Combining evidence-based healthcare with environmental sustainability: using the toothbrush as a model

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Key points

- This is the first study to quantify the environmental impact of electric and manual toothbrushes, including bamboo and replaceable-head manual brushes.
- Dentists and dental care professionals should use the results of this study when recommending toothbrushes to patients.
- The results of this study could be used to inform NHS policy and procurement for dental public health programmes.'

Abstract

Introduction Healthcare professionals should consider environmental sustainability when recommending medical devices to patients, although there is currently little quantitative data available. The toothbrush is a widely recommended healthcare device worldwide. The aim of this study was to compare the sustainability of different types of toothbrush.

Materials and methods Four types of toothbrush were studied: a traditional plastic and electric toothbrush, as well as a plastic manual toothbrush with replaceable heads and a bamboo manual toothbrush. Life cycle assessment (LCA) methodology was applied to quantify the environmental impact of these toothbrushes over five years.

Results The electric toothbrush performed consistently poorly compared to the three manual toothbrush types and had the greatest impact in 15 out of 16 environmental categories. The bamboo and replaceable-head plastic toothbrushes had the lowest impact in all categories. The climate change potential of the electric toothbrush was 11 times greater than the bamboo toothbrush.

Discussion Switching toothbrushes from the traditional toothbrushes to bamboo or replaceable-head plastic is more environmentally sustainable. These results could be used to inform individual consumer choice, oral health recommendations, procurement of toothbrushes for public health programmes and toothbrush manufacturers. LCA methodology can be used to make healthcare more sustainable.

Introduction

Environmental sustainability is a worldwide public health issue.[1] The planet and its global population face a range of challenges, including climate change, reduction in biodiversity, air and water pollution, and ozone depletion. Global healthcare is a significant contributor to national carbon dioxide emissions - and is, on average, responsible for 5% of emissions.[2] In England, the National Health Service (NHS) is responsible for 25% of England's public sector carbon footprint.[3] Established to improve population health, healthcare systems are harming the planet.

As an 'anchor organisation' in the UK, the NHS aims to be a sustainable healthcare system.[4] The NHS Long Term Plan commits to three environmental aims: to reduce air pollution, waste and greenhouse gas emissions.[5] In England, this is driven by the Sustainable Development Unit (SDU), which was established to embed sustainable development at all levels of healthcare.[6] One measure of success is that 'professionals are encouraged to consider sustainability principles when deciding what is right for patients and clients'. For NHS professionals to understand the environmental impact of a product or service, different methods can be used. These range from carbon footprint analysis to more detailed methods which look at wider environmental impacts.

Life cycle assessment (LCA) is used to measure the environmental impact of different services or products.[7,8] Also referred to as a cradle-to-grave analysis, LCA considers all aspects of a product along its life cycle, including raw materials, manufacture, use, transport and disposal. The NHS, along with other healthcare companies, established the Coalition for Sustainable Pharmaceuticals and Medical Devices (CSPM), which recommends LCA to compare services and enable policymakers to make informed recommendations.[9] More recently, the European Union adopted the Product Environment Footprint (PEF) to provide a consistent, standardised, comparable approach to undertaking LCA.[10]

There is currently little evidence or guidance regarding the sustainability of specific healthcare interventions, services or devices. This includes both evidence-based interventions within a healthcare setting (such as a hospital or dental practice) and those

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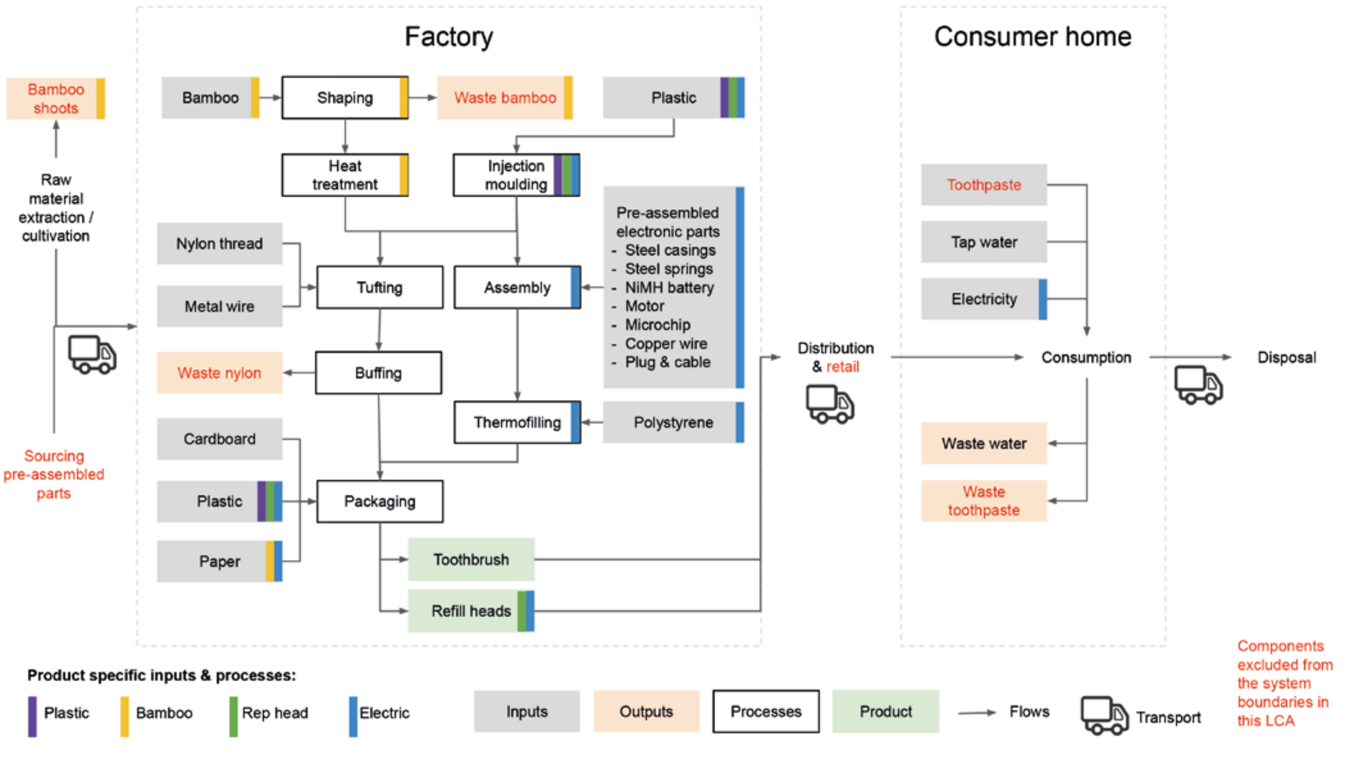


Fig. 1 LCA boundaries

carried out within the home setting. In this paper, we have selected a commonly prescribed intervention (the toothbrush) to explore the impact of this preventative device on the environment. Its efficacy as an intervention to prevent oral disease is well established.[11] There are several different types of toothbrush available in the UK, with different sustainability 'credentials'. Although there is evidence that electric toothbrushes are associated with a greater level of plaque and gingivitis reduction compared to manual toothbrushes, there is no evidence that any type of toothbrush is more clinically effective for the prevention of dental caries and periodontal disease.[12] Therefore, potentially, the environmental impact could be the prime consideration for NHS providers when selecting or recommending a product. The national Scottish oral health programme, Childsmile, has pledged to include sustainability as part of the product specification when procuring toothbrushes.[13]

This paper uses LCA methodology to quantify the environmental impact of perhaps the most used healthcare device worldwide: the toothbrush. The aim was to compare the sustainability of different types of toothbrush and identify which aspects of the life cycle have the greatest environmental impact.

Materials and methods

A comparative LCA of four different types of toothbrushes was undertaken at the Eastman Dental Hospital, London, in partnership with the Dublin Dental University Hospital (Trinity College Dublin, Ireland).

The software OpenLCA v1.8 was used for the LCA, alongside the reference database Ecoinvent v3.5. The LCA methodology was applied in line with ISO standards and PEF guidelines.[8,9,10]

The four types of toothbrush were:

1. Plastic manual: plastic handle with fixed head
2. Bamboo manual: bamboo handle with fixed head
3. Plastic manual with replaceable head: reusable plastic handle (made from a bioplastic) with replaceable heads
4. Electric: handle and charging unit, with replaceable heads.

Four individual products, available in the UK, were selected to represent each type of toothbrush. The specific brands and manufacturers have been anonymised.

An attributional LCA was conducted from cradle to grave, using physical allocation by mass. The functional unit was defined as individual toothbrush use over five years. The time period of five years was chosen as this is the average life span of the battery in an electric toothbrush.[14]

The system boundaries are shown in Figure 1. The entire product system, including geographical location, was compared, as only the bamboo toothbrush was manufactured outside of Europe (bamboo was cultivated and manufactured in China).

Environmental data for raw bamboo, used to form the handle of the bamboo manual toothbrush, was not available. Therefore, inputs from cultivation of raw bamboo in China were estimated by the consultancy firm GreenDelta (GmbH, 2019) and authors (SS and MC). All assumptions made in this study are listed in Table 1.

A life cycle inventory was created for each type of toothbrush. A sample of each product was dismantled to identify and weigh the component materials. Manufacturers were contacted to clarify any materials, manufacturing and packaging process, plus the transport route. The number of products needed over five years was calculated. For machinery not available in the database, the energy consumption (kWh) of the machine was used.

Data from the life cycle inventory was modelled in OpenLCA v1.8 for the life cycle impact assessment (LCIA). The impact categories and LCIA methods are shown in Table 2. The LCIA method for each category was selected based on the PEF Category Rules Guidance.[10]

Results

The life cycle inventory for each product is available in our online supplementary information.

The results of the LCIA are shown in Figure 2. The electric toothbrush had the greatest environmental impact in all categories, except water scarcity. The plastic manual replaceable-head and bamboo manual toothbrushes had the lowest environment impact in 11 and 5 of the impact categories, respectively.

Figure 3 demonstrates how each life cycle stage contributed to the impact assessment. For the bamboo manual toothbrush, the biggest contributing factor was consumer use (the tap water used during brushing). The materials contributed the most in both the manual plastic toothbrush and plastic manual replaceable-head toothbrush. The material polypropylene, used to make the plastic handle, was the single biggest contributing factor in both these toothbrushes (37% and 33%, respectively). The electric toothbrush was

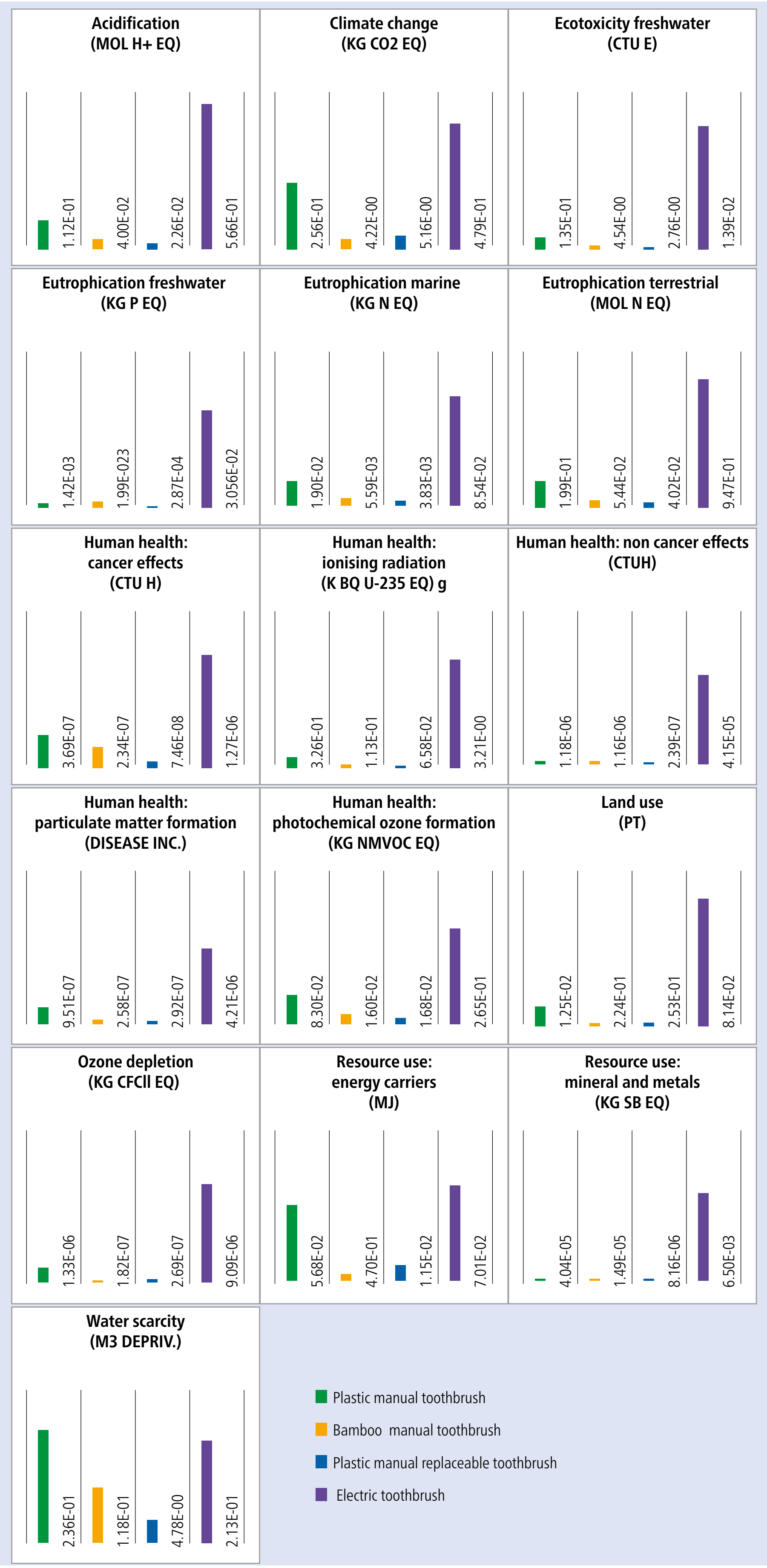
Table 1 Assumptions and exclusions

Area	Assumptions and exclusions
Materials	Any materials weighing <0.01 g were excluded To create the dataset for bamboo, the following assumptions were made about bamboo cultivation: Bamboo shoots produced during cultivation but are not used in toothbrushes were excluded The carbon sequestration was excluded as bamboo is assumed to be recycled back into the environment within 100 years No pesticides were applied[15] Nursery phase and emissions from crop residues were not included Fertilisers were applied once yearly. All fertilisers were from synthetic sources. Direct and indirect field emissions from nitrogen fertilisers, leaching potential and emissions to water from phosphorus fertiliser were based on agricural guidelines[16] The main agricultural values for yearly bamboo cultivation were taken from a report by the International Network for bamboo and Rattan[17] The agricultural machinery used diesel petrol Bamboo was transported via lorry directly to the manufacturer
Manufacture	All waste was recycled back into the manufacturing process Products were manufactured and packaged in one location
Transport	Products are transported directly from the factory location to the company UK headquarters Distances were determined using Google Maps
Consumer use	No toothbrush products were shared between individuals The toothbrush was used twice daily, every day for two minutes[11] The toothbrush, or the replaceable head, was changed every three months[18] The energy required to charge an electric toothbrush was 2.8 kW/year, as advised by the manufacturer For every episode of tooth brushing, 0.6 litres of tap water was used. This volume was estimated by measuring the volume of water used by ten colleagues The impact of toothpaste use was excluded All tap water used during tooth brushing is washed down the mains drain
Disposal	Every product was disposed of according to the manufacturer's instructions

Table 2 Impact categories and LCIA methods used in this study[10]

Impact category (abbreviation)	LCIA method (units)	Description
Acidification (A)	ILCD 2011 Midpoint+ (Mol H+ eq)	Acidification of soils and freshwater due to gas release
Climate change (CC)	IPCC 2013 GWP 100a (kg CO_2 eq)	Potential for global warming from greenhouse gas emissions
Ecotoxicity freshwater (ECF)	ILCD 2011 Midpoint+ (CTUe)	Harmful effects of toxic substances on freshwater organisms
Eutrophication freshwater (EUF)	ILCD 2011 Midpoint+ (kg P eq)	Changes in freshwater organisms and ecosystems caused by excess nutrients
Eutrophication marine (EUM)	ILCD 2011 Midpoint+ (kg N eq)	Changes in marine organisms and ecosystems caused by excess nutrients
Eutrophication terrestrial (EUT)	ILCD 2011 Midpoint+ (mol N eq)	Changes in land organisms from excess nutrients in soil and air
Human health: cancer effects (CE)	ILCD 2011 Midpoint+ (CTUh)	Harm to human health that causes or increases cancer risk
Human health: ionising radiation (IR)	ILCD 2011 Midpoint+ (kBq U^{235} eq)	Potential damage to human DNA from ionising radiation
Human health: non-cancer effects (NCE)	ILCD 2011 Midpoint+ (CTUh)	Harm to human health that is not related to cancer or ionising radiation
Human health: particulate matter formation (PMF)	PM method (disease incidence)	Harm to human health caused by particulate matter emissions (respiratory inorganics)
Human health: photochemical ozone formation (POF)	ILCD 2011 Midpoint+ (kg NMVOC eq)	Harm to human health from gas emissions that contribute to smog in the lower atmosphere
Land use (LU)	Soil quality index based on LANCA (pt)	Depletion of natural resources, change in soil quality and reduction in biodiversity
Ozone depletion (OD)	ILCD 2011 Midpoint+ (kg CFC11 eq)	Air emissions causing stratospheric ozone layer destruction
Resource use: energy carriers (REC)	CML-IA baseline (MJ)	Depletion of natural fossil fuels
Resource use: minerals and metals (RMM)	CML-IA baseline (kg Sb eq)	Depletion of natural non-fossil fuel resources
Water scarcity (WS)	AWARE (m^3 deprivation)	Potential for water deprivation to humans and ecosystems globally

Fig. 2 LCIA results



the heaviest product at 1.42 kg – the greatest contributor to its overall environmental impact was the transport (47%), followed closely by the materials (46%). All other aspects of the electric toothbrush had much less contribution to its overall impact, including the consumer energy use from charging the handle (0.69%) and disposal (0.16%).

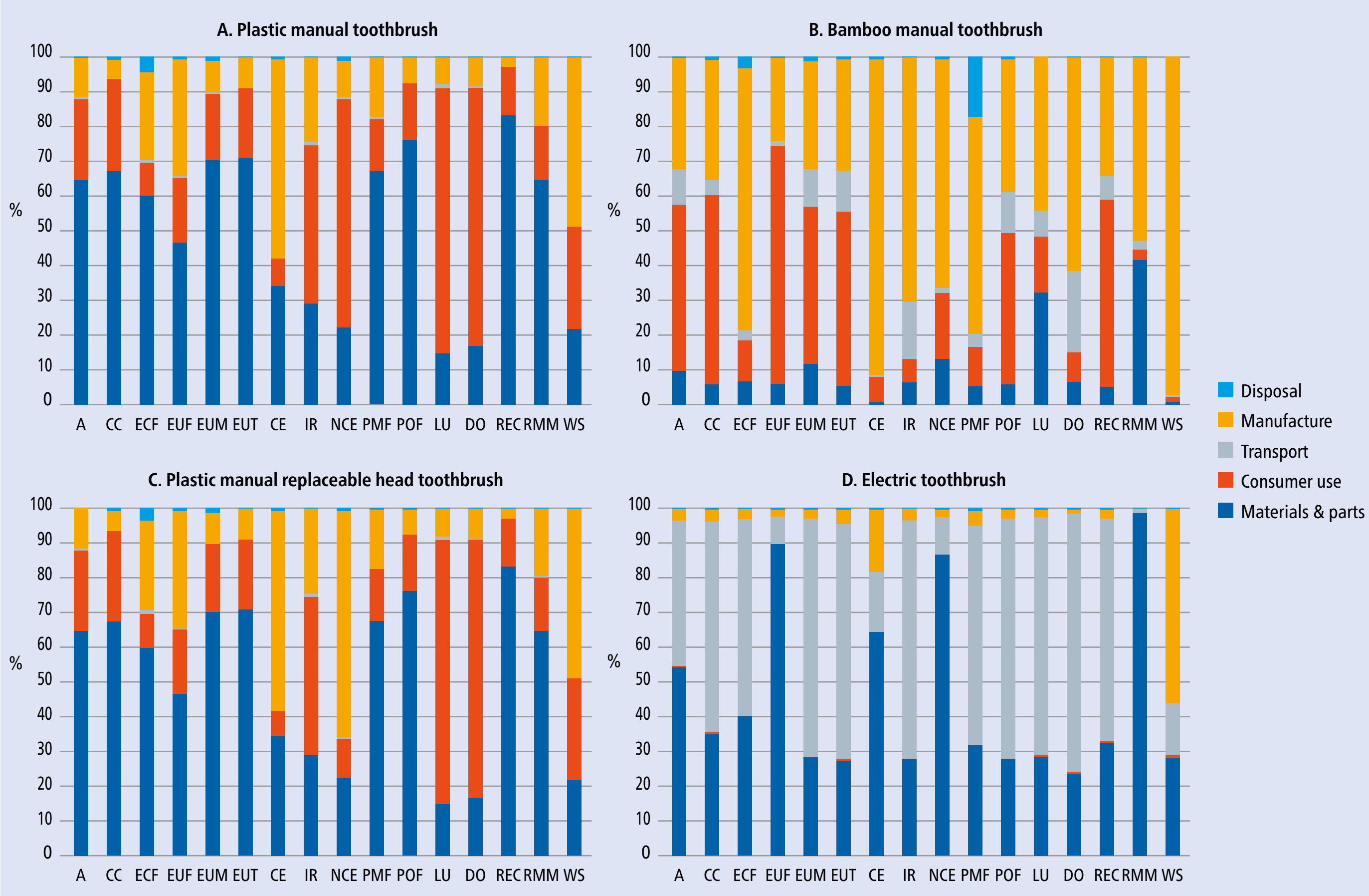
The disposal of the products had the smallest contribution to the environmental impact for all toothbrushes.

Discussion

This study found that both the bamboo manual and plastic manual replaceable-head toothbrushes performed consistently better than the plastic manual and electric toothbrushes, in all impact categories. The sustainability of the electric toothbrush was poor, having the greatest environmental impact in all but one category (water scarcity). The climate change impact of the electric toothbrush was over 11 times greater than the bamboo toothbrush. When considering land use, and the consequential reduction in biodiversity and habitat, the negative impact of the electric toothbrush was over 36 times that of the bamboo toothbrush.

There is increasing public concern about the use of plastics and this alone may be the most important environmental consideration for individual consumers.[19,20] All products in this study used plastic to make the toothbrush bristles (nylon), and all except the bamboo product also used plastic for the toothbrush handles (polypropylene) and as part of the packaging (polyethylene). The bamboo toothbrush used just 11 g of plastic over the five years, the lowest of all products (97% less plastic than the plastic manual toothbrush). The polypropylene in the handle of both the traditional plastic manual and the plastic manual replaceable-head toothbrushes had the greatest contribution to the overall environmental impact. The replaceable heads did use a bioplastic, with 30% of the polymer derived from starch, but the effect of this was unclear and our results suggest that the lower weight of plastic, from only replacing the head and not the handle, had a greater impact. Further research to identify the 'ideal' sustainable toothbrush could investigate the exact impact of switching polypropylene for biopolymers. If the average life expectancy in the UK is 80 years, then an individual using plastic manual toothbrushes over their lifetime

Fig. 3 Contribution analysis for: a) Plastic manual toothbrush. b) Bamboo manual toothbrush. c) Plastic manual replaceable-head toothbrush. d) Electric toothbrush



equates to 6.3 kg of plastic. A decrease in public demand for plastic and electric toothbrushes may in turn encourage manufacturers to use LCA to improve the environmental impact of their products and use more sustainable materials and processes.

There are limitations to using LCA to compare different healthcare products. There is a range of impact categories and allocation methods that can be used, along with different methods for the LCIA, and this can make the results difficult to interpret. Although guidance by the PEF aims to standardise the methodology, it advises that the toxicity-related results are interpreted with caution, as the corresponding three LCIA methods are still in development.[10] However, in this analysis, clear differences between the two manual toothbrushes and the electric toothbrush were seen.

In this study, four individual toothbrush products were selected to represent each type of toothbrush; however, the market is constantly changing. In particular, electric toothbrushes have a wide variability in design, and their features and composition are being continually updated. In this study, the simplest rechargeable electric toothbrush from a market-leading brand was selected, but is not necessarily representative of all electric toothbrushes. Since this study was commenced, new toothbrush materials have come to market, including reusable handles made from aluminium. As the market evolves and manufacturers change their materials, LCA should be repeated and recommendations reviewed.

LCA is usually conducted 'in-house' by the manufacturer, which was not the case in this study. In order to correctly identify all the correct product materials and processes, the authors had to request the relevant data from the manufacturers. Where it was not possible to confirm an exact material or process, or the manufacturer was unwilling to supply the information, assumptions were made by the authors based on industry knowledge. This would have affected the accuracy of the LCA inventory. Ideally, a sensitivity analysis of the most impactful processes and materials would have been carried out, in order to identify what changes in the material and manufacturing processes could be altered to improve the environmental impact of the product. However, this requires in-depth knowledge and data disclosure, and the authors feel that the responsibility to analyse this and make changes accordingly lies with the product manufacturer.

Including a bamboo product was challenging, as there was no available data for this raw material in the reference database. Therefore, the background processes to cultivate bamboo had to be separately modelled by GreenDelta and authors (SS and MC). Several assumptions and exclusions (Table 1) had to be made in order to produce the dataset, and the effect these assumptions had on the results would require further research and sensitivity analysis. However, bamboo cultivation practices can vary widely, altering the environmental impact of using bamboo as a product material. For example, fertilisers are used in less than 5% of industrial bamboo plantations as the fallen bamboo leaves provide sufficient nutrients for new shoots.[17] As a conservative estimate, in this study, we assumed yearly fertiliser application. Ideally, a robust dataset produced with the specific bamboo plantation used by the manufacturer would have been created, but this was beyond the scope of this study. Bamboo cultivation is currently assumed to be carbon-neutral, as bamboo ecosystems are carbon sinks, but an increasing demand for this material may, in future, lead to modifications in the bamboo ecosystem and bamboo cultivation could even become a carbon source.[21] It was confirmed that no glue is used in the manufacture of the bamboo toothbrush (the handle is made from shaping raw bamboo and heat treating the surface to sterilise), as concerns have been raised regarding the melamine resins used in the production of bamboo products, such as reusable cups.[22]

Some of the assumptions made about consumer use and disposal are likely to be unrealistic. Individual use of a toothbrush was based on clinical recommendations[11,18] and informed the number of products needed in five years, as well as the waste water used during tooth brushing. There is no data available on public compliance with these oral health recommendations, although studies of health recommendations, such as physical activity, suggest that public compliance is moderate at best.[23] For the electric toothbrush, it was assumed that the handle is only used by one individual and was disposed of after five years.[14] However, families may share one electric toothbrush handle, and may upgrade the handle and charging unit more often or less often than every five years. There is currently no data available about the sharing habits of electric toothbrush users. This LCA further assumed that individuals would dispose of their products according to manufacturers' recommendations – for the bamboo toothbrush, this includes removing the bristles and metal staples from the bamboo handle. This was undertaken by one of the authors (AL) as part of the product inventory – as it took almost 30 minutes to remove all the bristles and metal staples using tweezers, it was considered that this is unrealistic to expect from consumers. However, the authors felt that using the manufacturers' recommendations was reasonable, given that the disposal processes in the LCIA had little contribution to the overall impact for all the toothbrushes in this study. However, a sensitivity analysis using different disposal scenarios, including bamboo ending up in the ocean, could affect the results and is a topic for further research.

Furthermore, some toothbrush manufacturers have started offering recycling schemes for their products, which could reduce the impact of their materials. However, at the time of this study, the products in this trial were not offering a recycling scheme and the exact procedure used in any recycling scheme should be specifically analysed by the individual manufacturer, in order to ensure that the impact created from the transport and recycling processes doesn't outweigh the benefits of reusing the materials.

Other oral health cleaning aids, such as interdental brushes and floss, will also have an environmental impact and would be subject to a separate life cycle analysis, given their different recommendations and disposal. Research into this is already underway at the authors' institutions (UCL and Trinity College Dublin).

The NHS should recommend healthcare devices that are clinically effective, cost-effective and environmentally sustainable. There is currently no evidence that using an electric toothbrush reduces incidence of dental caries or periodontal disease, even if it is better for reducing plaque levels.[12] For this reason, there is currently no evidence that individuals switching to the more sustainable manual toothbrushes from this study will develop more dental disease, which could in turn increase the environmental impact of providing dental care. However, should new evidence emerge, the clinical benefit of one type of toothbrush should be considered together with sustainability and cost. Electric toothbrushes are more expensive, and less environmentally sustainable, than manual toothbrushes. This should be a strong consideration when recommending toothbrushes to the public. Similar principles should apply to toothbrushes procured by the NHS for public oral health programmes, and based on this study, either bamboo toothbrushes or replaceable-head manual toothbrushes should be considered over traditional plastic and electric toothbrushes. Admittedly, the cost of bamboo and replaceable-head manual toothbrushes, which are usually greater than simple plastic manual toothbrushes, may present a barrier to their widespread use by consumers and by public oral health improvement programmes.

Conclusion

This simple comparative LCA has shown that a plastic manual replaceable-head toothbrush and bamboo manual toothbrush perform better than traditional plastic manual and electric toothbrushes in every environmental impact outcome measure used in this study. These results could be used to inform individual consumer choice, oral health recommendations, procurement of toothbrushes for public health programmes and toothbrush manufacturers. Using LCA to inform healthcare policies and recommendations will help move the NHS towards a more environmentally sustainable system.

Conflict of interest

This study was funded by the Eastman Dental Institute (University College London). The authors declare no conflict of interest.

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Author contributions

AL collected the data and drafted the paper; PA co-initiated the collaborative project, monitored data collection and revised the draft paper; SS and MC refined the bamboo cultivation dataset, monitored data analysis and revised the paper; BU revised the paper; BD co-initiated the collaborative project, carried out all data analysis and revised the paper. All authors give their final approval and agree to be accountable for all aspects of the work.

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