the data is organized according to semantic content, and is then summarized and interpreted, with an attempt to theorize the significance of the patterns and their broader meanings and implications. A thematic analysis was used to identify, analyze and report patterns (themes) that arise through the review process.

The search strategy for the scoping review was undertaken in a series of distinct steps (Fig. 1). An initial search included published literature, internet web resources, all topics and all types of documents. A multidisciplinary research platform (Web of Science, Clarivate™-Institutional licence) was employed for this task as it enables simultaneous cross-searching of a range of citation indexes and databases (Table 1) [16]. Web of Science identified relevant literature, with no restriction on study design, article type (e.g., opinion pieces, editorials or patents etc.), source or date; and these were filtered later. No limitations were placed on the year of publication but only papers in the English language were

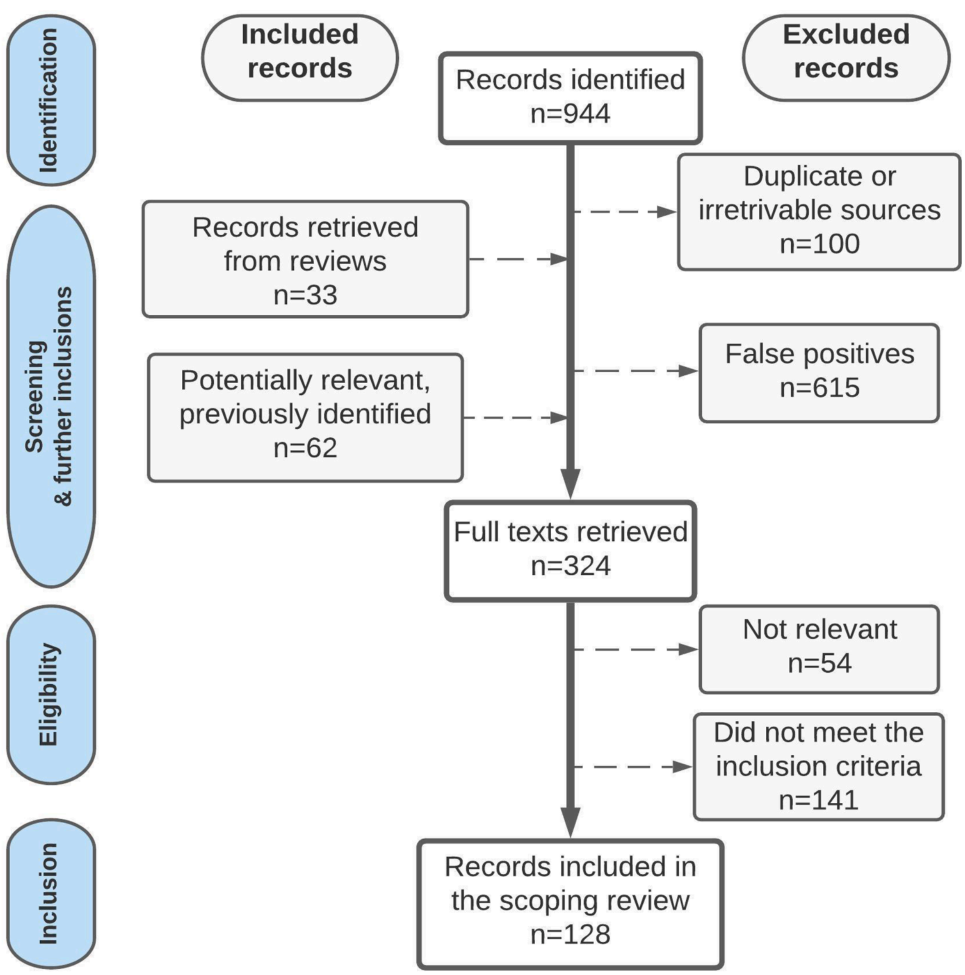

Fig. 1. Flow chart for record retrieval and inclusion (All outputs up to 30th April 2021).

Table 1
Search databases, search domains and search terms through web of science (16).

Database	Search domains
Web of Science Core Collection (1900-2021)	Publications: Journals (including open access), conference proceedings, patents, and books.Sources: Science Citation Index Expanded (1900–2021); Social Sciences Citation Index (1900–2021); Arts & Humanities Citation Index (1975–2021); Conference Proceedings Citation Index- Science (1990-2021); Conference Proceedings Citation Index- Social Science & Humanities (1990–2021); Book Citation Index-Science (2005–2020); Book Citation Index–Social Sciences & Humanities (2005–2020); Emerging Sources Citation Index (2015–2020); Current Chemical Reactions (1985-2020) [includes Institut National de la Propriete Industrielle structure data back to 1840); Index Chemicus (1993–2021).
BIOSIS Citation Index (1926-2021)	Publication: Journals (including open access), meetings, patents, and books.Domains: Pre-clinical and experimental research, methods and instrumentation, animal studies
BIOSIS Previews (1969-2021)	Publication: Journals (including open access), meetings, patents, and books.Domains: Pre-clinical and experimental research, methods and instrumentation, animal studies.
Current Contents Connect (1998-2021)	Publication: Complete tables of contents and bibliographic information from the world's leading scholarly journals.Domain: Social & Behavioural Sciences (1998–2021); Clinical Medicine (1998–2021); Life Sciences (1998–2021)
Data Citation Index (1900-2021)	Publication: Research data sets and data studies. Domain: Science (1900–2021); Social Sciences & Humanities (1900-2021)
Derwent Innovations Index (1963-2021)	Publication/Domain: Combines patent information indexed in the Derwent World Patent Index (1963–2020) with patent citations indexed from the Derwent Patents Citation Index (1973–2021).
KCI-Korean Journal Database (1980-2020)	Publication: Bibliographic information for scholarly literature published in Korea.Domain: National Research Foundation of Korea and contains
MEDLINE® (1950-2021)	Publications: Comprehensive bibliographic database. Domain: Life sciences database: The U.S. National Library of Medicine® (NLM®), NCBI databases and PubMed Related Articles
Russian Science Citation Index (2005-2021)	Publications: Selected and provided by the Scientific Electronic Library (eLIBRARY.RU)Domain: Across all domains
SciELO Citation Index (2002-2021)	Publications: Open access journals from Latin America, Portugal, Spain, and South Africa.Domain: Across all domains

included; as this is considered to be the main publishing language for scientific articles, governmental and national and international NGO reports. Since sustainability is an umbrella term which encompasses multiple subjects (e.g., climate change, carbon emissions, the use of plastics and many others), numerous searches were carried out with the aim to include as many relevant interpretations of sustainability as possible. The search terms used were: Carbon footprint; climate change; environmental impact; green dentistry; life cycle analysis or LCA; procurement; sustainable healthcare; sustainable dentistry; reduce, reuse, recycle or 3rs; reduce, reuse, recycle, rethink or 4rs; recycl*; single use plastics; waste management; and waste hierarchy. All search terms except sustainable healthcare and sustainable dentistry were compounded with the additional search term: Dentistry or dental care or dental practice or dental office. The search strategy was designed and agreed following consultation with the research team. The search was conducted between April 2020 to 30th April 2021 with this latter date marking the cut off for inclusion. This initial search identified 944 records.

Further screening was conducted by reviewing titles and abstracts with the authors working in pairs according to the inclusion/exclusion criteria and reaching consensual decisions (Table 2). Outputs were further excluded if they were duplicates ($n = 44$), irretrievable ($n = 56$) and not relevant at initial review (false positives) (615 papers). Further outputs were identified by the investigators from the bibliographies of the systematic and narrative reviews ($n = 95$). This process yielded 324 records, for which the full texts were retrieved.

Table 2
Inclusion and exclusion search criteria.

Inclusion criteria
Direct relation to dentistry
English language
Discussed sustainability in relation to the environment (not durability or other meanings)
All types of sources, including commentaries, opinion, reviews, reports and research.
Exclusion criteria
Contained search terms in a different context to the research question
Poor use of English language, poorly written or poorly translated, that prevented understanding
Papers not relevant to the research question
Research papers with absent or inadequate methodology

The full text papers were randomly divided into four groups to be analysed by four of the investigators (MS, GG, PA, MC). Each investigator individually read and critiqued a share of papers, summarising each with relative merits. The papers were tabulated in a spreadsheet to enable thematic analysis and coding with further filtering according to the inclusion/exclusion criteria (Table 2). Subsequently, the four investigators, working in pairs, cross-checked every paper. At this point, further papers were excluded. This process resulted in a final count 128 outputs to be included in the review.

The 128 papers included in this scoping review consisted of: Commentary [Letters, editorials, communication and opinion] ($n = 39$); Research ($n = 60$); Literature reviews ($n = 25$); Reports [Policy and legislation] ($n = 4$). Each record included was analysing for emerging themes as described. Key themes from each paper were coded against identified themes (Table 3, Fig. 2). Tabulated outputs up to the 31st April 2021 were included as the cut-off date from this scoping review (Table 4).

3. Results

The outputs are described thematically in eight separate headings as per Table 3. These are further divided into sub sections, where possible, to enable the reader to focus on specific points according to their general relevance. These subsections are detailed in two sequential publications:

- Awareness and barriers to sustainability in dentistry: A scoping review. This publication considers the literature with a focus on: *Background*, where appropriate; *Awareness* of society and the profession to the impact of oral health professional activities; and *Barriers* to develop and engage with sustainable practice.

- Drivers, opportunities and best practice for sustainability in dentistry: A scoping review [17]. This complementary publication considers the same body of the scoping literature review with a focus on: *Drivers* to develop and engage with sustainable practice; *Opportunities* to develop and engage with sustainable practice; *Recommendations & Best practice* for effective sustainable dental practice, based on guidance and real examples.

Table 3
Themes identified in the review of the literature.

Code	Theme Topic
1	Environmental impacts - CO_2e, air and water
2	Reduce, reuse, recycle and rethink
3	Policy and guidelines
4	Biomedical waste management
5	Plastic (SUPs)
6	Procurement
7	Research & Education
8	Materials

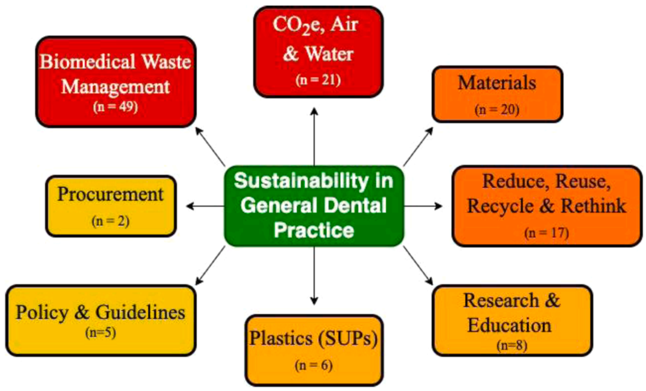

Fig. 2. Themes identified according to the number of records. Clockwise, red (most) to yellow (least) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

3.1. Theme 1: Environmental impacts-CO2e, air and water

3.1.1. Background

A series of recent articles by Duane et al., consider sustainability in a comprehensive manner and provide a very helpful contemporary context to this domain [18–25]. The introductory article highlights the relationship between planetary health and human health, focusing on an increased professional awareness to be environmentally sustainable but matched by an inability to act on this through lack of knowledge and tools [18]. This article also provides a series of useful definitions of greenhouse gases, global warming potential and CO_2e. The topics of air pollution, energy and water use, have a heavy predominance in the literature of this theme. There is a need to consider sustainability in dentistry within a wider context of modernisation of the dental profession and the services that it provides [26].

3.1.1.1. Air pollution. At a societal international level, the management of air pollution on a world-wide basis is led through the United Nations' body, The Intergovernmental Panel on Climate Change (IPCC) [27]. The IPCC aims to 'provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options.' Air pollution impacts every living being on planet Earth and every human citizen has a personal responsibility for managing this at an individual level. The professional literature has highlighted this point, noting that global greenhouse gases need to drop by 45% from 2010 levels in the next 12 years [18].

A major contributor to air pollution arises from petrol and diesel vehicles with significant health effects particularly on young children and people with respiratory and cardiovascular disease. Increased short-term exposure to elevated particulate matter can have adverse health effects [28]; in the UK, air pollution kills 40,000 people every year [9]. Healthcare is identified as a major contributor to CO_2 emissions and in the UK this is estimated to account for 5% of the national emissions [8]. At the level of professional activities in oral health care, air pollution is increasingly being understood and should not be underestimated [18, 30–34]. This arises from a number of different sectors, mainly incineration of waste, anaesthetic gases and CO_2 emissions associated with travel and transport; these are all considered separately in this report.

Waste management through incineration further contributes to air pollution. Medical waste incinerators release toxic air pollutants and ash, major contributors of dioxins in the environment; with a reported link to an increased risk of non-Hodgkin lymphoma and serum organochlorine concentrations [35]. Incineration of plastics is a recognised and significant contributor to the release of hazardous dioxins [36].

3.1.1.2. Patient and staff travel. Travel and transport accounts for 13% of CO_2 emissions associated with UK-NHS health, public health and social care. Travelling to and from practice by both patients and healthcare providers is the highest emission source (64.5%) [8,9,18,36–40].

The air pollution impact of travel related to dentistry is also significant and equates to around 8% of the total UK NHS air pollution impact from travel [21]. One tenth of air pollution emissions are from health care systems [36,41].

Dental-associated travel affects air quality, releasing over 443 tonnes of nitrogen oxides (NOx) and 22 tonnes of particulate matter (PM2.5) annually. The associated reduction in air quality reduces over 325 quality-adjusted life years (QALY) per year and costs £17.5 million a year [8,30]. There is a realisation that the profession's management of carbon emissions needs to be an integral part of normal sustainable practice [31].

3.1.1.3. Energy use. The energy use of buildings makes up 15% of the carbon footprint of primary dental care [9,36,39]. Without 'green' energy saving features, buildings contribute to 24% of the total UK NHS healthcare system carbon footprint by consuming more than £410 million worth of energy [36]. The annual carbon footprint of NHS dental electricity use is 51,939 tCO_2e and for gas 51,649 tCO_2e; this equates to 7.7% and 7.6% respectively of the total carbon footprint of NHS dental services in England [19,37]. Older smaller clinics, with no air conditioning and fewer meeting rooms generated lower carbon footprints than newer clinics. This suggests that new buildings are not necessarily more energy efficient [19]; the energy saving building features need have to be balanced against usage. A study by Duane et al. (2019) includes a useful comparative table of energy use within the dental practice [19]; e.g. autoclaves, washer disinfectors and ultrasonics use a lot of energy, although for a relatively low time through the day [19]. Building regulations and advisory groups can assist building owners to rate or create healthy, efficient and cost saving buildings; e.g., LEED (Leadership in Energy and Environmental Design) system in the UK or TERI in India [19,32,33,42–44]. A recent LCA that considers the overall environmental impact of dental examinations highlights their relative low impact, with the caveat for the need to consider the magnifying effect of the number of these procedures undertaken every year [45].

3.1.1.4. Water consumption. Water consumption also contributes to the carbon footprint; although compared to other activities, the direct impact on carbon emissions from oral care provision is lower. The water industry in the UK contributes 0.8 per cent of annual UK greenhouse gas emissions [46]. The proportion of the carbon footprint directly attributed to water use in the provision of oral healthcare is only 0.09% of the overall carbon footprint [34,37]. Water is a very precious resource that should be managed more effectively in dental practices. The European Dental Association (EDA) reports that dental offices consume 57,000 gallons (259,000 litres) of water a year [32], with an average water consumption estimated at around 33,000 litres per surgery per year [34]. Other reports estimate that the use of water in dental practices from tooth brushing at plaque stations and hand washing is presumed to be 17,000 gallons (77,284 litres) a year per dental surgery [47]. The indirect impact is significant, as the water used in dental offices needs to be treated before and after in water and sewage works; both requiring

Table 4
Thematic description of the literature (Eight tables: One table per theme). The 128 papers included in this scoping review are all published literature and consist of: Commentary [Letters, editorials, communication and opinion] ($n = 39$); Research ($n = 60$); Literature reviews ($n = 25$); Reports [Policy and legislation] ($n = 4$). Tables include outputs with primary focus (normal font) and secondary focus (*italic font*).

Author	Title	Year	Type	Subject matter reported	Location reported
Theme 1: Environmental impacts-CO_2e, air and water ($n = 21$)					
Borglin et al. [45]	The life cycle analysis of a dental examination: Quantifying the environmental burden of an examination in a hypothetical dental practice	2021	Research	Advice	Sweden
Duane et al. [8]	Sustainability in Dentistry: A Multifaceted Approach Needed	2020	Research	Advice-System approach	UK
Wilson et al. [40]	What impact is dentistry having on the environment and how can dentistry lead the way?	2020	Commentary	Advice, opportunity	UK
Verma et al. [30]	Knowledge, Attitude and Practice of Green Dentistry among Dental Professionals of Bhopal City: A Cross-sectional Survey	2020	Research	Perceptions	India
Duane et al. [18]	Environmentally sustainable dentistry: a brief introduction to sustainable concepts within the dental practice	2019	Review	Overview	UK
Duane et al. [22]	Environmental sustainability and biodiversity within the dental practice	2019	Review	Advice, opportunity	UK
Duane et al. [19]	Environmentally sustainable dentistry: energy use within the dental practice	2019	Review	Advice	UK
Duane et al. [23]	Environmental sustainability: measuring and embedding sustainable practice into the dental practice	2019	Review	Advice	UK
Duane et al. [21]	Environmental sustainability and travel within the dental practice	2019	Review	Awareness, opportunity	UK
Nagpal et al. [51]	Green Dentistry: Daunting for Developing Countries	2019	Commentary	Challenges	UK
Duane & Dougall [41]	Guest Editorial: Sustainable Dentistry	2019	Commentary	Advice, challenges and opportunity	UK
Hurley & White [37]	Carbon modelling within dentistry	2018	Report	Recommendations	UK
Phillipson J. [39]	The need for sustainable dentistry	2018	Commentary	Advice	UK
Grose et al. [149]	Developing sustainability in a dental practice through an action research approach	2018	Research	Advice	UK
Duane et al. [38]	An estimated carbon footprint of NHS primary dental care within England. How can dentistry be more environmentally sustainable?	2017	Research	Assessment	UK- England
Sachdev et al. [133]	Green route indeed a need for dental practice	2017	Review	Advice	India
Aggarwal et al. [150]	Go green: A new prospective in dentistry	2017	Commentary	Advice	India
Mulimani et al. [151]	Green dentistry: The art and science of sustainable practice	2017	Review	Awareness, advice	UK
Richardson et al. [29]	What's in a bin: A case study of dental clinical waste composition and potential greenhouse gas emission savings.	2016	Research	Awareness	UK
Carney et al. [47]	The D Word	2015	Commentary	Awareness	USA-California
Duane et al. [152]	Green Dentistry - Motivating change	2014	Commentary	Challenges and advice	UK
Holland C. [153]	Greening up the bottom line	2014	Commentary	Advice	UK
Avinash et al. [132]	Going Green with Eco-friendly Dentistry	2013	Commentary	Advice	UK
Duane et al. [31]	Taking a bite out of Scotland's dental carbon emissions in the transition to a low carbon future	2012	Research	Awareness	UK- Scotland
Theme 2: Reduce, reuse, recycle and rethink (n=17)					
Bowden et al. [101]	Evaluating the environmental impact of the Welsh national childhood oral health improvement programme, Designed to Smile	2021	Review	Awareness	UK-Wales
Su et al. [154]	Additive manufacturing of dental prosthesis using pristine and recycled zirconia solvent-based slurry stereolithography	2020	Research	Awareness	China
Lyne et al. [25]	Combining evidence-based healthcare with environmental sustainability: using the toothbrush as a model	2020	Research	Awareness	Not reported
Ahmadifard A. [72]	Unmasking the hidden pandemic: sustainability in the setting of the COVID-19 pandemic	2020	Commentary	Awareness	UK
Duane et al. [24]	Incorporating sustainability into assessment of oral health interventions	2020	Research	Awareness	Not reported
Duane & Dougall [41]	Guest Editorial: Sustainable Dentistry	2019	Commentary	Attitudes	Not reported
Khanna et al. [155]	Green dentistry: A systematic review of ecological dental practices	2019	Review	Awareness, advice	Not reported
Harford et al. [9]	Sustainable Dentistry: How-to Guide for Dental Practices	2018	Commentary	Advice	Not reported
Grose et al. [50]	Developing sustainability in a dental practice through an action research approach	2018	Research	Advice	Not reported
Phillipson J. [39]	The need for sustainable dentistry	2018	Commentary	Awareness, advice	Not reported
Eram et al.[156]	Eco Dentistry: A new wave of the future dental practice	2017	Commentary	Awareness, advice	Not reported
Pithon et al. [148]	Sustainability in Orthodontics: what can we do to save our planet?	2017	Commentary	Awareness, advice	Not reported
Kakkar et al. [43]	Go green: a new prospective in dentistry	2017	Commentary	Awareness, advice	Not reported
Sachdev et al. [133]	Green route indeed a need for dental practice: A review	2017	Review	Advice	Not reported
Ranjan et al. [79]	Awareness about biomedical waste management and knowledge of effective recycling of dental materials among dental students	2016	Research	Awareness	Not reported
Rupa et al. [53]	Taking a Step Towards Greener Future: Practical Guideline for Eco-Friendly Dentistry	2015	Commentary	Overview	Not reported
Chadha et al. [157]	Establishing an Eco-friendly Dental Practice:A Review	2015	Review	Advice	Not reported
Rastogi et al. [110]	Green Dentistry, A Metamorphosis Towards an Eco-Friendly Dentistry: A Short Communication	2014	Commentary	Awareness	Not reported
Chopra et al. [33]	Eco Dentistry: The environment-friendly dentistry	2014	Commentary	Awareness, advice	Not reported
Rahman et al. [158]	Green Dentistry - Clean Dentistry	2014	Commentary	Awareness, advice	Not reported
Al Shatrat et al. [103]	Jordanian dentists' knowledge and implementation of eco-friendly dental office strategies	2013	Research	Advice	Jordan
Garg and Guez [42]	Trends in Implant Dentistry - Green dentistry	2010	Commentary	Awareness	Not reported
Anderson et al. [106]	Creating an environmentally friendly dental practice	1999	Commentary	Awareness	Not reported

(*continued on next page*)

Table 4 (*continued*)

Author	Title	Year	Type	Subject matter reported	Location reported
Theme 3: Policy & Guidelines (n=5)					
Wolf et al. [26]	Changing Dental Profession—Modern Forms and Challenges in Dental Practice	2021	Commentary	Awareness, advice	Not reported
Wilson et al. [40]	What impact is dentistry having on the environment and how can dentistry lead the way?	2020	Commentary	Awareness, advice	UK
Australian Dental Association [159]	Policy Statement 6.21 – Dentistry and Sustainability	2020	Report	Awareness	Australia
Chopra et al. [160]	Green Dentistry: Practices and Perceived Barriers Among Dental Practitioners of Chandigarh, Panchkula, and Mohali (Tricity), India	2017	Research	Awareness, advice	India
Arora et al. [44]	Eco-friendly dentistry: Need of future. An overview	2017	Review	Awareness, advice	India
Chadha et al. [104]	Establishing an Eco-friendly Dental Practice: A Review	2015	Review	Awareness, advice	South East Asia
Fan et al. [124]	Laboratory evaluation of amalgam separators	2002	Research	Awareness, advice	USA
Theme 4: Biomedical waste management, including amalgam (n=49)					
Musliu et al. [63]	The use of dental amalgam and amalgam waste management in Kosova. An environmental policy approach	2021	Commentary	Awareness, barrier, opportunity	Kosova
Wolf et al. [26]	Changing Dental Profession—Modern Forms and Challenges in Dental Practice	2021	Commentary	Awareness	Not reported
Martin et al. [49]	Waste Plastics in Clinical Environments: A Multi-disciplinary Challenge	2020	Research	Awareness, barrier	UK
Akkajit et al. [189]	Assessment of Knowledge, Attitude, and Practice in respect of Medical Waste Management among Healthcare Workers in Clinics	2020	Research	Awareness, barrier, opportunity	Thailand
Tompe et al. [83]	A Systematic Review to Evaluate Knowledge, Attitude, and Practice Regarding Biomedical Waste Management among Dental Teaching Institutions and Private Practitioners in Asian Countries	2020	Review	Awareness, barrier, opportunity	Asia
Subramanian et al. [85]	Biomedical waste management practice in dentistry	2020	Research	Awareness, opportunity	India
Choudhary et al. [161]	Assessment of Knowledge and Awareness About Biomedical WasteManagement among Health Care Personnel in a Tertiary Care Dental Facility in Delhi	2020	Research	Awareness, barrier, opportunity	India
Aghalari et al. [162]	Determining the amount, type and management of dental wastes in general and specialized dentistry offices of Northern Iran	2020	Research	Awareness, best practice	Iran
Makanjuola et al. [163]	Managing the phase-down of amalgam amongst Nigerian dental professionals and students: A national survey	2020	Research	Barriers, opportunity	Nigeria
Duane et al. [34]	Environmental sustainability and waste within the dental practice	2019	Commentary	Awareness, drivers, opportunities	Not reported
Duane & Dougall [41]	Guest Editorial: Sustainable Dentistry	2019	Commentary	Awareness, Drivers	Not reported
Sultan et al. [164]	Establishing mercury-free medical facilities: a Malaysian case study	2019	Research	Barrier, opportunity	Malaysia
Phillipson J. [39]	The need for sustainable dentistry	2018	Commentary	Drivers, opportunity	Not reported
Mulligan et al. [105]	The environmental impact of dental amalgam and resin-based composite material	2018	Review	Awareness, opportunities	Not reported
Ilić-Živojinović et al. [165]	Knowledge and Attitudes on medical waste management among Belgrade medical and dental students	2018	Research	Awareness barriers, opportunity	Serbia
Singh et al. [68]	Awareness of Biomedical Waste Management in Dental Students in Different Dental Colleges in Nepal	2018	Research	Awareness barrier, opportunity	Nepal
Momeni et al. [73]	Composition, Production Rate and Management of Dental Solid Waste in 2017 in Birjand, Iran	2017	Research	Opportunity, awareness	Iran
Teixeira et al. [166]	Waste diagnosis in public dental facilities in Recôncavo Baiano county: contributions to integrated waste management	2017	Research	Awareness, opportunity	Brasil
Sachdev et al. [133]	Green route indeed a need for dental practice: A review	2017	Review	Opportunity	Not reported
Eram et al. [93]	Eco Dentistry: A new wave of the future dental practice	2017	Education	Opportunity	Not reported
Richardson et al. [29]	What's in a bin: A case study of dental clinical waste composition and potential greenhouse gas emission savings.	2016	Commentary	Awareness, opportunity	UK
Khwaja et al. [136]	Mercury exposure in the work place and humanhealth: dental amalgam use in dentistry at dentalteaching institutions and private dental clinics inselected cities of Pakistan	2016	Research	barriers, opportunity, best practice	Pakistan
Ranjan et al. [79]	Awareness about biomedical waste management and knowledge of effective recycling of dental materials among dental students	2016	Research	Awareness barriers, opportunity	India
Abhishek et al. [62]	Awareness-Knowledge and Practices of Dental WasteManagement among Private Practitioners.	2016	Research	Barriers, opportunity	India
Shah et al. [167]	Knowledge, Attitude and Practices of Interns,Graduates and Postgraduate Students at PrivateDental Colleges in Ahmedabad RegardingBio Medical Waste Management	2015	Research	Awareness, Barriers	India
Rupa et al. [53]	Taking a Step Towards Greener Future: Practical Guideline for Eco-Friendly Dentistry	2015	Commentary	Opportunity	Not reported
Allen [142]	Disposing of clinical and dental waste	2015	Commentary	Awareness, opportunity	UK
Bathala et al. [168]	"There's plenty of room at the bottom": The biomedical waste management in dentistry	2014	Commentary	Awareness	India
Chopra, et al. [33]	Eco Dentistry: The environment-friendly dentistry	2014	Commentary	Opportunity	Not reported
Singh et al. [77]	Mercury and Other Biomedical Waste ManagementPractices among Dental Practitioners in India	2014	Research	Awareness, barriers, opportunity, best practice	India
Rastogi et al. [110]	Green Dentistry, A Metamorphosis Towards an Eco-Friendly Dentistry: A Short Communication	2014	Commentary	Awareness, opportunity	Not reported
Unger et al. [89]	Comparative life cycle assessment of reused versus disposable dental burs	2014	Research	Opportunity, best practice	Not reported

(*continued on next page*)

Table 4 (*continued*)

Author	Title	Year	Type	Subject matter reported	Location reported
Holland C. [58]	Greening up the bottom line	2014	Commentary	Opportunity	Not reported
Govan P. [86]	Waste management in dental practice	2014	Commentary	Drivers, best practice, opportunity	South Africa
Kapoor et al. [169]	Knowledge and awareness regarding biomedical waste management in dental teaching institutions in India- A systematic review	2014	Review	Awareness, barriers, opportunity	India
Bansal et al. [70]	Knowledge, Attitudes and Practices of dental care waste management among private dental practitioners in Tricity (Chandigarh, Panchkula and Mohali)	2013	Research	Awareness, barriers, opportunity	India
Avinash et al. [132]	Going Green with Eco-friendly Dentistry	2013	Commentary	Barriers, opportunity, best practice	Not reported
Nabizadeh et al. [82]	Composition and production rate of dental solid waste and associated management practices in Hamadan, Iran	2012	Research	Awareness, best practice	Iran
Koolivand et al. [66]	Investigating composition and productionrate of healthcare waste and associatedmanagement practices in BandarAbbass, Iran	2012	Research	Barriers, opportunity	Iran
De Souza et al. [112]	Improper Waste Disposal of Silver-Mercury Amalgam	2012	Research	Awareness barriers, opportunity	Not reported
Agarwal et al [94]	Waste management in dental office - Letter	2012	Commentary	Awareness, best practice	India
Yasny & White. [141]	Environmental Implications of Anesthetic Gases	2012	Review	Opportunity, best practice,	Not reported
Rudraswamy et al. [78]	Staff's attitude regarding hospital waste management in the dental college hospitals of Bangalore city, India	2012	Research	Awareness, barriers	India
Kumar [109]	Green dentistry; eco-friendly dentistry: beneficial for patients, beneficial for the environment.	2012	Commentary	Barriers, opportunity	Not reported
Sood & Sood. [71]	Dental perspective on biomedical waste and mercurymanagement: A knowledge, attitude, and practice survey	2011	Research	Barriers, opportunity	India
Muhamedagic et al. [125]	Dental Office Waste - Public Health and Ecological Risk	2009	Review	Awareness, opportunity	Not reported
Cocchiarella et al. [57]	Report of the Council on Scientific AffairsBiohazardous Waste Management: What the Physician Needs to Know	2009	Report	Barriers, opportunity	USA
Guedes et al. [128]	First detection of lead in black paper from intraoral filmAn environmental concern	2009	Research	Awareness, opportunity	Not reported
Al-Khatib et al. [59]	Dental solid and hazardous waste management andsafety practices in developing countries: Nablusdistrict, Palestine	2009	Research	Barriers	Palestine
Sudhakar and Chandrashekar. [80]	Dental health care waste disposal among private dental practices in Bangalore City, India	2008	Research	Awareness, barriers	India
Al-Khatib & Darwish [137]	Assessment of waste amalgam management indental clinics in Ramallah and al-Bireh cities inPalestine	2007	Research	Barriers, opportunity	Palestine
Hiltz [170]	The Environmental Impact of Dentistry	2007	Commentary	Awareness, opportunity	Canada
Iano et al. [171]	Optimizing the procedure for mercuryrecovery from dental amalgam	2007	Research	Opportunity	Brazil
Batchu et al. [134]	Evaluating Amalgam Separators Using and International Standard	2006	Research	Best Practice, opportunity	Not reported
Batchu et al. [130]	The effect of disinfectants and line cleaners on the release of mercury from amalgam	2006	Research	Awareness	India
Hylander et al. [116]	High mercury emissions from dental clinics despite amalgam separators	2005	Research	Barriers, opportunity	Not reported
Ozbek & Sanin [56]	A study of the dental solid waste produced in a school of dentistry in Turkey	2004	Research	Awareness	Turkey
Journal of Irish Dental Association [76]	Update on Waste Management for the practice of dentistry	2004	Commentary	Background, best practice	Ireland
ADA Council on Scientific Affairs [147]	Managing silver and lead waste in dental offices	2003	Report	Opportunity, best practice	USA
Fan et al. [124]	Laboratory evaluation of amalgam separators.	2002	Research	Best Practice	USA
Wilson N. [35]	Dental practice and the environment	1998	Review	Awareness, opportunity	Not reported
Theme 5: Plastics (SUPs) (n=6)					
Bardolia et al. [108]	The environmental impact of dentistry	2019	Commentary	Awareness, opportunity	Not reported
Zeri et al. [172]	Floating plastics in Adriatic waters (Mediterranean Sea): From the macro-to the micro-scale.	2018	Commentary	Awareness	Not reported
Nesic et al. [173]	Chitosan-triclosan films for potential use as bio-antimicrobial bags in healthcare sector	2017	Research	Opportunity	Not reported
Nasser et al. [174]	Evidence summary: can plastics used in dentistry act as an environmental pollutant? Can we avoid the use of plastics in dental practice?	2012	Review	Awareness	Not reported
Palosuo et al.[175]	Latex Medical Gloves: Time for a Reappraisal	2011	Commentary	Barriers:	Not reported
Sasaki et al. [176]	Salivary bisphenol-A levels detected by ELISA after restoration with composite resin.	2005	Research	Awareness	Not reported
Theme 6: Procurement (n=2)					
Joy et al. [100]	Mercury in Dental Amalgam, Online Retail, and the Minamata Convention on Mercury	2020	Commentary	Awareness, opportunity	Not reported
Wilson et al. [40]	What impact is dentistry having on the environment and how can dentistry lead the way?	2020	Commentary	Awareness, opportunity, barriers	UK
Duane et al. [20]	Environmental sustainability and procurement: purchasing products for the dental setting	2019	Commentary	Awareness, opportunity	Not reported
Phillipson J. [39]	The need for sustainable dentistry	2018	Commentary	Drivers, opportunity	UK

(*continued on next page*)

Table 4 (*continued*)

Author	Title	Year	Type	Subject matter reported	Location reported
Theme 7: Research & Education (n=8)					
Borglin et al. [45]	The life cycle analysis of a dental examination- Quantifying the environmental burden of an examination in a hypothetical dental practice	2021	Research	Awareness	Sweden
Duane et al. [177]	Environmental sustainability in endodontics.A life cycle assessment (LCA) of a root canaltreatment procedure	2020	Research	Awareness	Not reported
Lyne et al. [25]	Combining evidence-based healthcare with environmental sustainability-using the toothbrush as a model	2020	Research	Awareness	Not reported
Duane et al. [178]	Embedding environmental sustainability within the modern dental curriculum— Exploring current practice and developing a shared understanding	2020	Commentary	Awareness, opportunity	Europe
de Leon [179]	Barriers to environmentally sustainable initiatives in oral health care clinical settings	2020	Commentary	Awareness, barriers	Canada
Wilson et al. [40]	What impact is dentistry having on theenvironment and how can dentistry leadthe way?	2020	Commentary	Awareness, barriers, opportunity	UK
Verma et al. [30]	Knowledge, Attitude and Practice of Green Dentistry among Dental Professionals of Bhopal City: A Cross-Sectional Survey	2020	Research	Awareness, knowledge, attitude	India
Ilić-Živojinović et al. [81]	Knowledge and Attitudes on medical waste management among Belgrade medical and dental students	2018	Research	Awareness, knowledge, attitude	Serbia
Bansal et al. [70]	Knowledge, Attitudes and Practices of dental care waste management among private dental practitioners in Tricity (Chandigarh, Panchkula and Mohali)	2013	Research	Awareness, knowledge, attitude	India
Prathima et al. [102]	Knowledge, attitude and practices towards eco-friendly dentistry among dental practioners.	2017	Research	Awareness, knowledge, attitude	India
Theme 8: Materials (n=20)					
Shiyo et al. [180]	Recycling of Plaster of Paris	2020	Research	Opportunities	Not reported
Makanjuola et al. [139]	Managing the phase-down of amalgam amongst Nigerian dental professionals and students: A national survey	2020	Research	Barriers, opportunity	Nigeria
Amir Sultan et al. [127]	Establishing mercury-free medical facilities: a Malaysian case study	2019	Research	Opportunities	Malaysia
De Bortoli et al. [181]	Ecological footprint of biomaterials for implant dentistry: is the metal-free practice an eco-friendly shift?	2019	Review	Best practice, opportunity	Not reported
Mulligan et al. [182]	The environmental impact of dental amalgam and resin-based composite material	2018	Review	Awareness, opportunities	Not reported
Gavrilescu et al. [28]	The advantages and disadvantages of nanotechnology	2018	Review	Barriers, opportunity	Not reported
Teixeira et al. [140]	Waste diagnosis in public dental facilities in Recôncavo Baiano county: contributions to integrated waste management	2017	Research	Awareness, opportunity	Brasil
Bakhurji et al. [183]	Dentists' perspective about dental amalgam: current use and future direction	2017	Research	Attitudes	Not reported
Pithon et al. [148]	Sustainability in Orthodontics: what can we do to save our planet?	2017	Commentary	Opportunities.	Not reported
Sachdev et al. [133]	Green route indeed a need for dental practice: A review	2017	Review	Opportunities	Not reported
Kakkar et al. [43]	Go green: a new prospective in dentistry	2017	Commentary	Opportunities	Not reported
Sadasiva et al. [184]	Recovery of Mercury from Dental Amalgam Scrap-Indian Perspective	2017	Research	Awareness	India
Khwaja et al. [136]	Mercury exposure in the work place and human health: dental amalgam use in dentistry at dental teaching institutions and private dental clinics in selected cities of Pakistan	2016	Research	Barriers, opportunity, best practice	Pakistan
Chadha et al. [104]	Establishing an Eco-friendly Dental Practice: A review	2015	Review	Opportunities	Not reported
Singh et al. [77]	Mercury and other biomedical waste managementpractices among dental practitioners in India	2014	Research	Awareness, barriers, opportunity, best practice	India
Rekow et al. [185]	What constitutes an ideal dental restorative material?	2013	Commentary	Opportunities	Not reported
Panasiuk & Głodek. [129]	Substance flow analysis for mercury emission in Poland	2013	Research	Awareness, opportunities	Poland
Bayne et al. [186]	The challenge for innovation in direct restorative materials	2013	Commentary	Barriers, opportunities	Not reported
Erdal & Orris [121]	Mercury in dental amalgam and resin-based alternatives: A comparative health risk evaluation	2012	Research	Opportunities	Not reported
de Souza et al. [112]	Improper Waste Disposal of Silver-Mercury Amalgam	2012	Research	Awareness, barriers	Not reported
Sawair et al. [187]	Observance of proper mercury hygiene practices Jordanian general dental practitioners	2010	Research	Barriers, opportunity	Jordan
Muhamedagic et al. [125]	Dental office waste - public health and ecological risk	2009	Review	Awareness, opportunities	Not reported
Al-Khatib & Darwish. [137]	Assessment of waste amalgam management in dental clinics in Ramallah and al-Bireh cities in Palestine	2007	Research	Barriers, opportunities	Palestine
Iano et al. [115]	Optimizing the procedure for mercury recovery from dental amalgam	2007	Research	Opportunities	Not reported
Jokstad et al. [126]	Amalgam waste management	2006	Commentary	Awareness	Not reported
Batchu et al.[134]	Evaluating amalgam separators using and international standard	2006	Research	Best practice	Not reported
Hylander et al. [116]	High mercury emissions from dental clinics despite amalgam separators	2005	Research	Barriers, opportunities	Not reported
Hörsted-Bindslev. [119]	Amalgam Toxicity - environmental and occupational hazards	2004	Commentary	Awareness, background	Not reported
Journal of Irish Dental Association [76]	Update on Waste Management for the practice of dentistry	2004	Commentary	Awareness, best practice	Republic of Ireland
ADA Council on Scientific Affairs. [147]	Managing silver and lead waste in dental offices	2003	Report	Awareness, opportunities	USA
Drummond et al. [188]	Mercury generation potential from dental waste amalgam	2003	Research	Opportunities	Not reported
Fan et al. [124]	Laboratory evaluation of amalgam separators.	2002	Research	Best practice	Not reported
Chin et al. [114]	The environmental effects of dental amalgam	2000	Review	Awareness	Not reported
Anderson. [106]	Creating an environmentally friendly dental practice	1999	Commentary	Opportunities	Not reported

(*continued on next page*)

Table 4 (*continued*)

Author	Title	Year	Type	Subject matter reported	Location reported
Arenholt-Bindslev [111]	Environmental aspects of dental filling materials	1998	Review	Awareness	Not reported
Westman et al. [131]	Amalgam waste management - Issues and Answers	1994	Review	Awareness	Not reported
Arenholt, Bindsley. [118]	Dental amalgam-environmental aspects	1992	Review	Awareness, best practice,	Scandinavia

significant energy and further contributing to CO_2 emissions.

These CO_2 emissions contribute in a circular manner to unpredictable water precipitations associated with climate change, creating periods of draught and desertification [48].

3.1.2. Awareness

General individual awareness for carbon emissions and their impact on the environment is high, albeit translation into the professional oral health domains is not as pervasive. Evidence for the effect of the carbon footprint of dentistry is noted with an appreciation for lack of practical action and the need for education of the profession at all levels [2]. Wealthier countries are the largest contributors to carbon footprint but are least affected by the consequences [31].

The provision of oral healthcare, like any other business or intervention, creates a significant carbon footprint that is not limited to the actual intervention itself, but it is the sum of the emissions created by each stakeholder in the supply chain. The linear economy supply chain is considered as a continuum from mineral extraction, processing and synthesizing of raw materials, to manufacturing and ultimately waste management; with oral healthcare and dentistry included within it, as the principal intended beneficiaries of these services and products [49] (Fig. 3).

In the UK (2013–14), the Government through Public Health England conducted a comprehensive calculation of the carbon emissions of NHS dental services in England to identify the types of dental procedures which are responsible for large amounts of greenhouse gas emissions [37,38]. This included patient travel, staff commuting, business travel, procurement, gas and electricity use, waste disposal, water use and nitrous oxide release. In 2013 to 2014, the total greenhouse gas emissions of NHS dental services in England were 675,706 tonnes of carbon dioxide equivalents (tCO2e). This is equivalent to flying 50,000 times from the UK to Hong Kong and makes up 3% of the overall carbon footprint of the NHS in England. The highest proportion of these emissions is caused by travel, followed by procurement, energy, nitrous oxide, waste and water [18,37,39].

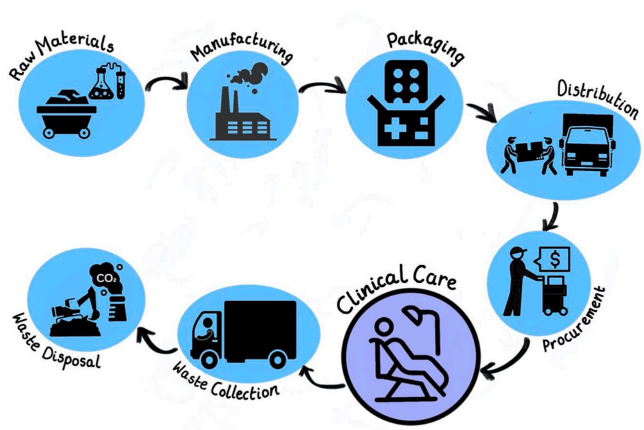

Fig. 3. Linear economy supply chain: Mineral extraction, processing and synthesizing of raw materials >> Manufacturing and packaging of the dental restoratives, sundries and equipment products >> Distribution and purchase of these products >> Clinical procedure with further energy expenditure, water use and use of materials >> Collection and disposal of waste (associated with different levels of contamination), mostly managed through landfill and incineration.

An earlier study for National Health Service (NHS) dental services in Scotland (2004) estimated a contribution of 17.9 kg CO_2eq per patient appointment [31]. Both studies provide a breakdown, with travel commute making the largest contribution (46% for Scotland and 64.5% for England) that accounts for 3% of the overall carbon footprint of the NHS in England [21,50]. These studies are indicative of the size of the problem and have the limitation that they do not include full LCA of procedures as there is insufficient data to support this type of study. Some data collection for calculating water and waste are performed only in small regional areas and cannot be considered to be fully representative of the whole population. Nevertheless, these studies provide an invaluable insight into the nature and the size of the CO_2 emissions. Equivalent services in USA and Australia contribute 10% and 7% respectively to total CO_2 footprint [18]. In 2014, Health and Social Care agreed to reduce the carbon footprint of the NHS in England by 80% by 2050 from the 2008 baseline in accordance with the Climate Change Act. [31,36–40].

A practical guide has been developed by the Centre for Sustainable Healthcare in the UK with suggestions on how dental practices can become more sustainable through travel, supplies, energy waste management, biodiversity and green space. It includes real life examples of suggestions made in dental practices and considers cost, return on investment, environmental benefit and ease of implementation of each suggestion [9].

3.1.3. Barriers to change

The problem of implementation of sustainability behaviours and attitudes is a significant challenge and even more so in in developing countries; where the greatest barriers are a lack of economic feasibility and knowledge-base [51].

Broad sustainability aims and guidance are beginning to be introduced into healthcare contracts, but these are neither sufficiently pervasive nor enforceable by the employer or law. For example, in the UK, the NHS England standard contract, contains three clauses which currently are not applicable to primary healthcare [18]: Providers must take all reasonable steps to minimise their impact on the environment; demonstrate their progress on climate change adaptation, mitigation and sustainable development; and provide annual summaries of this to commissioners. Considering travel, the alternatives to the use of private cars, of cycling and walking are not readably available options for many due to the lack of infrastructure that facilitates this [21].

When it comes to the choice of most commonly used dental materials, amalgam and resin-based composites are the greatest exponents. However, the comparative carbon footprint of these two materials is unknown with an absence of more concrete life cycle analysis data for each material. There is a requirement to provide this analysis so that informed choices can be made by the profession and the public [38,40].

Ultimately, the decision-making for oral healthcare professionals of cost and inconvenience vs positive impact on the environment is highly subjective and lacks sufficient evidence that will support strong arguments [21].

3.1.4. Biodiversity

A recent UNEP report [52], highlights that climate change is causing an 'unprecedented' and 'accelerated' rate of species extinction across the world with a profound effect on biodiversity that can have catastrophic consequences. Within the UK, 15% of around 8,000 species assessed are facing extinction [22]. In addition to our contribution to global warming through CO_2 emissions, some of our activities in dentistry have a direct negative impact on biodiversity; such as the presence of mercury in waste-water works from dental practices that don't use traps. Mercury is neurotoxic and teratogenic; it can accumulate as it rises through the food chain and it can also impact the microbiological activity in soil. Manufacturing and distribution of supplies has an environmental impact via mining and procurement of raw materials, manufacturing environmental impacts and transport in the supply chain. This can affect emissions, land and water pollution and changes to landscapes resulting in changes to biodiversity [9].

Every sector can contribute in a positive manner by promoting biodiversity within their own operational environments. Biodiversity refers to the variety of living species which interact with one another to form ecosystems: This means, the promotion of the growth and development of green spaces for habituation of insects and animals [9]. Dental practices can consider gravel or grass instead of tarmac; that has an impact on insects (essential building block for biodiversity) and lowers the risk of flooding. Trees provide shelter and shade, and in this way contribute to a reduction in a building's energy budget, through reduced air conditioning usage and improved solar gain. Reduction of the use of harmful pesticides when caring for practice gardens/lawns also improves biodiversity [44,53]. Green roofs help mitigate the urban heat island effect (an urban area is significantly warmer than the surrounding countryside), and help with both energy conservation and stormwater management [9]. In addition to the above, dental professionals can offset CO_2 emissions by investing in reforestation campaigns [43]. There is a need for effective quality research that demonstrates the cost benefits of providing a biodiverse space [22].

3.2. Theme 2: Reduce, reuse, recycle and rethink

3.2.1. Background

Within the setting of the dental surgery, the complex and mostly contaminated nature of the waste produced in the delivery of oral healthcare makes it difficult or impossible in some instances to implement policies of reuse, reduce and recycle. Many of the polymers used are highly cross-linked and processed so that they may not be easily broken down into the constituent raw materials or derivatives. Polymer devices used in a clinical environment are at high risk of contamination, and the nature of the polymers and/or the complex shape of the devices makes it costly and difficult to clean, disinfect and sterilize [49,54,55]. Items that are currently easily recycled (e.g., paper, plastic and glass products) should be also be recycled in the workplace, to help reduce the depletion of natural resources and lower carbon emissions [34]. Sustainable activity through the recognised strategies of reduce, reuse, recycle and rethink are considered in the literature. Although commonly grouped together, the individual distinct focus of each strategy, requires that they should be considered as separate entities in the review of the literature and are considered in detail under the headings of opportunities and best practice in the second part of this review [17].

3.2.2. Barriers

Difficulties and barriers to recycling are the main reason for lack of engagement. The following have been identified that affect oral healthcare provision: The need for additional storage space and the cost of transport for moving waste; staff training and co-operation are essential; the (real and perceived) risks associated with waste segregation need to be managed; availability of waste recycling facilities (especially in developing economies); and a lack of cultural understanding of the need and benefits associated with recycling [34,59,79,125].

3.3. Theme 3: Policy

3.3.1. Background

The provision of healthcare in dentistry and the management of waste arising from this, has to operate within the boundaries of legislative regulation to ensure safety and sustainable practice; thus, presenting a conflicting challenge. These frameworks vary both in their remit from guidelines to legally enforceable laws, and across countries [56,57]. Given that they are designed to operate within their own country, they are normally published in their native language, and thus are excluded from this review if not in English. There is a need to protect the public from communicable infectious diseases, with increased use of SUPs and PPE in dental practices that has a deleterious effect on environmental sustainability in dentistry. An example of this was the introduction of new infection control guidance that was introduced in England and Wales (2009 and revised in 2013) under the Health Technical Memorandum HTM01-05; that focused on management of cross-infection control with no consideration to sustainable practice [29,58]. An in-practice study identified a 58% increase in waste management costs over a four-year period following the introduction of HTM01-05 [29]. In the UK, the Control of Substances Hazardous to Health Regulations (COSHH) requires all dental employers to control exposure to hazardous substances to prevent ill health [9].

Concerning the management of waste, there is an abundance of legislation surrounding the use of hazardous substances in healthcare. The main basis for dental waste management in the European Union is the Waste Framework Directive that requires Member States to take necessary measures to ensure waste is disposed of without endangering human health or the environment. Directive 91/689/EEC addresses hazardous waste and by Decision 2000/532/EC a list of wastes was adopted, which includes dental amalgam waste [59]. Waste management in the UK is governed by the Environmental Protection Act (1990) that imposes legal 'duty of care' requirements on waste producers, to ensure the appropriate safe handling and disposal/treatment of waste [60]. The Hazardous Waste Regulations (England and Wales) 2005 outline the legally binding requirements for hazardous waste which must be properly segregated, packaged and labelled [34].

In the UK, confusion often arises around interpretation of HTM01-05 making cross-infection and appropriate waste management difficult to follow. This creates an unnecessary burden and frustration in the ability to engage with sustainable practice with fear of litigation [40,61,62]. Other examples cite the need for effective legislative frameworks for the safe and environmentally sustainable management of amalgam waste [63]. When designing policy and regulatory frameworks, there is a need to consider sustainability in dentistry within a wider context of modernisation of the dental profession and the services that it provides [26].

3.4. Theme 4: Biomedical waste management

3.4.1. Background

The term biomedical waste has been defined as "any waste that is generated during the diagnosis, treatment, or immunization of human beings or animals, or in the research activities pertaining to or in the production or testing of biological and includes categories mentioned in Schedule I of the Biomedical Waste (Management and Handling) rules 1998 [64–70]. Biohazardous waste has been referred to as medical waste, infectious waste, red bag waste, biomedical waste, and regulated medical waste. Most agencies and states assume that biohazardous waste is waste capable of transmitting infectious disease, and therefore includes materials sufficiently contaminated with blood or body fluids to transmit disease. In a physician's office, this would include supplies or disposable materials saturated with blood or body fluids [57].

Waste management is a significant and expensive problem for the healthcare sector [49,55]. This is due to the complexity of the waste generated and its contaminated/infectious status. The volume of biomedical waste (BMW) produced across the world is staggering, with a reported 5.5kg of waste/patient/day in the UK-NHS and 0.4 kg/patient/day in Germany [39]. According to WHO and SEARO, the South-East Asian countries, collectively produce approximately 1000 tonnes a day (approx. 350,000 tonnes of BMW a year) [71]. These are pre-COVID pandemic figures and will be much greater during the pandemic with the increased use of single-use disposable PPE that has been necessary [72].

Biomedical waste has steadily increased in oral healthcare over recent decades due to the increased use of plastic barriers, gloves and masks [37,73]. For example, the Eco-Dentistry Association [74], estimated that 1.7 billion sterilization pouches and 680 million patient barriers were disposed by US dental practices every year [31,73,75]. It is of note that high income countries produce more waste then medium and low-income countries [67]. BMW that is inadequately managed, can cause water, air and soil pollution [73,76].

The carbon emissions embedded in the disposal of all dental-related waste streams is approximately 1,493 tCO_2e, which is 0.22% of the overall carbon footprint of NHS dental services in England [37]. However, it is important to bear in mind that it is the actual toxicity of the waste that may have the greatest impact on the environment, rather than the associated CO_2 emissions [37]. Incineration of clinical waste releases greenhouse gases that contribute 1% of Europe's carbon emissions [39]. Part of the problem is that BMW is not always effectively managed due to practical, logistic or financial reasons, with much that can be recycled ending in incineration and landfill [37]. Incineration of healthcare waste is linked to air pollution affecting public health [34]. A rapid increase in the number of healthcare institutions, results in an increased burden of biomedical waste [68,70,77,78]. Generation of BMW, despite being smaller than regular domestic waste, becomes significant when taking into account the risks associated with pathogens, chemicals and their respective toxicities.

Various European directives provided for specific regimes (take-back, recovery and recycling) to deal with waste packaging, waste electrical, electronic equipment and waste batteries [34].

3.4.2. Barriers to change

Biomedical waste is heterogenous making it difficult to manage [69]. This is particularly the case of dental waste that uses a wide range of materials [49,61].

Inadequate knowledge and poor attitudes exist towards the generation and management of biomedical waste across the world and in particular in some developing economies lacking adequate regulatory frameworks that consider BMW to be no different from household waste. [39,59,62,65,66,77–83].

A good level of knowledge, a positive attitude and effective infrastructure is key to implementing effective waste management; which are often missing [62,84,85]. These are often lacking due to a lack of education, financial support and appropriate supportive legislation [34,53,65,79–86].

An increase in the prevalence of infectious diseases coupled with much greater patient safety awareness, measures and regulation results in a significant increase in the quantity of SUP solid waste generated (e.g., plastic barriers, gloves and masks) in dentistry. This accounts for about 90% of the total solid waste generated [29,41,59,61,62,76]. The increased regulation creates confusion with regards to managing sustainability [39].

3.5. Theme 5: Plastics

3.5.1. Background

Plastics are an integral and essential part of modern life and the global economy and exhibit a range of properties that make them invaluable in clinical settings. Polymers can be assembled in a wide range of combinations using compound multi-layered structures and forming highly specific complex shapes, that create a clinical item or packaging with optimised properties. Plastic items and devices provide clinical and public confidence of using a new clean and/or sterile device every time. The low cost of raw materials and bulk fabrication means that a wide variety of single-use products may be manufactured at exceptionally low costs. The combined manufacturing versatility, cleanliness/sterility guarantee and cost effectiveness of plastic devices makes reusing and/or recycling economically unattractive, with disposal being the more likely solution [49,55]. This results in a highly wasteful linear economy for Single Use Plastics (SUPs) with significant environmental impacts and greenhouse gas emissions affecting biodiversity and health (Fig. 3). Eight million tonnes of plastic enter our oceans each year, that does not naturally biodegrade but breaks down into smaller particles 'micro-plastics' [9]. Rates of plastic use have grown exponentially since the 1950's, reaching 350 million tonnes (Mt) globally in 2017. In Europe, production of plastics has been estimated at 60 million tonnes in 2018, which is around 17% of global plastic production [87].

The amount of plastic packaging discarded by the healthcare sector in the UK is significant ; with over 590,000 tonnes generated annually, more than the entire municipal waste output of Luxembourg (England Chief Medical Officer Report 2016–17) [88].

In dentistry, single-use instruments are common, driven by short-term cost and a perceived drive to infection prevention [73,89]. The industry produces many non-reusable materials, such as single-use plastic tubes of toothpaste, with lids that cannot be recycled [8]. The reasons for an increased use of plastics in dentistry are highlighted as: Improved infection control, ability to manufacture complex sophisticated shaped items, ease of manufacturing and ease of use and ease of disposal [32,76,89]. Ultimately, plastics from dentistry follow the same fate as other plastics which are pervasive in the environment [90].

A recent study showed that an average of 20 SUP items are used on average for every routine adult primary care dental procedure in the UK [49]. The use of SUP items per adult care procedure is greatest for routine dental fillings, followed by root canal treatment, oral surgery for dental extractions/minor surgical procedures, provision of crowns, bridges and dentures and finally periodontics. The most commonly used products are PPE for the dentist and nurse. On average, more than one pair of gloves, masks, wipes, autoclave-sterilization sleeves and tray liners were used with each patient, independent from the type of procedure delivered. This was compounded by the large number of items necessary for setting-up before and for decontaminating after procedures. In the UK, based on the number of dentists and dental therapists registered with the General Dental Council in 2019 ($n \approx 45{,}000$), it is possible to use this data to extrapolate the national usage of the approximate number of SUPs used in a 40-week working year, working four days per week and considering a conservative estimate of five procedures per day. A mean of 20 SUP items/dental procedure translates to a conservative estimate in excess of 720 million dental SUP items/year that end up as waste in the UK [91]. The SUP items identified in this study were approximately 50:50 single plastics and multiple plastics forming compound structures [48]. This is a situation that is not sustainable in the long-term [76,92]. Disposal of these plastics through high temperature incineration releases the carcinogens dioxin and furan [35,93]. Plastics containing PVC produce acidic gases when incinerated and are difficult to recycle [42,53,94].

To address the impacts that plastics are causing a number of organizations, such as the Ellen McArthur Foundation [95] and WRAP [96], have been at the forefront in helping to push through changes in policy at an international and national level. The UK Plastic Pack initiative led by WRAP, largely focuses on plastic packaging, with major goals to be achieved by 2025 for 100% of all plastic packaging to be reusable, recyclable or compostable, 70% of plastic packaging to be recycled or composted, elimination of single-use plastic packaging and 30% recycled content to be used in all plastic packaging.

3.5.2. Barriers to change

There is an overriding requirement to protect patient safety through IPAC processes (Infection Prevention and Control) operating in an increasingly litigious society with sustainability concerns becoming very secondary. The need to comply with control of infection regulations that focus on IPAC processes is an additional barrier [97,98]. There is an urgent need to weigh these complex interplaying issues of environmental harm and personal harm [8]. A second factor is the need to understand that the disposal of the actual plastic waste contributes a small percentage to the overall impact on pollution and CO_2 emissions that arise from plastic usage in healthcare. The major contribution comes upstream in the supply chain from manufacturing, processing, distribution and logistics [99].

3.6. Theme 6: Procurement

3.6.1. Background

Sustainable procurement, when applied to dentistry, is the practice by which the dental surgery addresses environmental and social/ethical considerations when they purchase goods or services [20]. 'Green procurement' is a process whereby public authorities meet their procurement needs by choosing solutions 'that have a reduced impact on the environment throughout their life-cycle, as compared to alternative products/solutions' [20].

Each stakeholder of the supply chain, has a significant impact on the environment through the process of procurement of raw materials, manufacture, transport, distribution etc. In the UK, the carbon footprint of dental services provided by the NHS, public health and social care accounts for 72% of the total [36]. This impact is in the form of GHG emissions, land and water pollution and changes to landscapes resulting in changes to biodiversity [8,9]. Procurement is a major hotspot, noted as the 2nd highest contributor (19%) of the UK NHS dentistry's carbon footprint [9,18,20,37,39]. There is a recognition to coordinate procurement of products that use plastic as a container or packaging with waste management that can recover and recycle this waste [49]. This approach can have significant financial gains by mapping procured plastic (at all levels of packaging) with sustainable recovery and recycling technologies.

Extensive and complex care plans, requiring multiple appointments are more resource intensive. This highlights the need to promote prevention as the most effective way of managing this pollution burden [18,37]. A focus on sustainable purchasing leads to lower costs, environmental and health benefits. Importantly, procurement should also be ethical with due regard to products originating from developing economies with regard to labour, safety and human rights of workers [20].

3.6.2. Barriers to change

The limited supply of sustainable products [36] and the user convenience of some products (e.g., disposable gowns) overrides the desire for more sustainable options [20]. There is a lack of knowledge and evidence on best practice that balances safety and sustainability for products. The need to adhere to legally-binding regulations and laws that stipulate patient safety as the main concern. The high cost of some recycled products, such as recycled paper that is twice the price of non-recycled paper is a barrier to its use [20]. An example for the use of effective procurement as a tool to reduce the use of amalgam, in line with Minamata phase down plans, is through sales made only to registered practitioners via a Know Your Customer approach [100]. In this way the volume of sales, suitability, and risks involved can be monitored more effectively.

3.7. Theme 7: Research and education

3.7.1. Awareness

This theme considers knowledge acquisition through *research* and knowledge delivery through *education.*

An increasing body of research in sustainable practice is evident through this literature review that pervades all the identified themes (Table 4). A prevailing finding is the paucity of high-quality research into the provision of environmentally sustainable oral healthcare in general and that is linked to the requirement to provide equally high-quality patient-centred care outcomes [8,23,50,101].

With regards to education, there is a growing awareness of a lack of education in both undergraduate and postgraduate curricula, as part of formal education or informally through continuing professional education programs [30,65,70,81,102]. This educational provision is inversely proportional to an increasing level of interest in the dental profession for education into approaches for engagement with and the delivery of sustainable practice [18,22,30,65,62,79]. It is also set against a backdrop of generalised lack of awareness and knowledge in this area; as highlighted in the relevant sections for each theme in this review. A study in India reported that 76% of private practitioners were aware of the harm they were doing to the environment; 95% of them reported they felt a responsibility to not harm the environment [75].

Some changes are beginning to take place, with evidence of sustainability included in the undergraduate curriculum [30,41,79,103]. There is a perceived lack of encouragement from curriculum regulatory and governing bodies [18]. There is a growing and distinct need to reverse this trend with eco-friendly curricula that focuses on the education of staff and students on sustainability using a range of media and resources [9,23,35,40,65,68,71,79,97,104,159]

3.8. Theme 8: Dental materials

Dental materials, are used in various formats, either for direct clinical application or indirectly associated with oral healthcare provision. The literature covers a wide spectrum of materials and in the context of sustainability, this theme is undoubtably the one that goes furthest back in time, with references to a number of materials used directly or indirectly for clinical care; each of these is considered individually.

Dental materials have a high pollution impact, from all levels of the supply chain: Synthesis of raw materials, manufacturing, distribution, procurement, clinical use and ultimately waste management. It is indisputable that these materials are required for the provision of effective oral healthcare, but there is also a need to understand this impact and how to affect this as a user [49].

3.8.1. Barriers

Life cycle analyses are possible but are not specific to the CO_2 footprint due to the lack of analysis of processes that are necessary to make materials suitable for healthcare. Carbon conversion factors for making the manufacturing of materials are not readily available outside industry; making it very difficult to develop appropriate strategies [9,31,37].

For many decades, the dental environmental spotlight has focused on dental amalgam. A greater appreciation and understanding of the pollutant potential of other dental materials should drive further research in this field. Most dental suction units are evacuating by-products of restorations (for example, mercury and particulate waste containing monomers) and, increasingly, derivatives of ceramic products originating from milling, yet very little research exists on their potential harm to the environment [8,105].

3.8.2. Dental amalgam

3.8.2.1. Background. Worldwide consumption of mercury is around 300 tons per annum [73]. Mercury is the heavy metal of primary concern, making up to 50% by weight of dental amalgam. Mercury is bioaccumulating and exposure to mercury is known to have toxic effects in plants, animals and humans. Mercury can be neurotoxic and teratogenic; it can accumulate as it rises through the food chain and it can also impact the microbiological activity in soil. Once in the environment, a number of factors contribute (pH, temperature, oxygen, bacteria) to convert it into the more toxic methylmercury that is more bioavailable and can now accumulate in the food chain [32,33,44,59,61,64,73,94,103,105–121].

Dental mercury accounts for 3-4% of terrestrial mercury [64,111,114,118,120]. The UNEP Global Mercury Assessment of 2013 revealed that in 2010 an estimated 270–341 metric tonnes of mercury globally were derived from the use of dental amalgam [122]. 75 metric tonnes of amalgam per annum were used in the EU alone [105]. The subsequent 2018 report notes that the category of 'mercury-added products' that includes dental amalgam, remains a major source of mercury release, but according to the latest 2015 global inventory, these levels are in decline, especially in developed countries [123].

Disposal of dental amalgam directly into the sewage system is common practice around the world. A study in Chicago, revealed a discharge of 35mg of mercury (as amalgam) a day into sewers, that contributed around 8–14% of total mercury in wastewater treatment plants [56,124]. Notwithstanding, the mercury waste from dental amalgam, accounts for less than 1% of mercury discharged by human activity into the environment [77,92].

Beyond the dental practice, the amalgam legacy in the form of mercury emissions from crematoria will rapidly increase until 2020. This is predicted to plateau around 2035; returning to the lower levels seen in 2000 by 2055 [105].

3.8.2.2. Pollution pathways for dental amalgam. Mercury from amalgam enters the environment as dental waste from the placement and removal of restorations into waste water systems, due to intra-oral degradation of amalgam and release through human excretion, incineration of clinical waste (extracted teeth with amalgam fillings) or at the end-of-life following burial and cremation [32,33,35,53,56,59,63,65,71,73,77,92,105–107,111,114,116–120,125–130]. A 2005 Scandinavian study revealed that the output of mercury per chair exceeded the maximum recommended output [116]. The incineration of extracted teeth with amalgam as clinical waste releases mercury into the atmosphere [56,59,71,77,81,106,111,114,121,125,126,131]. In a similar manner, inappropriate disposal of Hg to landfill is a further pollution source as this can leach into the environment [77,112,121,126,129]. A 1998 study reported that end-of-life cremation accounted for 7% of Hg emissions in Sweden [111] and a subsequent Malaysian case study reported that in 2013, 3.6 tonnes of Hg were released from the cremation of bodies with amalgam [127]. Dissolved mercury is the most reactive fraction and should be included when considering total mercury emissions as this causes the most severe environmental effects [116]

Dental separators are designed to capture amalgam waste at the point of clinical use in the dental surgery. These are not widely used throughout much of the world and are approximately 90% effective [9,30,18,44,53,58,103,105,111,125,126,132–135]. The amalgam waste that is not captured in a separator, will flow directly into the municipal waste water network. Sediments are likely to accumulate in the pipes of dental practices and in the sewage pipes through natural precipitation. As an example, an average 1.2 kg of mercury per clinic was found during the remediation of abandoned Swedish facilities in 1993-2003 and similar quantities were observed in more recent work [116]. Separators are not 100% effective because mercury can form colloids which are able to pass through traps/separators [116]. Also, fine mercury particles are produced when using high speed handpiece, these are particularly hard to recover and are overlooked in ISO 11143 [116].

Mercury contamination from these routes is cited as a reason to cease the use of amalgam as a dental restorative material [94,111,116,119]. Moreover, it is difficult to control mercury waste as enters the environment in different forms as elemental vapour, amalgam sludge, amalgam scrap or amalgam waste [110,125,135].

Cleaners containing oxidising agents and hypochlorite (sodium hypochlorite and sodium dichloroisocyanate), that are used to disinfect the dental chair and the effluent pipes potentiate the release of mercury [33,92,114,130,134].

Mercury levels in the air were found to be higher than permissible limits in dental surgeries [136]. Reasons for this are: Difficulty in implementing best practice [107], mishandling of materials, lack of ventilation and use of hand mixing rather than capsules [136].

3.8.2.3. Barriers to change. There is a lack of consistency at an international level and across jurisdictions with regards to the availability of legislation and regulation [63,113,127,137], and limited access to collection agencies and sites for waste amalgam waste [112,113,135].

The low cost of amalgam prevails over sustainability concerns [59,113]. This is especially the case in developing economies, where affordability of dental care is a major concern. In these economies, a switch to a more costly or complex technique or material may exclude a large portion of a population from receiving simple dental care [107,127,138,139]. A lack of knowledge prevails in some countries with limited understanding of the merits of alternative materials [107]. An interesting observation has been raised that an increase in the use of resin-based composites to replace existing amalgam restorations could produce a spike in environmental mercury levels [112].

There is a lack of general knowledge and awareness for the management of amalgam waste and disposal [65,62,81,127,139]; noting that a lack of education on the environmental sustainability of dental amalgam in the undergraduate curriculum [136]. There is significant evidence of inappropriate disposal of amalgam in many countries, with the use of a common bin followed by incineration as common practice [30,59,61,77,103,106,115,129,137].

The use of amalgam separators is not universal, with the main cited reasons being: A lack of equipment in developing countries [84,107], resistance from the dental profession that objected to this being imposed as a mandatory requirement [117] and a combination of inadequate legislative frameworks and failure to implement existing regulations [63].

There is a need to avoid Hg pollution risks high mercury emissions from dental clinics despite amalgam separators [92,103,107,109,136,140].

3.9. Anaesthetic gases

3.9.1. Background

The major atmospheric effects that may arise from the emission of volatile anaesthetics are their contributions to ozone depletion in the stratosphere and to greenhouse warming in the troposphere. These agents are also a recognized greenhouse gas, accounting for around 6% of the heating effect of greenhouse gases in the atmosphere [35]. Nitrous oxide (N_2O) is a gas with a global warming potential of 298 times that of CO_2e [34]. N_2O also causes ozone depletion [141]. Most of the organic anaesthetic gases remain for a long time in the atmosphere, where they have the potential to act as greenhouse gases.

The bromide-containing agent halothane is the most destructive against ozone, although it is rarely used. Isoflurane and enflurane (which contains only chloride and fluoride ion substitutions) have a lesser impact [141]

Published atmospheric lifetimes range between 1.4 and 21.4 years for sevoflurane and desflurane, respectively. N_2O emissions from all of its various environmental sources are currently the single most important ozone-depleting substance emission and are expected to remain the largest throughout the 21st century [141]. On average, 163 litres of N_2O are used per patient episode, equating to around 90 kg CO_2e (without considering carbon emissions of producing NO2 and cylinder rental). Nitrous oxide used by NHS dental services in England is responsible for 1.3% of the total nitrous oxide use of NHS England and makes up 0.9% of the total carbon footprint of NHS dental services in England [34].

3.10. Pollution pathway

Two main pollution pathways are the anaesthetic technique and the actual anaesthetic machine delivery system. Incidents associated with these routes include: Poorly fitting masks, not turning off valves immediately once removed from patient; leakage of gas when re-filling tanks; gas in system may leak into the environment if not flushed correctly; underinflated cuff of laryngeal mask; leaks from valves, connectors in circuit, tubing, reservoir bags etc. [141]. Scavenged gas is vented into the outside environment. As anaesthetic gases undergo very little metabolic change inside the body, upon exhalation by the patient these agents remain in a form that may pollute the environment [141].

3.11. Gypsum

3.11.1. Background

Gypsum is an essential material that is widely used in dental laboratories for the manufacture of all indirect prosthodontic devices. When this is disposed, it is most likely to go to landfill where it can form H_2S gas. H_2S gas can cause irritation to the eyes, nose, or throat and may also cause difficulty in breathing for some asthmatics. Headaches, poor memory, tiredness, and balance problems may also occur. Permanent or long-term effects include headaches, poor attention span, poor memory, and poor motor function. For these reasons, gypsum is a banned waste from normal landfill in many countries, but this practice is not the norm. Gypsum waste should be disposed into a separate cell for high sulphide waste [44,79,142,143].

3.12. Resin-based dental composite

3.13.1. Background

Resin-based composite materials (RBCs) are not inert plastic materials and they have an environmental impact associated with the release of microparticles and elution of resin monomer components, including BPA that is of significant environmental concern [105,144].

3.12.2. Barriers

There is a lack of knowledge associated with the environmental impacts of RBCs [20,105,121]. Early studies show tentative results and conclusions with regard to how composite and BPA act in the body as well as in the environment. The impact of certain oestrogenic xenobiotic effects on development, health and reproductive systems are debatable [111].

3.13. Lead

3.13.1. Awareness

Lead is toxic and persists in the environment. Even at low levels of exposure, lead exerts adverse health effects on both children and adults [71,94,97,108,128]. Lead waste can remain in soil for as long as 2000 years where it can be readily picked up by plants and enter food systems [97]. According to the US Environmental Protection Agency (EPA), dental offices generate 4.8 million lead foils a year according [145]. Lead foil from dental radiograph films is the main contributor and if disposed in regular domestic waste, lead can leach and persist for a long time in soil and groundwater [32,33,53,146].

3.13.2. Barriers

There is wide disparity across all dental sectors for the management of radiographic film waste lead, with reports of inappropriate disposal [70,73,78]. Additionally, some manufacturers only report a 5% return rate of lead from film for recycling [135].

3.14. Metals

Silver thiosulfate is a solution used to fix the image on exposed dental radiographs that presents a significant environmental concern [106,108,125,133,146,147]. According to the US EPA, dental practices generate 28 million litres of silver thiosulphate x-ray fixer a year [145]. In wastewater treatment plants, this is converted into silver sulphide which settles in sludge [53,76,125,147]. Higher up the supply chain, toxic by-products are released through mining, processing and refining the natural resources and ores. These toxic by-products are leached into the environment creating a major source of environmental pollution [35].

Lead is toxic and persists in the environment. Even at low levels of exposure, lead exerts adverse health effects on both children and adults [71,94,97,108,128]. Lead waste can remain in soil for as long as 2000 years where it can be readily picked up by plants and enter food systems [97]. According to the US Environmental Protection Agency (EPA), dental offices generate 4.8 million lead foils a year according [145]. Lead foil from dental radiograph films is the main contributor and if disposed in regular domestic waste, lead can leach and persist for a long time in soil and groundwater [32,33,53,146].

Other metals that are regularly used in dentistry, have the potential for re-using and re-cycling; such as orthodontic brackets and wires. Alternative materials with lower carbon footprints to stainless steel (6.15 kgCO2e/kg), should be considered, such as ceramics (1.14 $kgCO_2e/kg$) and brass (2.42 $kgCO_2e/kg$) [32,36,53,79,148].

3.14.1. Barriers

A significant challenge to reusing metallic devices is a very protectionist and negative psychological reaction towards reusing medical/dental devices [36].

There is a lack of regulation and control with regard the disposal of potentially toxic solutions. For example, silver thiosulphate x-ray fixer is poorly regulated in parts of the world, with most of this going into the municipal waste water drains [59,70].

There is wide disparity across all dental sectors for the management of radiographic film waste lead, with reports of inappropriate disposal [70,73,78]. Additionally, some manufacturers only report a 5% return rate of lead from film for recycling [135].

3.15. Nanotechnology & Microparticles

3.15.1. Background

Nanoecotoxicology defines dangerous exposure that considers the entry routes of air, water/soil via ingestion together with the circuit of nanomaterials in the abiotic and biotic environment. Their size enables a wide distribution and uptake by the smallest life forms and some nanoparticles that are not naturally present in the environment, such as nanosilver, nano-copper and nano-zinc that have antimicrobial properties, have the potential to pose great threat to microbial communities [28]. Healthcare is a significant contributor of microplastics as part of the waste stream that can enter the food chain; these can absorb other chemicals, poisoning wildlife, destroying ecosystems and putting human health at risk [9,105]. The dangers of ingestion of particles by marine life are four-fold: toxicity from ingesting the particle itself, contaminants leaching from the microplastics, ingestion of attracted pollutants bound to the microplastics and accumulation of particles within the organism [9].

3.16. Disinfectants

Disinfectants such as hypochlorite, glutaraldehydes, iodophors, phenolic derivatives, alcohol-based preparations can inactivate essential biological systems [35,53,92].

4. Conclusions

This scoping review has identified 128 records that contribute to our understanding of environmentally sustainable oral healthcare. The thematic analysis highlights eight diverse but closely interlinked themes that influence the sustainability of oral health provision on a world-wide basis: Environmental impacts (CO_2e, air and water); Reduce, reuse, recycle and rethink; Policy and guidelines; Biomedical waste management; Plastics (SUPs); Procurement; Research & Education; Materials. The following headline conclusions are encapsulated with a focus on the levels of awareness and the real and perceived barriers to develop and engage with sustainable practice.

Public awareness of the need to decarbonise and reduce pollution from our activities on a global basis is at an all-time high and this is directly proportional to the increasing urgency to engage with this problem. Professional awareness is much lower as there is a perceived disengagement between citizenship responsibility and that of our professional activities, that are led by the aims of the core professional activities. This is a constant theme throughout the literature and undoubtably both the greatest barrier and opportunity to engage in effective and impactful sustainable outcomes.

The greatest forms of carbon emissions arise from patient travel, staff commuting, business travel, procurement, gas and electricity use, waste disposal, water use and nitrous oxide release. Of these, patient and staff commuter travel account for the greatest contribution to the profession's carbon foot print. A number of studies support the preliminary evidence that provides a heightened level of awareness into the source and magnitude of these emissions.

The greatest barrier to the implementation of sustainability are the behaviours and attitudes that exist within the profession and that do not consider or prioritise sustainable practices. These are particularly pervasive in developing countries; where the greatest barriers are a lack of economic feasibility and a poor knowledge-base on the subject.

In addition to our contribution to global warming through CO_2 emissions, some of our activities in dentistry have a direct negative impact on biodiversity; such as the presence of mercury in waste-water works from dental practices that don't use amalgam traps. The manufacturing, distribution and poor waste management of equipment, sundries and associated packaging, that are part of a linear economy supply chain, presents a pollutant environmental impact.

The provision of oral healthcare in a clinical setting creates complex and contaminated waste that makes it difficult or impossible in some instances to implement policies of reuse, reduce and recycle. This is especially poignant in respect of single use plastics that are found in the form of different complex polymer combinations. Plastic is an indispensable component of modern safe healthcare and their use is unavoidable. Plastic items and devices provide clinical and public confidence of using a new clean and/or sterile device every time. The combined manufacturing versatility, cleanliness/sterility guarantee and cost effectiveness of plastic devices makes reusing and/or recycling economically unattractive. The challenge is that these devices are costly and difficult to clean, disinfect and sterilize. Recovery for recycling is often not cost-effective, possible and not supported by appropriate legislation.

The provision of healthcare in dentistry and the management of waste arising from this has to operate within the boundaries of legislative regulation to ensure safety and sustainable practice. There is a recognized conflict between the need to operate within the regulatory frameworks of safe health provision and doing so in a sustainable manner. Most states and agencies assume that biohazardous waste is waste capable of transmitting infectious disease, and consequently its management automatically favours incineration and discounts any form of recovery. Waste management policies are often not sophisticated enough to identify and compel stakeholders to establish effective pathways for segregation of waste that enable effective recovery for recycling. Current waste management focuses on landfill and incineration, both with significant environmental impacts. There is a lack of awareness and understanding of the actual impact of disposal of plastic waste. Most of the CO_2 emissions have occurred upstream in the supply chain. Ease, convenience and availability of low-cost products with high environmental impacts override a desire for more sustainable options. Procurement is also driven by the need to adhere to regulatory frameworks, that focus on clinical effectiveness and do not consider environmental impacts.

Lack of knowledge, awareness and educational programs are pervasive throughout the literature and identified as a common barrier to engagement and change in all themes. There is a distinct lack of quality research that supports and enables the provision of environmentally sustainable oral health provision.

Dental materials present the highest level of pollution, at all levels of the supply chain, from manufacturing, through to distribution, procurement, clinical use and ultimately waste management. The impact from dental materials is material-specific, with much of the evidence focused on dental amalgam. There is a distinct need to establish effective life cycle analysis studies to provide baseline data for key restorative materials and subsequently identify ways to minimize their use and facilitate recovery.

Declaration of Competing Interest

The authors confirm that there is no conflict of interest.

Acknowledgments

This work was financially supported by the FDI World Dental Federation as part of the Sustainability in Dentistry project. The support and encouragement of the FDI Sustainability in Dentistry Project Team is graciously acknowledged. The authors thank Ms. Hannah Martin for the graphical illustrations included in this manuscript.

References

[1] Bindoff N., Stott P., AchutaRao K., Allen M., Gillett N., Gutzler K., Hansingo G., Hegerl Y., Hu Y., Detection and attribution of climate change: from global to regional, in: Intergovernmental Panel on Climate Change (Ed.), Clim. Chang. 2013 - Phys. Sci. Basis, Cambridge University Press, Cambridge, n.d.

[2] C. Field, V. Barros, D.J. Dokken, K. Mach, T. Mastrandea, Climate Change 2014 Impacts, Adaptation, and Vulnerability, Cambridge University Press, Cambridge, 2014.

[3] W. Steffen, K. Richardson, J. Rockstrom, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs, S.R. Carpenter, W. de Vries, C.A. de Wit, C. Folke, D. Gerten, J. Heinke, G.M. Mace, L.M. Persson, V. Ramanathan, B. Reyers, S. Sorlin, Planetary boundaries: guiding human development on a changing planet, Science (2015) 347.

[4] Allen W.M., Dube O.P. , Solecki W., Aragón–Durand F., Cramer W., Humphreys S., Kainuma M., Kala J., Mahowald N., Mulugetta Y, Perez R., Wairiu M., Zickfeld K., 2018, Framing and context supplementary material. In: Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels And Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty V.Masson-Delmotte, P.Zhai, H. O.Pörtner, D.Roberts, J.Skea, P.R.Shukla, A.Pirani, W. Moufouma-Okia, C.Péan, R.Pidcock, S.Connors, J. B. R.Matthews, Y.Chen, X. Zhou, M. I.Gomis, E.Lonnoy, T.Maycock, M.Tignor, T.Waterfield. Available from https://www.ipcc.ch/sr15.

[5] G. Forzieri, A. Cescatti, F.B. e Silva, L. Feyen, Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study, Lancet Planet Health 1 (5) (2017) E200–E208.

[6] The health and environment linkages initiative (HELI): Priority risks, 2021. https://www.who.int/heli/risks/climate/climatechange/en/ (Accessed March 3, 2021).

[7] Climate Change and Health, 2018. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health (Accessed March 3, 2021).

[8] B. Duane, R. Stancliffe, F.A. Miller, J. Sherman, E. Pasdeki-Clewer, Sustainability in dentistry: a multifaceted approach needed, J. Dent. Res. 99 (2020) 998–1003.

[9] S. Harford, D. Ramasubbu, B. Duane, F. Mortimer, Sustainable dentistry: How-to guide for dental practices, Centre for Sustainable Healthcare (2018). https://sustainablehealthcare.org.uk/dental-guide (Accessed March 3, 2021).).

[10] H. Arksey, L. O'Malley, Scoping studies: towards a methodological framework, Int. J. Soc. Res. Methodol. 88 (1) (2005) 19–32.

[11] A.C. Tricco, E. Lillie, W. Zarin, K.K. O'Brien, H. Colquhoun, D. Levac, D. Moher, M.D.J. Peters, T. Horsley, L. Weeks, S. Hempel, E.A. Akl, C. Chang, J. McGowan, L. Stewart, L. Hartling, A. Aldcroft, M.G. Wilson, C. Garritty, S. Lewin, C. M. Godfrey, M.T. Macdonald, E.V. Langlois, K. Soares-Weiser, J. Moriarty, T. Clifford, Ö. Tunçalp, S.E. Straus, PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation, Ann. Intern. Med. (2018) 169.

[12] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2) (2006) 77–101.

[13] V. Braun, V. Clarke, What can "thematic analysis" offer health and wellbeing researchers? Int. J. Qual. Stud. Health Well Being 9 (2014) 1.

[14] H. Frith, K. Gleeson, Clothing and embodiment: men managing body image and appearance, Psychol. Men Masc. 5 (2004) 40–48.

[15] K.A. Knafl, M.Q. Patton, Qualitative Evaluation and Research Methods, 2nd Ed., Sage, Res. Nurs. Health., Newbury Park, CA, 1990, p. 14 (1991).

[16] Clarivate, Web of Science, Https://Clarivate.Com/. (2021). (Accessed March 3, 2021).

[17] N. Martin, M. Sheppard, G. Gorasia, P. Arora, M. Cooper, S. Mulligan, Drivers, opportunities and best practice for sustainability in dentistry: A scoping review, Journal of Dentistry 112 (2021) 103737.

[18] B. Duane, S. Harford, D. Ramasubbu, R. Stancliffe, E. Pasdeki-Clewer, R. Lomax, I. Steinbach, Environmentally sustainable dentistry: a brief introduction to sustainable concepts within the dental practice, Br. Dent. J. 226 (2019) 292–295.

[19] B. Duane, S. Harford, I. Steinbach, R. Stancliffe, J. Swan, R. Lomax, E. Pasdeki-Clewer, D. Ramasubbu, Environmentally sustainable dentistry: energy use within the dental practice, Br. Dent. J. 226 (2019) 367–373.

[20] B. Duane, D. Ramasubbu, S. Harford, I. Steinbach, R. Stancliffe, K. Croasdale, E. Pasdeki-Clewer, Environmental sustainability and procurement: purchasing products for the dental setting, Br. Dent. J. 226 (2019) 453–458.

[21] B. Duane, I. Steinbach, D. Ramasubbu, R. Stancliffe, K. Croasdale, S. Harford, R. Lomax, Environmental sustainability and travel within the dental practice, Br. Dent. J. 226 (2019) 525–530.

[22] B. Duane, D. Ramasubbu, S. Harford, I. Steinbach, R. Stancliffe, G. Ballantyne, Environmental sustainability and biodiversity within the dental practice, Br. Dent. J. 226 (2019) 701–705.

[23] B. Duane, K. Croasdale, D. Ramasubbu, S. Harford, I. Steinbach, R. Stancliffe, D. Vadher, Environmental sustainability: measuring and embedding sustainable practice into the dental practice, Br. Dent. J. 226 (2019) 891–896.

[24] B. Duane, P. Ashley, S. Saget, D. Richards, E. Pasdeki-Clewer, A. Lyne, Incorporating sustainability into assessment of oral health interventions, Br. Dent. J. (2020) 229.

[25] A. Lyne, P. Ashley, S. Saget, M. Porto Costa, B. Underwood, B. Duane, Combining evidence-based healthcare with environmental sustainability: using the toothbrush as a model, Br. Dent. J. (2020) 229.

[26] T.G. Wolf, G. Campus, Changing dental profession-modern forms and challenges in dental practice, Int. J. Environ. Res. Public Health 18 (2021).

[27] United Nations, The intergovernmental panel on climate change, https://www.Ipcc.Ch/. (2021). (Accessed March 3, 2021).

[28] C.M. Gavrilescu, C. Paraschiv, P. Horjinec, D.M. Sotropa, R.M. Barbu, The advantages and disadvantages of nanotechnology, Rom, J. Oral Rehabil. 10 (2018) 153–159.

[29] J. Richardson, J. Grose, S. Manzi, I. Mills, D.R. Moles, R. Mukonoweshuro, M. Nasser, A. Nichols, What's in a bin: a case study of dental clinical waste composition and potential greenhouse gas emission savings, Br. Dent. J. 220 (2016) 61–66.

[30] S. Verma, A. Jain, R. Thakur, S. Maran, A. Kale, K. Sagar, S. Mishra, Knowledge, attitude and practice of green dentistry among dental professionals of Bhopal city: a cross-sectional survey, J. Clin. Diagn. Res. (2020).

[31] B. Duane, J. Hyland, J.S. Rowan, B. Archibald, Taking a bite out of Scotland's dental carbon emissions in the transition to a low carbon future, Public Health 126 (2012) 770–777.

[32] S.S. Khanna, P.A. Dhaimade, Green dentistry: a systematic review of ecological dental practices, Environ. Dev. Sustain. 21 (2019) 2599–2618.

[33] A. Chopra, N. Gupta, N. Rao, S. Vashisth, Eco-dentistry: the environment-friendly dentistry, Saudi J. Heal. Sci. 3 (2014).

[34] B. Duane, D. Ramasubbu, S. Harford, I. Steinbach, J. Swan, K. Croasdale, R. Stancliffe, Environmental sustainability and waste within the dental practice, Br. Dent. J. 226 (2019) 611–618.

[35] Wilson NH, Bellinger EG, Mjör IA. Dental practice and the environment. Int Dent J. 1998 Jun;48(3):161-6. PMID: 9779094.

[36] P. Mulimani, Green dentistry: the art and science of sustainable practice, Br. Dent. J. 222 (2017) 954–961.

[37] S. Hurley, S. White, Carbon Modeling Within Dentistry: Towards a Sustainable Future, Public Health England, UK, 2018. https://www.gov.uk/government/publications/carbon-modelling-within-dentistry-towards-a-sustainable-future (Accessed March 3, 2021).

[38] B. Duane, M.B. Lee, S. White, R. Stancliffe, I. Steinbach, An estimated carbon footprint of NHS primary dental care within England. how can dentistry be more environmentally sustainable? Br. Dent. J. 223 (2017) 589–593.

[39] J. Phillipson, The need for sustainable dentistry, Br Dent J InPractice (2018) 31–32.

[40] G.J. Wilson, S. Shah, H. Pugh, What impact is dentistry having on the environment and how can dentistry lead the way? Fac. Dent. J. (2020) 11.

[41] B. Duane, A. Dougall, Guest editorial: sustainable dentistry, Spec. Care Dent. 39 (2019) 351–353.

[42] A. Garg, G. Guez, Trends in implant dentistry: green dentistry, Dent. Implantol. Update. 21 (12) (2010) 91–96. PMID: 21265472.

[43] A. Kakkar, V.P. Aggarwal, S. Singh, Go green: a new prospective in dentistry, MOJ Curr. Res. Rev. 1 (2017) 7–10.

[44] S. Arora, S. Mittal, V. Dogra, Eco-friendly dentistry: need of future. an overview, J. Dent. Allied Sci. 6 (2017) 22.

[45] L. Borglin, S. Pekarski, S. Saget, B. Duane, The life cycle analysis of a dental examination: quantifying the environmental burden of an examination in a hypothetical dental practice, Community Dent. Oral Epidemiol. (2021).

[46] E. Reffold, F. Leighton, F. Choudhury, P.S. Rayner, Using science to create a better place: greenhouse gas emissions of water supply and demand management options, Environment Agency, Bristol, UK. Science Report – SC070010 (2008). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291728/scho0708bofv-e-e.pdf.

[47] K. Carney K., T.D. Word, J. Calif, The D word, J Calif Dent Association 43 (2015) 561–562. PMID: 26798904.

[48] Climate Change and Land, 2021. https://www.ipcc.ch/srccl/. (Accessed March 3, 2021).

[49] N. Martin, S. Mulligan, P. Fuzesi, T. Webb, H. Baird, S. Spain, T. Neal, A. Garforth, A. Tedstone, P. Hatton, Waste plastics in clinical environments: a multi-disciplinary challenge, in: Creat. circ. econ. approaches elimin. plast. waste. UK res. innov. UK circ. plast. netw., 2020: pp. 86–91. https://www.ukcpn.co.uk/wp-content/uploads/2020/08/PRIF-Conference-Brochure-Final-1.pdf (accessed March 4, 2021).

[50] J. Grose, L. Burns, R. Mukonoweshuro, J. Richardson, I. Mills, M. Nasser, D. Moles, Developing sustainability in a dental practice through an action research approach, Br. Dent. J. 225 (2018) 409–412.

[51] A. Nagpal, G. Sharma, Daunting for developing countries, Br. Dent. J. (2019) 227.

[52] https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/, Intergovernmental science-policy platform on biodiversity and ecosystem services, 2019. (Accessed March 3, 2021).

[53] K. Rupa, L. Chatra, P. Shenai, M. V.K., P. Kumar Rao, R. Prabhu, Taking a step towards greener future: practical guideline for eco-friendly dentistry, Arch, Med. Rev. J. 24 (2015) 135–148.

[54] Creative Circular economy: approaches to eliminate plastic waste, in: UK circ. plast. netw., UK research & innovation and plastics research and innovation fund (PRIF),. https://www.ukcpn.co.uk/wp-content/uploads/2020/08/PRIF-Conference-Brochure-Final-1.pdf (accessed March 4, 2021).

[55] A. Tedstone, C. Fletcher, A. Greer, K. Oster, R. St Clair, M. Tomatis, A. Azapagic, R. Cuellar Franca, A. Garforth, C. Hardacre, M. Sharmina, Sustainable hospitals-recycling healthcare plastics, Plastic Research and Innovation Fund Conference. 2020. (2020) 80–85.

[56] M. Ozbek, F.D. Sanin, A study of the dental solid waste produced in a school of dentistry in Turkey, Waste Manag. 24 (2004) 339–345.

[57] Cocchiarella L., Deitchman S.D., Young D.C. Report of the Council on Scientific Affairs. Biohazardous waste management: what the physician needs to know.

American Medical Association. Arch Fam Med. 2000 Jan;9(1):26-9. PMID: 10664638.
[58] C. Holland, Investigation: greening up the bottom line, Br. Dent. J. 217 (2014) 10–11.
[59] I.A. Al-Khatib, M. Monou, S.A. Mosleh, M.M. Al-Subu, D. Kassinos, Dental solid and hazardous waste management and safety practices in developing countries: nablus district, Palestine, Waste Manag. Res. 28 (2010) 436–444.
[60] NHS Estates, Total Waste Management : Best Practice Advice on Local Waste Management for the NHS in England, The Stationery Office, London, 2004.
[61] J. Grose, J. Richardson, I. Mills, D. Moles, M. Nasser, Exploring attitudes and knowledge of climate change and sustainability in a dental practice: a feasibility study into resource management, Br. Dent. J. 220 (2016) 187–191.
[62] K.N. Abhishek, S. Supreetha, N. Varma Penumatsa, G. Sam, S.C. Khanapure, S. Sivarajan, Awareness-knowledge and practices of dental waste management among private practitioners, Kathmandu Univ. Med. J. 14 (2016) 17–21.
[63] A. Musliu, L. Beqa, G. Kastrati, The use of dental amalgam and amalgam waste management in Kosova: an environmental policy approach, Integr. Environ. Assess. Manag. (2021).
[64] L. Bathala, B. Jupidi, M. Thota, K. Theruru, S. Shaik, S. Rayapati, There's plenty of room at the bottom": the biomedical waste management in dentistry, J. Dr. NTR Univ. Heal. Sci. 3 (2014) 149.
[65] M. Choudhary, M. Verma, S. Ghosh, J. Dhillon, Assessment of knowledge and awareness about biomedical waste management among health care personnel in a tertiary care dental facility in Delhi, Indian J. Dent. Res. 31 (2020) 26–30.
[66] A. Koolivand, A.H. Mahvi, V. Alipoor, K. Azizi, M. Binavapour, Investigating composition and production rate of healthcare waste and associated management practices in Bandar Abbass, Iran, Waste Manag. Res. 30 (2012) 601–606.
[67] M.M. Hasan, M.H. Rahman, Assessment of healthcare waste management paradigms and its suitable treatment alternative: a case study, J. Environ. Public Health 2018 (2018).
[68] T. Singh, T.R. Ghimire, S.K. Agrawal, Awareness of biomedical waste management in dental students in different dental colleges in Nepal, Biomed. Res. Int. 2018 (2018).
[69] D. Kapoor, A. Nirola, V. Kapoor, R.S. Gambhir, Knowledge and awareness regarding biomedical waste management in dental teaching institutions in India-a systematic review, J. Clin. Exp. Dent. 6 (2014) e419–e424.
[70] M. Bansal, N. Gupta, S. Vashisth, Knowledge, awareness and practices of dental care waste management among private dental practitioners in Tricity (Chandigarh, Panchkula and Mohali), J. Int. Soc. Prev. Commun. Dent. 3 (2013) 72.
[71] A.G. Sood, A. Sood, Dental perspective on biomedical waste and mercury management: A knowledge, attitude, and practice survey, Indian J. Dent. Res. 22 (2011) 371–375.
[72] A. Ahmadifard, Unmasking the hidden pandemic: sustainability in the setting of the COVID-19 pandemic, Br. Dent. J. (2020) 229.
[73] H. Momeni, S.F. Tabatabaei Fard, A. Arefinejad, A. Afzali, F. Talebi, E.R Salmani, Composition, production rate and management of dental solid waste in 2017 in Birjand, Iran, Int. J. Occup. Environ. Med. 9 (2018).
[74] Eco Dentistry Association, (n.d.). https://ecodentistry.org/(accessed March 4, 2021).
[75] V. Prathima, K.P. Vellore, A. Kotha, S. Malathi, V.S. Kumar, M. Koneru, Knowledge, attitude and practices towards eco-friendly dentistry among dental practioners, J. Res. Dent. 4 (2017) 123.
[76] Update on waste management for the practice of dentistry, J. Ir. Dent. Assoc. 50 (2004) 62–63.
[77] R.D. Singh, S.K. Jurel, S. Tripathi, K.K. Agrawal, R. Kumari, Mercury and other biomedical waste management practices among dental practitioners in India, Biomed. Res. Int. 2014 (2014).
[78] S. Rudraswamy, N. Sampath, N. Doggalli, Staff's attitude regarding hospital waste management in the dental college hospitals of Bangalore city, India, Indian J. Occup. Environ. Med. 16 (2012) 75–78.
[79] R. Ranjan, R. Pathak, D.K. Singh, M. Jalaluddin, S.A. Kore, A.R. Kore, Awareness about biomedical waste management and knowledge of effective recycling of dental materials among dental students, J. Int. Soc. Prev. Commun. Dent. 6 (2016) 474–479.
[80] V. Sudhakar, J. Chandrashekar, Dental health care waste disposal among private dental practices in Bangalore City, India, Int. Dent. J. 58 (2008) 51–54.
[81] J.B. Ilić-Živojinović, B.B. Ilić, D. Backović, M. Tomanić, A. Gavrilović, L. Bogdanović, Knowledge and attitudes on medical waste management among Belgrade medical and dental students, Srp. Arh. Celok. Lek. 2019 (2019) 281–285.
[82] R. Nabizadeh, A. Koolivand, A.J. Jafari, M. Yunesian, G. Omrani, Composition and production rate of dental solid waste and associated management practices in Hamadan, Iran, Waste Manag. Res. 30 (2012) 619–624.
[83] P. Tompe, N. Pande, B. Kamble, U. Manohar Radke, B. Acharya, A systematic review to evaluate knowledge, attitude, and practice regarding biomedical waste management among dental teaching institutions and private practitioners in Asian countries, J. Int. Soc. Prev. Commun. Dent. 10 (2020) 531–539.
[84] H.G. Shah, M. Parikh, I. Mehta, M. Nair, P. Desai, V. Sodani, Knowledge, attitude and practices of interns, graduates and postgraduate students at private dental colleges in ahmedabad regarding bio medical waste management, J. Adv. Oral Res. 6 (2015) 25–28.
[85] A.K. Subramanian, Biomedical waste management practice in dentistry, Bioinformation (2020) 16.
[86] P. Govan, Waste management in dental practice, SADJ 69 (2014) 178–181.
[87] L.C.M. Lebreton, J. van der Zwet, J.-W. Damsteeg, B. Slat, A. Andrady, J. Reisser, River plastic emissions to the world's oceans, Nat. Commun. 8 (2017).
[88] Davies S.C. Health Impacts of All Pollution – what do we know? Annual Report of the Chief Medical Officer 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/690846/CMO_Annual_Report_2017_Health_Impacts_of_All_Pollution_what_do_we_know.pdf (Accessed 31 June 2021).
[89] S.R. Unger, A.E. Landis, Comparative life cycle assessment of reused versus disposable dental burs, Int. J. Life Cycle Assess. 19 (2014) 1623–1631.
[90] C. Zeri, A. Adamopoulou, D. Bojanić Varezić, T. Fortibuoni, M. Kovač Viršek, A. Kržan, M. Mandic, C. Mazziotti, A. Palatinus, M. Peterlin, M. Prvan, F. Ronchi, J. Siljic, P. Tutman, T. Vlachogianni, Floating plastics in adriatic waters (Mediterranean Sea): From the macro- to the micro-scale, Mar. Pollut. Bull. 136 (2018) 341–350.
[91] S. Mulligan, L. Smith, N. Martin, Sustainable oral healthcare and the environment: challenges, Dent. Update 48 (2021) 493–501 (Unpublished results).
[92] H. Rahman, R. Chandra, S. Triphathi, S. Singh, Green dentistry- clean dentistry, Indian J. Restor. Dent. 3 (2014) 56–61.
[93] P. Eram, S. Shabina, M. Rizwana, N. Rana, Eco dentistry: a new wave of the future dental practice, Ann. Dent. Spec. 5 (2017) 14–17.
[94] B. Agarwal, S.V. Singh, S. Bhansali, S. Agarwal, Waste management in dental office, Indian J. Commun. Med. 37 (2012) 201–202.
[95] Ellen McArthur Foundation. https://www.ellenmacarthurfoundation.org (Accessed March 3, 2021).
[96] WRAP-Circular Economy & Resource Efficiency Experts. https://wrap.org.uk (Accessed March 3, 2021).
[97] R. Sachdev, Green route indeed a need for dental practice: a review, Artic. World J. Pharm. Res. (2017).
[98] M. Nasser, Evidence summary: can plastics used in dentistry act as an environmental pollutant? Can we avoid the use of plastics in dental practice? Br. Dent. J. 212 (2012) 89–91.
[99] C. Rizan, M.F. Bhutta, M. Reed, R Lillywhite, The carbon footprint of healthcare waste streams in a UK hospital, Journal of Cleaner Production 286 (2021) 125446.
[100] A. Joy, A. Qureshi, Mercury in dental amalgam, online retail, and the minamata convention on mercury, Environ. Sci. Technol. (2020) 54.
[101] B. Bowden, A. Iomhair, M. Wilson, Evaluating the environmental impact of the welsh national childhood oral health improvement programme, designed to smile, Commun. Dent. Heal 38 (2021) 15–20.
[102] V. Prathima, K.P. Vellore, A. Kotha, S. Malathi, V.S. Kumar, M. Koneru, Knowledge, attitude and practices towards eco-friendly dentistry among dental practioners, J. Res. Dent. 4 (2017) 123.
[103] S.M. Al Shatrat, D. Shuman, M.L. Darby, H.A. Jeng, Jordanian dentists' knowledge and implementation of eco-friendly dental office strategies, Int. Dent. J. 63 (2013) 161–168.
[104] G.M. Chadha, G. Shenoy Panchmal, R.P. Shenoy, S. Siddique, P. Jodalli, Establishing an eco-friendly dental practice: a review, IJSS Case Rep. Rev. (2015) 11.
[105] S. Mulligan, G. Kakonyi, K. Moharamzadeh, S.F. Thornton, N. Martin, The environmental impact of dental amalgam and resin-based composite materials, Br. Dent. J. 224 (2018) 542–548.
[106] K. Anderson, Creating an Environmentally Friendly Dental Practice, Chicago Dent. Soc, 1999, pp. 12–18.
[107] S. Bayne, P.E. Petersen, D. Piper, G. Schmalz, D. Meyer, The challenge for innovation in direct restorative materials, Adv. Dent. Res. 25 (2013) 8–17.
[108] P. Bardolia, The environmental impact of dentistry, Br. Dent. J. 226 (2019), 634–634.
[109] G.B Kumar, Green dentistry; ecofriendly dentistry: beneficial for patients, beneficial for the environment, Ann. Essences Dent. 4 (2012) 72–74.
[110] V. Rastogi, R. Sharma, L. Yadav, P. Satpute, V. Sharma, Green dentistry, a metamorphosis towards an eco-friendly dentistry: a short communication, J. Clin. Diagn. Res. 8 (2014).
[111] D. Arenholt-Bindslev, Environmental aspects of dental filling materials, Eur. J. Oral Sci. 106 (1998) 713–720.
[112] J.P.B.L. de Souza, S.R. Nozawa, R.T. Honda, Improper waste disposal of silver-mercury amalgam, Bull. Environ. Contam. Toxicol. 88 (2012) 797–801.
[113] F.A. Sawair, Y. Hassoneh, A.O. Jamleh, M. Al-Rabab'Ah, Observance of proper mercury hygiene practices by Jordanian general dental practitioners, Int. J. Occup. Med. Environ. Health 23 (2010) 47–54.
[114] Chin G, Chong J, Kluczewska A, Lau A, Gorjy S, Tennant M. The environmental effects of dental amalgam. Aust Dent J. 2000 Dec;45(4):246-9. PMID: 11225525.
[115] F.G. Iano, O. dos Santos Sobrinho, T.L. da Silva, M.A. Pereira, P.J.M. Figueiredo, L.B.A. Alberguini, J.M. Granjeiro, Optimizing the procedure for mercury recovery from dental amalgam, Braz. Oral Res. 22 (2008) 119–124.
[116] L.D. Hylander, A. Lindvall, L. Gahnberg, High mercury emissions from dental clinics despite amalgam separators, Sci. Total Environ. 362 (2006).
[117] E. Bakhurji, T. Scott, T. Mangione, W. Sohn, Dentists' perspective about dental amalgam: current use and future direction, J. Public Health Dent. 77 (2017) 207–215.
[118] Arenholt-Bindslev D. Dental amalgam–environmental aspects. Adv Dent Res. 1992 ;6:125-30. PMID: 1292452.
[119] P. Hörsted-Bindslev, Amalgam toxicity - Environmental and occupational hazards, J. Dent. 32 (2004) 359–365.
[120] K. Sadasiva, S. Rayar, U. Manu, K. Senthilkumar, S. Daya, N. Anushaa, Recovery of mercury from dental amalgam scrap-Indian perspective, J. Pharm. Bioallied Sci. 9 (2017). S79–S81.

[121] S. Erdal, P. Orris, Mercury in dental amalgam and resin-based alternatives - A comparative health risk evaluation, Healthcare Research Collaborative (June) (2012) 1–71. https://noharm-europe.org/sites/default/files/documents-files/72/Mercury_in_Dental_Amalgam.pdf (Accessed March 3, 2021).

[122] Global Mercury Assessment, 2013: Sources, emissions, releases and environmental transport. Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport, 2013, UNEP Chemicals Branch, Geneva, Switzerland UNEP, 2013. http://www.unep.org/hazardoussubstances/Mercury/Informationmaterials/ReportsandPublications/tabid/3593/Default.aspx (accessed March 4, 2021).

[123] 2019. Global Mercury Assessment 2018. UN environment programme, chemicals and health branch Geneva, Switzerland UN environment, global mercury assessment 2018, 2019. https://www.unep.org/resources/publication/global-mercury-assessment-2018 (Accessed March 3, 2021).

[124] P.L. Fan, H. Batchu, H.N. Chou, W. Gasparac, J. Sandrik, D.M. Meyer, Laboratory evaluation of amalgam separators, J. Am. Dent. Assoc. 133 (2002) 577–589.

[125] B. Muhamedagic, L. Muhamedagic, I. Masic, Dental office waste-public health and ecological risk, Mater. Soci. Med. 21 (2009) 35.

[126] A. Jokstad, P.L. Fan, Amalgam waste management, Int. Dent. J. 56 (2006) 147–153.

[127] M.M. Amir Sultan, C.T. Goh, S.E. Wan Puteh, M. Mokhtar, Establishing mercury-free medical facilities: a Malaysian case study, Int. J. Health Care Qual. Assur. 32 (2019) 34–44.

[128] D.F.C. Guedes, R.S. Silva, M.A.M.S. da Veiga, J.D. Pecora, First detection of lead in black paper from intraoral film. an environmental concern, J. Hazard. Mater. 170 (2009) 855–860.

[129] D. Panasiuk, A. Glodek, Substance flow analysis for mercury emission in Poland, in: Proceedings of the 16th Int. Confrence Heavy Met. Environ, 2013, pp. 1–4.

[130] H. Batchu, H.N. Chou, D. Rakowski, P.L. Fan, The effect of disinfectants and line cleaners on the release of mercury from amalgam, J. Am. Dent. Assoc. 137 (2006) 1419–1425.

[131] J.F. Westman, T. Tuominen, Amalgam waste management. issues & answers, N. Y. State Dent. J. 66 (2000) 20–24.

[132] B. Avinash, B.S. Avinash, B.M. Shivalinga, S. Jyothikiran, M.N. Padmini, Going green with eco-friendly dentistry, J. Contemp. Dent. Pract. 14 (2013) 766–769.

[133] R. Sachdev, K. Garg, Green route indeed a need for dental practice: a review, World J. Pharm. Res. 6 (2017) 1878–1884.

[134] H. Batchu, D. Rakowski, P.L. Fan, D.M. Meyer, Evaluating amalgam separators using an international standard, J. Am. Dent. Assoc. 137 (2006) 999–1005.

[135] M. Hiltz, The environmental impact of dentistry, J. Can. Dent. Assoc. 73 (2007) 59–62 (Tor). www.cda-adc.ca/jcda.

[136] M.A. Khwaja, S. Nawaz, S.W. Ali, Mercury exposure in the work place and human health: dental amalgam use in dentistry at dental teaching institutions and private dental clinics in selected cities of Pakistan, Rev. Environ. Health 31 (2016) 21–27.

[137] I.A. Al-Khatib, R. Darwish, Assessment of waste amalgam management in dental clinics in Ramallah and al-Bireh cities in palestine, Int. J. Environ. Health Res. 14 (2004) 179–183.

[138] E.D. Rekow, S.C. Bayne, R.M. Carvalho, J.G. Steele, What constitutes an ideal dental restorative material? Adv. Dent. Res. 25 (2013) 18–23.

[139] J.O. Makanjuola, D.C. Umesi, A.N. Ndukwe, L.L. Enone, O.A. Sotunde, J.O. Omo, P.I. Idon, O. Alalade, G.E. Adebayo, U.I. Ekowmwnhenhen, G.T. Arotiba, Managing the phase-down of amalgam amongst Nigerian dental professionals and students: a national survey, Eur. J. Dent. Educ. (2020).

[140] A.C. De Oliveira Cravo Teixeira, L.R. Borges-Paluch, C.C.B. De Jacobi, Waste diagnosis in public dental facilities in Recôncavo Baiano county: contributions to integrated waste management, Mundo Da Saude 41 (2017) 682–691.

[141] J.S. Yasny, J. White, Environmental implications of anesthetic gases, Anesth. Prog. 59 (2012) 154–158.

[142] R. Allen, Disposing of clinical and dental waste, BDJ Team (2015) 1.

[143] S. Shiyo, J. Nagels, H.G. Shangali, Recycling of plaster of Paris, Afr. J. Disabil. 9 (2020).

[144] N. Sasaki, K. Okuda, T. Kato, H. Kakishima, H. Okuma, K. Abe, H. Tachino, K. Tuchida, K. Kubono, Salivary bisphenol-a levels detected by ELISA after restoration with composite resin, J. Mater. Sci. Mater. Med. 16 (2005) 297–300.

[145] Dental Effluent Guidelines, 2017. https://www.epa.gov/eg/dental-effluent-guidelines (accessed March 8, 2021).

[146] A. Chopra, K. Raju, Green dentistry: practices and perceived barriers among dental practitioners of Chandigarh, Panchkula, and Mohali (Tricity), India, J. Indian Assoc. Public Heal. Dent. 15 (2017) 53–56.

[147] A.D.A. Council on Scientific Affairs, Managing silver and lead waste in dental offices, Dent. Assist. 73 (2004) 41–42.

[148] M.M. Pithon, L.C.M. de Faria, O.M. Tanaka, A.C. de O. Ruellas, L.S. de S.G. Primo, Sustainability in orthodontics: what can we do to save our planet? Dent. Press J. Orthod. (2017) 22.

[149] J. Grose, L. Burns, R. Mukonoweshuro, J. Richardson, I. Mills, M. Nasser, D. Moles, Developing sustainability in a dental practice through an action research approach, Br. Dent. J. 225 (2018) 409–412.

[150] V.P. Aggarwal, A. Kakkar, S. Singh, Go green: a new prospective in dentistry, MOJ Curr. Res. Rev. 1 (2017) 7–10.

[151] P. Mulimani, Green dentistry: the art and science of sustainable practice, Br. Dent. J. 222 (2017) 954–961.

[152] B. Duane, Green dentistry: motivating change, Br. Dent. J. 217 (2014), 388–388.

[153] C. Holland, Greening up the bottom line, Br. Dent. J. 217 (2014) 10–11.

[154] C.-Y. Su, D.-S.C J.-C.Wang, C.-C Chuang, C.-K. Lin, Additive manufacturing of dental prosthesis using pristine and recycled zirconia solvent-based slurry stereolithography, Ceram. Int. 46 (2020) 28701–28709.

[155] S.S. Khanna, P.A. Dhaimade, Green dentistry: a systematic review of ecological dental practices, Environ. Dev. Sustain. 21 (2019) 2599–2618.

[156] P. Eram, S. Shabina, M. Rizwana, N. Rana, Eco dentistry: a new wave of the future dental practice, Ann. Dent. Spec. 5 (2017) 14–17. www.ecodentistry.org.

[157] G.M. Chadha, G. Shenoy Panchmal, R.P. Shenoy, S. Siddique, P. Jodalli, Establishing an eco-friendly dental practice: a review, IJSS Case Rep. Rev. (2015) 11.

[158] H. Rahman, R. Chandra, S. Triphathi, S. Singh, Green dentistry-clean dentistry, Indian J. Restor. Dent. 3 (2014) 56–61. www.jrdindia.org.

[159] Australian Dental Association, Policy statement 6.21- Dentistry and sustainability, ADA Policies (August 21) (2020). https://www.ada.org.au/Professional-Information/Policies/Dental-Practice/6-21-Dentistry-and-Sustainability/ADAPolicies_6-21_DentistryandSustainability_V1.aspx).

[160] A. Chopra, K. Raju, Green dentistry: practices and perceived barriers among dental practitioners of Chandigarh, Panchkula, and Mohali (Tricity), India, J. Indian Assoc. Public Heal. Dent. 15 (2017) 53–56.

[161] M. Choudhary, M. Verma, S. Ghosh, J. Dhillon, Assessment of knowledge and awareness about biomedical waste management among health care personnel in a tertiary care dental facility in Delhi, Indian J. Dent. Res. 31 (2020) 26–30.

[162] Z. Aghalari, A. Amouei, S. Jafarian, Determining the amount, type and management of dental wastes in general and specialized dentistry offices of Northern Iran, J. Mater. Cycles Waste Manag. 22 (2020) 150–158.

[163] J.O. Makanjuola, D.C. Umesi, A.N. Ndukwe, L.L. Enone, O.A. Sotunde, J.O. Omo, P.I. Idon, O. Alalade, G.E. Adebayo, U.I. Ekowmwnhenhen, G.T. Arotiba, Managing the phase-down of amalgam amongst Nigerian dental professionals and students: a national survey, Eur. J. Dent. Educ. (2020).

[164] M.M. Amir Sultan, C.T. Goh, S.E. Wan Puteh, M. Mokhtar, Establishing mercury-free medical facilities: a Malaysian case study, Int. J. Health Care Qual. Assur. 32 (2019) 34–44.

[165] J.B. Ilić-Živojinović, B.B. Ilić, D. Backović, M. Tomanić, A. Gavrilović, L. Bogdanović, Knowledge and attitudes on medical waste management among Belgrade medical and dental students, Srp. Arh. Celok. Lek. 2019 (2019) 281–285.

[166] A.C. De Oliveira Cravo Teixeira, L.R. Borges-Paluch, C.C.B. De Jacobi, Waste diagnosis in public dental facilities in Recôncavo Baiano county: contributions to integrated waste management, Mundo Da Saude 41 (2017) 682–691.

[167] H.G. Shah, M. Parikh, I. Mehta, M. Nair, P. Desai, V. Sodani, Knowledge, attitude and practices of interns, graduates and postgraduate students at private dental colleges in ahmedabad regarding bio medical waste management, J. Adv. Oral Res. 6 (2015) 25–28.

[168] L. Bathala, B. Jupidi, M. Thota, K. Theruru, S. Shaik, S. Rayapati, There's plenty of room at the bottom": the biomedical waste management in dentistry, J. Dr. NTR Univ. Heal. Sci. 3 (2014) 149.

[169] D. Kapoor, A. Nirola, V. Kapoor, R.S. Gambhir, Knowledge and awareness regarding biomedical waste management in dental teaching institutions in India-a systematic review, J. Clin. Exp. Dent. 6 (2014) e419–e424.

[170] M. Hiltz, The environmental impact of dentistry, J. Can. Dent. Assoc. 73 (2007).

[171] F.G. Iano, O. dos Santos Sobrinho, T.L. da Silva, M.A. Pereira, P.J.M. Figueiredo, L.B.A. Alberguini, J.M. Granjeiro, Optimizing the procedure for mercury recovery from dental amalgam, Braz. Oral Res. 22 (2008) 119–124.

[172] C. Zeri, A. Adamopoulou, D. Bojanić Varezić, T. Fortibuoni, M. Kovač Viršek, A. Kržan, M. Mandic, C. Mazziotti, A. Palatinus, M. Peterlin, M. Prvan, F. Ronchi, J. Siljic, P. Tutman, T. Vlachogianni, Floating plastics in adriatic waters (Mediterranean Sea): from the macro- to the micro-scale, Mar. Pollut. Bull. 136 (2018) 341–350.

[173] A. Nesic, M. Gordic, A. Onjia, S. Davidovic, M. Miljkovic, S. Dimitrijevic-Brankovic, Chitosan-triclosan films for potential use as bio-antimicrobial bags in healthcare sector, Mater. Lett. 186 (2017) 368–371.

[174] M. Nasser, Evidence summary: can plastics used in dentistry act as an environmental pollutant? Can we avoid the use of plastics in dental practice? Br. Dent. J. 212 (2012) 89–91.

[175] T. Palosuo, I. Antoniadou, F. Gottrup, P. Phillips, Latex medical gloves: time for a reappraisal, Int. Arch. Allergy Immunol. 156 (2011) 234–246.

[176] N. Sasaki, K. Okuda, T. Kato, H. Kakishima, H. Okuma, K. Abe, H. Tachino, K. Tuchida, K. Kubono, Salivary bisphenol-a levels detected by ELISA after restoration with composite resin, J. Mater. Sci. Mater. Med. 16 (2005) 297–300.

[177] B. Duane, L. Borglin, S. Pekarski, S. Saget, H.F. Duncan, Environmental sustainability in endodontics. a life cycle assessment (LCA) of a root canal treatment procedure, BMC Oral Health 20 (2020).

[178] B. Duane, J. Dixon, G. Ambibola, C. Aldana, J. Couglan, D. Henao, T. Daniela, N. Veiga, N. Martin, J. Darragh, D. Ramasubbu, F. Perez, F. Schwendicke, M. Correia, M. Quinteros, M. Van Harten, C. Paganelli, P. Vos, R.M Lopez, J. Field, Embedding environmental sustainability within the modern dental curriculum- exploring current practice and developing a shared understanding, Eur. J. Dent. Educ. (2021).

[179] M.L. de Leon, Barriers to environmentally sustainable initiatives in oral health care clinical settings, Can. J. Dent. Hyg. 1 (2020) 156–160.

[180] S. Shiyo, J. Nagels, H.G. Shangali, Recycling of plaster of Paris, Afr. J. Disabil. 9 (2020).

[181] L.S. De Bortoli, L.M. Schabbach, M.C. Fredel, D. Hotza, B. Henriques, Ecological footprint of biomaterials for implant dentistry: is the metal-free practice an eco-friendly shift? J. Clean. Prod. 213 (2019) 723–732.

[182] S. Mulligan, G. Kakonyi, K. Moharamzadeh, S.F. Thornton, N. Martin, The environmental impact of dental amalgam and resin-based composite materials, Br. Dent. J. 224 (2018) 542–548.

[183] E. Bakhurji, T. Scott, T. Mangione, W. Sohn, Dentists' perspective about dental amalgam: current use and future direction, J. Public Health Dent. 77 (2017) 207–215.
[184] K. Sadasiva, S. Rayar, U. Manu, K. Senthilkumar, S. Daya, N. Anushaa, Recovery of mercury from dental amalgam scrap-Indian perspective, J. Pharm. Bioallied Sci. 9 (2017). S79–S81.
[185] E.D. Rekow, S.C. Bayne, R.M. Carvalho, J.G. Steele, What constitutes an ideal dental restorative material? Adv. Dent. Res. 25 (2013) 18–23.
[186] S. Bayne, P.E. Petersen, D. Piper, G. Schmalz, D. Meyer, The challenge for innovation in direct restorative materials, Adv. Dent. Res. 25 (2013) 8–17.
[187] F.A. Sawair, Y. Hassoneh, A.O. Jamleh, M. Al-Rabab'Ah, Observance of proper mercury hygiene practices by Jordanian general dental practitioners, Int. J. Occup. Med. Environ. Health 23 (2010) 47–54.
[188] J.L. Drummond, M.D. Cailas, K. Croke, Mercury generation potential from dental waste amalgam, J. Dent. 31 (2003) 493–501.
[189] P. Akkajit, H. Romin, M. Assawadithalerd, I.A. Al-Khatib, Assessment of Knowledge, Attitude, and Practice in respect of Medical Waste Management among Healthcare Workers in Clinics, J. Environ. Public Health 2020 (2020).