ARTICLE IN PRESS

Contact Lens and Anterior Eye xxx (xxxx) xxx

Contents lists available at ScienceDirect

Contact Lens and Anterior Eye

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

An investigation into disposal and recycling options for daily disposable and monthly replacement soft contact lens modalities

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ARTICLE INFO

Keywords:
Contact lenses
Daily disposable
Monthly reusable
Environment
Recycling

ABSTRACT

Purpose: To examine the annualised waste and end-of-life disposal options with two representative soft contact lens (CL) modalities.

Methods: The component parts of two representative soft CL modalities were catalogued, separated, weighed and inspected for material identification: somofilcon A soft CLs (clariti elite, CooperVision Inc.) used with multi-purpose solution (MPS) (All in one Light, CooperVision Inc.) and somofilcon A CLs (clariti 1 day, CooperVision Inc). Using a model that assumed compliant wear and care of CLs, the mass of material solid waste generated by CL use over a year was calculated. Disposal options were explored using household and specialist recycling streams in order to develop recommendations for responsible disposal of CL waste.

Results: Full-time daily disposable (DD) CL wear generates 1.06 kg of waste annually compared to 0.83 kg generated by reusable-monthly replacement daily wear ('reusable') CLs. Plastic was the dominant material in both modalities. With full-time use of DD CLs, 64% of waste by mass was plastic blister trays. For full-time use of reusable CLs, where figures from lens and MPS packaging are combined, plastics accounted for 67% of waste by mass. MPS bottles alone made up almost half the waste (45%) associated with full-time reusable CL wear.

Conclusion: Full-time DD wear generates 27% more waste annually than full-time reusable lens wear. Reusable CL wearers can recycle 78% of waste at home. DD lens wearers have access to recycling options that allow them to recycle 100% of CL related waste. Full-time CL lens wear represents just 0.20–0.26% of the 412 kg of household waste generated per person, per year in the United Kingdom. Worn CLs should never be disposed of down the sink or lavatory. CL wearers should be aware of responsible end-of-life recycling and disposal options for all CL waste.

1. Introduction

The increased awareness of environmental sustainability and reliance on disposable plastics raise some important questions for eye care professionals (ECPs) with regard to the environmentally responsible options for the disposal of soft contact lenses (CLs) and associated packaging. This issue is perhaps most pertinent to single-use, daily disposable (DD) soft contact lenses which were introduced in the mid 1990s, and which have transformed the contact lens market worldwide, providing a relatively safe [1] and convenient form of contact lens wear to millions worldwide [2].

Across all industries, it is estimated that 8300 million tons of virgin plastics have been produced to date. It is suggested that 60% (4900 million tons) have been discarded and are accumulating in landfill or the natural environment. If current production and waste management trends continue, roughly 12,000 million metric tons of plastic waste will be in landfills or in the natural environment by 2050 [3].

The 2017 British Broadcasting Corporation documentary Blue Planet II brought the effects of plastic pollution on the marine environment to a wider public audience. Single use and disposable plastic items such as plastic bags, straws and cutlery were identified as a substantial source of plastic marine pollution [4].

Focus fell on CL wearers when a 2018 conference report and subsequent paper [5] reported that 21% of CL wearers in the United States (US) were flushing their lenses down the sink or lavatory. They estimated that in the US alone this amounted to about 20–23 tonnes of

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https://doi.org/10.1016/j.clae.2021.03.002
Received 7 December 2020; Received in revised form 17 February 2021; Accepted 7 March 2021

waste water-borne plastics annually and the work made headlines around the world [6–8]. Against this backdrop, anecdotal reports to ECPs indicated that some CL wearers were beginning to question the relative benefits of the convenience of DD lenses against the perceived environmental impact of increased waste.

The CL industry had already taken steps toward end-of-life options for contact lenses. In 2016 the first recycling program for contact lenses and their packaging was launched in the United States [9]. Similar schemes launched in selected European markets, including the United Kingdom (UK) in 2019 [10,11]. Through a network of locations, many of which are situated within optometry practices, individuals can drop-off contact lenses and blister packaging into a designated recycling box.

Promoting recycling has become a key priority in the UK and the European Union (EU). The EU intends to increase the amount of packaging waste that is recovered and recycled. Among the targets to be achieved by 2030 are a recycling rate of 85% for paper and 55% for plastic [12]. The UK government has an ambition of zero avoidable waste by 2050 and eliminating avoidable plastic waste, where practicable, at each stage of the product life cycle by 2042 [13].

Despite public engagement and new legislative targets on waste, only one paper has been published in the literature on the subject of CL waste [14]. This 2003 study illustrated the environmental impact of waste generated through CL use but there was no investigation in that paper as to end-of-life disposal.

This new study takes some of the original methodology from the work of Morgan et al [14] and proceeds to investigate disposal options. The aim was to quantify the amount of waste generated by a year of full-time and part-time soft CL wear, to identify the type of waste generated and to report on responsible disposal. The results of this study should be relevant to ECPs, consumers and the wider CL industry.

2. Method

The products selected for this project were taken to be representative of soft CL modalities commonly prescribed in the UK [15]. Using typical pack sizes available to consumers, the component parts of two representative soft CL replacement modalities, reusable-monthly replacement daily wear ("reusable") and DD, were catalogued, separated and weighed.

All products required to wear and care for the two modalities of CLs were included. The reusable system consisted of the packaging and contents of a retail pack of three −3.00DS reusable somofilcon A soft CLs (clariti elite, CooperVision Inc.) along with a retail pack of MPS (All in one Light, CooperVision Inc.) containing three 250mL bottles and three cases. The DD system consisted of a retail pack of thirty −3.00DS DD somofilcon A CLs (clariti 1 day, CooperVision inc).

Packaging was disassembled and materials separated. Once categorised, the components were weighed using an analytical balance (Mettler B154, Metttler-Toledo Ltd, Leicester) accurate to 10^{-4} g.

In this study, foils were detached from the blister packaging in order to weigh the individual components. When using specialist recycling schemes, it is not necessary to detach the foil completely [16]. However, blister packaging must be open and any liquid drained before depositing.

CL blister packaging was rinsed with water then air dried before weighing to eliminate residual salts forming. Lenses were inspected then dehydrated in an oven (UNB 100, Memmert GmbH + Co.KG, Germany) at 50 °C over 12 h before being weighed.

Packaging and contents were inspected for material identification and disposal advice. This included looking for the Mobius Loop symbol [17]. The appearance of the symbol indicates that packaging can be recycled, but it does not mean that packaging will be universally accepted in all recycling collection systems [18] and consumers should aware of local restrictions.

Identification of plastic within the samples was done where possible using the resin identification code (RIC) which was developed to facilitate recycling of post-consumer plastics. The RIC typically appears as chasing arrows that cycle clockwise to form a triangle enclosing a number which indicates the form of plastic used. At present, seven types of plastics are commonly identified with the following RIC: (1) polyethylene terephthalate (PET), (2) high-density polyethylene (HDPE), (3) polyvinyl chloride (PVC), (4) low-density polyethylene (LDPE), (5) polypropylene (PP), (6) polystyrene (PS), and (7) 'other', which is primarily polycarbonate (PC) Once materials were identified, the disposal options available to residents of Greater Manchester (population 2.8 million [19]) were considered which included household recycling [20] and use of a free CL recycling scheme [21] available at drop-off locations within eye-care practices.

Masses of components within the sample were recorded, and then the data were multiplied to calculate the annualised waste that full-time CL use could generate. To do this, certain reasonable assumptions were made: lenses were worn bilaterally and wearers were compliant. DD lenses were worn 360 days per year on a single use, daily wear basis. Reusable lenses were worn on a daily wear basis with lenses and cases replaced each calendar month. It was nominally assumed that a bottle of 250 mL MPS would be used each month. This is consistent with the number of bottles typically supplied to CL wearers on subscription schemes widely used by practices in the UK. Using these assumptions, values for dry material waste for DD CL wearers were calculated based on 24 packs, each pack containing 30 CLs. For reusable wearers, dry waste was calculated based on eight retail packs, each pack containing three lenses. Additionally, four retail packs of MPS (each containing instructions for use), three empty MPS bottles and three CL cases were included.

It was possible to create an additional model for CL waste generated by part-time CL wear. For part-time use of reusable CLs, it was assumed that CLs (including blister trays, lens foils and associated packaging) and CL cases were replaced monthly. The waste produced annually by those components is fixed regardless of days per week of lens wear. In the full-time model, it was assumed that a single bottle of MPS was used each month; part-time wear requires only a proportion of this. It was assumed that MPS bottles and contents were discarded three months after opening as instructed on the packaging within this sample. Within this model, a minimum of one MPS bottle was to be used every three months, and the model did not allow the theoretical usage of MPS to fall below this. Exterior cardboard packaging from the MPS pack and the patient information leaflet were linked to the rate of use of the MPS bottles. For infrequent CL wear, this model assumes that CLs cases continue to be changed monthly, and therefore with greater frequency than MPS solution bottles. Cardboard packaging that would normally be associated with purchasing additional CL cases as a standalone item have not been included in this model.

The model for part-time wear of DD CLs is more straightforward. The mass of waste generated by part-time DD CL use is directly proportional to days per week of CL wear.

Further analysis of the dry material waste associated with full-time wear of both modalities was investigated to understand how the waste generated could be responsibly disposed of.

Data capture and analysis was done using Excel v16.43 (Microsoft, Washington, USA) and charts were produced with Prism v9.0.0 (GraphPad, California, USA).

The University of Manchester Ethics Decision Tool confirmed that ethical approval by The University of Manchester was not required for this research.

3. Results

The masses of materials and disposal options for items within the two representative modalities are shown in Table 1.

Paper and cardboard were used for external packaging and patient information leaflets. All exterior cardboard packaging carried the Mobius Loop symbol [17].

Table 1
Description of the items within the audit included for analysis, the material composition, suggested disposal route and mass. Household recycling should be used where available; specialist recycling indicates use of a drop-off location.

Modality	Description	Material	Disposal route	Mass (g)
Daily disposable (pack of 30 lenses)	External packaging	Cardboard	Household recycling	8.62
	Contact lenses	somofilcon A	Specialist recycling	0.41
	Foils	Laminate	Specialist recycling	6.77
	Blister trays	PP	Specialist recycling	28.46
Monthly reusable (pack of 3 lenses)	External packaging	Cardboard	Household recycling	4.61
	Contact lenses	somofilcon A	Specialist recycling	0.04
	Blister trays	PP	Specialist recycling	2.88
	Foils	Laminate	Specialist recycling	0.68
MPS	External packaging	Cardboard	Household recycling	54.17
(3 month pack)	Patient leaflet	Paper	Household recycling	5.42
	MPS bottles	HDPE	Household recycling	93.76
	MPS lids	HDPE	Household waste	6.09
	MPS tamper evident rings	HDPE	Household waste	0.75
	MPS stoppers	LDPE	Household waste	3.25
	Contact lens cases	HDPE	Household waste	28.80

Within this sample, five types of plastic were identified. RIC assisted in identifying the CL blister trays as PP (RIC 5). MPS bottles and the base of CL cases were HDPE (RIC 2). MPS bottle lids, tamper-evident rings, bottle stoppers and lids of CL cases, did not carry the RIC and would not be identifiable to the consumer. For the purposes of this audit, an industry source was able to confirm that MPS lids and tamper evident rings were HDPE, bottle stoppers were LDPE [22]. The CLs were somofilcon A, a silicone hydrogel plastic.

Commonly referred to as 'foils' by the CL industry and ECPs, the material which seals a lens blister is actually a laminate material, formed of layers of aluminium and plastic [23,24]. There were no recycling or material identification codes on the foils. An industry contact confirmed the material composition of the foils in this audit to be a polymer laminate including polyethylene plastic and a significant aluminium content [25].

Referring to local authority guidance for recycling, paper, cardboard and plastic bottles from the sample were included in household recycling figures. Lens blister packs, foils and CLs were included in recyclable waste figures using the specialist CL recycling scheme.

Other items including bottle lids and CL cases are not accepted for recycling; responsible disposal of these items was considered to be using household waste bins.

Calculated figures for annualised waste are shown Table 2. The data indicate that full-time DD CL wear generates 27% more dry waste annually than reusable CL wear (1.06 kg and 0.83 kg respectively).

Annualised waste based on days per week of CL wear is shown in Fig. 1. This figure shows the relationship between the numbers of days of wear per week and the waste generated annually. DD CL wear generates less waste than reusable lenses when CLs are worn one or two days per week. Waste generated is similar if lenses are worn three days per week (455 g for DD lenses and 443 g for reusable lenses). Wearing CLs four to seven days per week, DD CLs generate more waste than monthly reusable lens wear.

The composition of waste generated when CLs are worn full-time differed between modalities. Within the DD modality, the most prevalent dry material was PP plastic from the blister packs, which constituted 64% of waste by mass. For the reusable lens system, where figures from lens packaging and care products are combined, the most prevalent dry material was also plastic, at 67%. MPS bottles alone accounted for almost half the waste (45%) associated with full-time use of reusable CLs.

The mix of materials within each sample, and how materials are used (shape and form), has an effect on the proportion of waste that can be recycled. For wearers of DD lenses only cardboard can be recycled at home, which accounts for 19% of total waste. Of CL waste generated by full-time wear of reusable lenses, 78% consists of cardboard and plastic bottles that can be recycled at home.

Table 2
Annualised mass of waste from both occasional wear (one day per week) and full-time wear of two contact lens replacement modalities and associated care systems. Figures in brackets represent the percentage of total waste. For materials and disposal options see Table 1.

Modality	Description	Replacement interval	Annual waste			
			One day per week		Full-time wear	
			Mass (g)		Mass (g)	
Daily disposable	External packaging	When necessary	29.54	(19)	206.78	(19)
	Contact lenses	Daily	1.41	(1)	9.89	(1)
	Foils	Daily	23.20	(15)	162.43	(15)
	Blister trays	Daily	97.57	(64)	682.96	(64)
TOTAL			**151.72**	**(100)**	**1062.06**	**(100)**
Monthly reusable	External packaging	3–9 months	18.43	(5)	36.86	(4)
	Contact lenses	Monthly	0.33	(0)	0.33	(0)
	Blister trays	Monthly	23.05	(6)	23.05	(3)
	Foils	Monthly	5.40	(1)	5.40	(1)
MPS pack	External packaging	3–9 months	72.22	(19)	216.67	(26)
	Patient leaflet	3–9 months	7.24	(2)	21.70	(3)
	Contact lens cases	Monthly	115.19	(30)	115.19	(14)
	MPS bottles	1–3 months	125.02	(33)	375.05	(45)
	MPS lids	1–3 months	8.12	(2)	24.37	(3)
	MPS tamper evident rings	1–3 months	1.00	(0)	2.99	(0)
	MPS stoppers	1–3 months	4.33	(1)	13.00	(2)
TOTAL			**380.32**	**(100)**	**834.59**	**(100)**

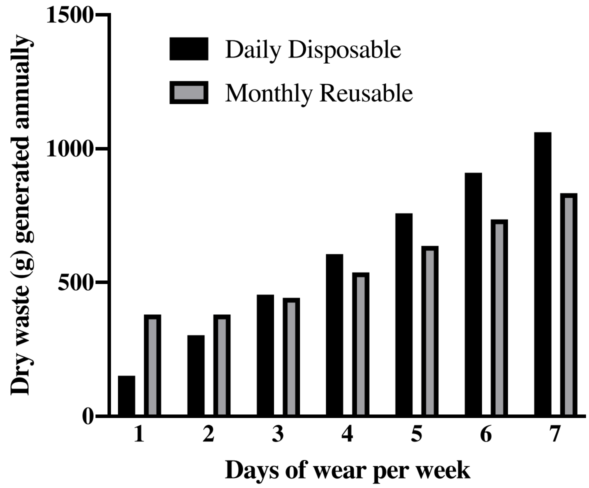

Fig. 1. Annualised waste based on days of wear per week. For DD CL wear, increased use leads to increased waste with a linear relationship. For monthly CL wear there is a similar linear relationship between use and waste, but for infrequent use (1–2 days per week) the waste is dominated by a constant component from MPS bottles, which are assumed to be replaced after three months regardless of whether they are empty.

When recycling rates are considered using household recycling in conjunction with a specialist scheme for CL recycling, 100% of DD waste can be recycled, compared to 81% of waste from a reusable lens system (Fig. 2). The limiting factor with a reusable modality is that the tamper evident rings, bottle lids, bottle stoppers and CL cases are not accepted for household recycling in Greater Manchester or via the specialist recycling scheme included in this study. This would result in 156 g of CL associated waste going into waste bins annually for an individual full-time reusable CL wearer.

4. Discussion

Although the action of discarding a DD CL after a single use may feel wasteful, this study indicates that full-time DD wear generates just 27% more waste annually than full-time reusable lens wear.

Waste from households in the UK, before recycling, amounted to 22.8 million tonnes in 2016, equivalent to 412 kg per person [26,27]. As such, for a typical individual the additional waste associated with CL use would constitute a 0.20–0.26% increase to this total.

Over 75% of waste associated with monthly reusable CL wear can be recycled at home, compared to almost 20% for DD lens wear. DD lens wearers should be aware that 100% of lens waste can be recycled by using both household collection and partnership schemes. This is a potentially powerful and simple message that ECPs can promote to DD lens wearers.

Reusable CL wear produces some currently non-recyclable waste which accounts for 19% of total waste, including CL cases, bottle tops, bottle stoppers and tamper evident rings. This small proportion is destined for household waste bins.

Recycling plays an important role in waste management, but consideration should be given to the reduction of waste in the first instance [28]. The mass of dry waste in both the modalities tested here were lower than the products tested by Morgan et al [14] in 2003. The lens brands and solutions used were not matched between studies but the representative DD and reusable modalities weighed 23% and 28% less respectively than those used in the 2003 study, probably due to efforts by contact lens manufacturers to reduce waste over the past two decades (Fig. 3).

The model used in the calculations assumed a proactive and informed approach to recycling within the Greater Manchester region to deliver the best possible result for recycling figures. However, there are systematic challenges to post-consumer recycling and these are not limited to CLs. There are many common household products for which it can be difficult for the end user to accurately determine the most appropriate disposal route. In a survey of UK households, almost two thirds (66%) expressed uncertainty over what could be put in the recycling bin. Over three quarters (76%) add one or more items into their recycling that are not accepted and over half (53%) of UK households dispose of one or more items that are collected for recycling [27].

Restrictions as to what plastics are accepted for household recycling

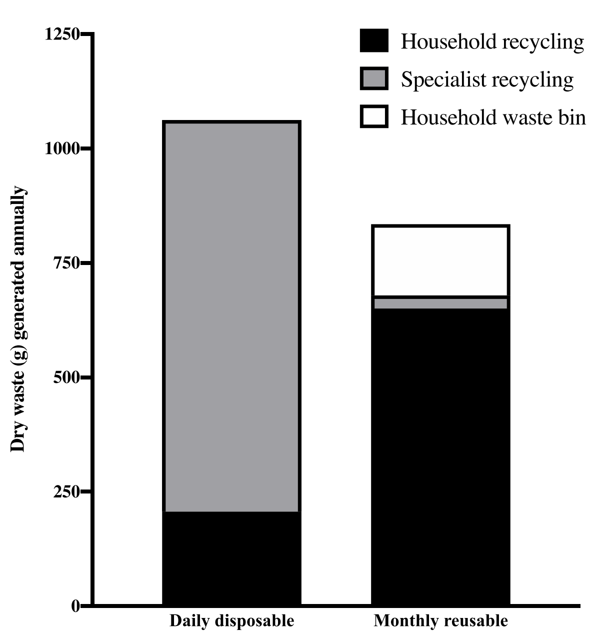

Fig. 2. Mass of dry waste for two representative CL modalities, separated into components that can be recycled through household recycling schemes, can be recycled if deposited at a specialist outlet (e.g. participating optometry practice), or must be discarded with standard household waste.

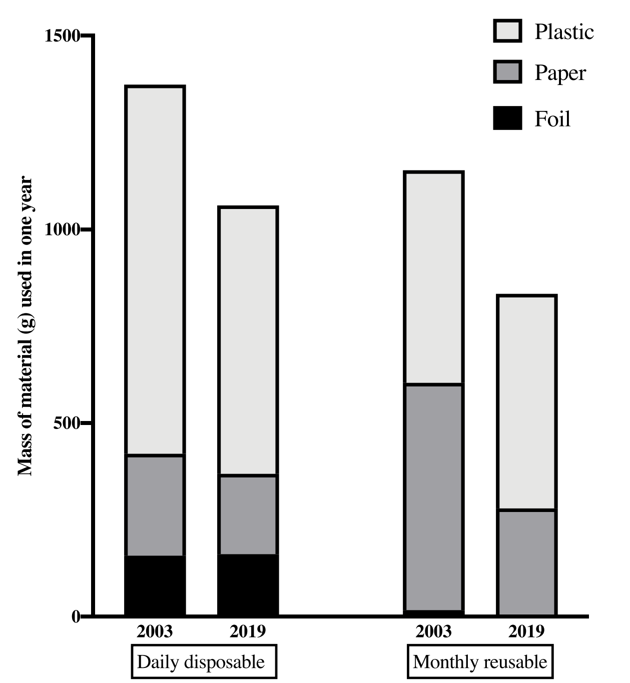

Fig. 3. Annualised waste generated by two representative replacement modalities comparing products from this study (2019) and those from Morgan et al [14] (2003).

may be geographical, political, or based on size and the market value of the recovered material [29–31]. Within Greater Manchester, the only plastics currently accepted for household recycling are plastic bottles. The presence of an RIC on a plastic product does not necessarily indicate that it is accepted locally for recycling, or that its absence means the object is not recyclable. It is reasonable to suggest that items such as CL blister packs and CL cases which are marked with an RIC may be erroneously placed in household recycling by well-meaning consumers. Lens foils, which contain a proportion of aluminium but are actually a laminate material, are not accepted for household recycling. Environmentally, the recovery and recycling of aluminium, as well as reducing the demand for virgin materials, can save considerable energy [32]. Foil (e.g. household foil, aluminium trays) is accepted in Greater Manchester household recycling but care must be taken to avoid confusion with metallised plastic films e.g. crisp packets or laminate materials such as coffee pouches, toothpaste tubes and CL foils.

Although the individual components of laminates and metallised films are technically recyclable [33], the difficulty in sorting and separating the material is economically prohibitive [34] and industrial processes for recycling laminated packaging are not yet broadly available [32]. The small size of lens foils and incomplete separation from the blister can also create problems depending on the local recycling capabilities.

There are regulatory requirements for labelling of all medical devices [35,36] and labels in this sample were compliant with the regulatory requirements relevant to the UK [37]. Within this sample, there was no advice regarding disposal of products. Given a global supply chain and the variation across countries and regions regarding waste disposal, providing universal advice regarding disposal is a challenge, but it does suggest that ECPs and their support staff could play a key role in informing their patients about recycling options available locally for CL, care products and packaging.

An advantage of a specialist scheme for recycling CL waste, is that where there may be ambiguity or local variation as to items accepted for household recycling, CL wearers can be advised that lens foils and blister trays are universally accepted within the specialist scheme. Soft CL wearers in the UK can choose to collect worn contact lenses, blister trays and foils and drop them off at one of the many public CL recycling collection points. These collection points are typically and conveniently situated within participating optometry practices. In addition, small desktop collection boxes can be added to consulting rooms, enabling ECPs to promote and educate CL wearers on responsible disposal at the time of CL aftercare or CL fitting. All CL wearers should understand that worn CLs should never enter a water system and CLs should never be disposed of down the sink or lavatory.

A limitation of this study is that assumptions were made to calculate annual usage of products and actual use may vary by patient depending on wearing pattern and compliance to lens wear and care.

Wearing pattern is particularly relevant with respect to DD lens wearers. A significant proportion of DD lens wearers wear CLs on a part-time basis. It is not uncommon for DD lens wearers to use lenses just two days per week [38]. For these part-time wearers, in addition to the established benefits of ease of use and cost effectiveness of DD CLs [39], annual waste produced by wearing DD CLs two days per week is only 303 g, or 20% less than equivalent wear with a monthly reusable CL (380 g).

For reusable lens wearers, this model assumed that CL cases were replaced monthly regardless of days per week of wear. There is limited clinical evidence regarding the optimal interval for CL case replacement [40] with a suggestion that CL cases are replaced with each MPS bottle [41]. In that case, annual waste would, in some situations, be slightly less than is reported here. There is a second scheme for CL recycling, not included in this model, which is supported directly by Terracycle and does accept CL cases [16]. These collection boxes must be purchased, but are free at the point of use. Where available, the option to recycle CL cases would increase the recycling figures for reusable lens wearers.

This study only investigated end-of-life disposal of dry waste associated with CL use. The full environmental footprint of a product is more complex. Life cycle assessment is not a legislative requirement [42], but consideration of this cycle allows manufacturers to think carefully about the life cycle stages that can be controlled or influenced and to prevent or reduce high-risk environmental impacts at each stage: raw materials, product design and packaging, production, transportation, use, and end-of-life disposal [43–46]. Life cycle assessment can improve resource efficiency, reduce waste, conserve energy and reduce the overall carbon footprint. The CL industry is already working towards greater sustainability across all areas of the product life cycle with initiatives from all the major CL manufacturers [47–50]. Manufacturing sites are increasingly powered in part or entirely from renewable sources. Manufacturing processes have been re-engineered to reduce consumption of raw materials. Recycling rates of post industrial waste within the industry are typically greater than 90% [47,48]. Recycling of post industrial waste is advantageous as it typically has a known composition, often from a single source, and is uncontaminated [51]. These changes, although not visible to the end user, have the potential to substantially reduce the overall carbon footprint associated with CL wear.

An understanding of the entire product life cycle is helpful, for example, when considering the role of liquids. As only dry materials are included in recycling or household waste streams, liquids from blister packing solution and MPS were excluded from analysis in this study. The full-time annualised totals of wet and dry materials from this audit are 1.9 kg for DD wearers and 3.9 kg for reusable lens wearers. The additional mass associated with reusable lens wear, primarily driven by MPS, inevitably impacts on the environmental footprint associated with manufacture, distribution and delivery to the end user.

The needs of the patient have to be carefully considered when prescribing CLs, and these may be both clinical and non-clinical. The perceived financial cost remains a barrier to the prescribing of DDs [52], although ECPs are more familiar with managing financial expectations and have tools to have these conversations [39]. Anecdotal reports from ECPs are that an increasing number of patients are factoring in the perceived environmental cost of DD CLs when making lens choices and ECPs should be equipped to offer some context to their views.

Reducing CL waste, as with many other consumer products, will ultimately involve collaborative efforts including manufacturing innovation, product design and behavioural change from consumers [53,54].

5. Conclusion

The total waste generated by an individual CL wearer is relatively low, and the proportion of lens waste generated by full-time wear accounts for only a tiny fraction of annual household waste. Annual waste generated by full-time DD lens wear is not, in an environmental context, significantly different to reusable lens wear. DD lens wearers in the UK have access to recycling options that allow them to recycle 100% of waste.

Patients and ECPs who are environmentally conscious may be reassured by the findings from this work that the majority of CL waste, if not all, can be recycled. ECPs have an opportunity to promote and share with patients the local recycling options available to them including the simple steps that can divert tonnes of CL waste away from the global marine and natural environment each year.

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