ARTICLE

Quantifying the reduction in economic and environmental waste from multiuse phacoemulsification tubing/cassettes and diamond blades

Stephanie P. Chen, MD, Gitanjali B. Baveja, MD, David F. Chang, MD

Purpose: To quantify and compare the cost, waste, and carbon emissions of single-use and reusable phacoemulsification tubing/cassettes and knives.

Setting: Private, single-specialty ambulatory surgery center (Mountain View, California).

Design: Retrospective data review.

Methods: The cost, waste, and carbon emissions from using an approved multiuse tubing/cassette system from July 1, 2024, through June 30, 2025, were estimated and compared with those generated by single-use tubing/cassettes with the same phacoemulsification machine (part 1). In part 2, the cost, waste, and carbon emissions from reusable diamond knives were estimated and compared with those from using single-use metal knives for the equivalent number of cataract and other intraocular lens (IOL)–related surgeries over a 10-year period. Life cycle equivalent analysis was performed to determine the carbon footprint of each component.

Results: For 2700 cataract and IOL-related surgeries performed during 1 year, reusable cassette/tubing packs reduced cost by 66.7% ($121 500 for single-use vs $40 500 for multiuse). For every 1000 procedures, the reusable pack would save 322.8 kg of plastic waste and 938.3 kgCO_2eq, equivalent to driving a car 2283 miles (3674 km). Over 10 years, 50 100 procedures were performed at our center. For every 1000 procedures, using diamond knives was estimated to save $18 300 (keratomes) and $12 130 (paracentesis blades) compared with disposable metal alternatives, as well as reducing plastic waste and carbon emissions by more than 99%.

Conclusions: Cost, waste, and carbon emissions are considerably reduced by reusable phacoemulsification products, such as diamond surgical knives and multiuse phacoemulsification tubing/cassettes. This provides a major opportunity to improve the sustainability of cataract surgery.

J Cataract Refract Surg 2026; 52:124–130 Copyright © 2025 Published by Wolters Kluwer on behalf of ASCRS and ESCRS

An estimated 4.4% of total greenhouse gas emissions globally is attributed to the healthcare sector; this increases to nearly 10% of greenhouse gas emissions in the United States (U.S.).[1,2] Most of this carbon footprint comes from the manufacture, use, and disposal of supplies, especially from operating rooms (ORs).[2] As one of the highest volume procedures performed annually at more than 4 million in the U.S. and nearly 30 million worldwide, cataract surgery is a leading driver of OR waste. In a 2020 North American survey of more than 1300 cataract surgeons, an overwhelming majority (92%) agreed that the waste generated from cataract surgery was excessive.[3] Similar attitudes were expressed when the survey was repeated among European surgeons in 2023.[4] This underscores the global imperative facing ophthalmologists to reduce unnecessary surgical waste and its associated financial and environmental impact.[5]

Plastic waste, in particular, is nonbiodegradable and poses a uniquely significant threat to the environment given its ubiquity in daily life. Over time, plastic materials degrade into progressively smaller particles, known as microplastics and nanoplastics (MNPs). Direct and indirect impacts on human health can occur in the form of ingesting MNPs, inhaling toxic fumes from the burning of plastic waste for disposal, water flow blockage, and infectious disease transmission. Exposure to MNPs is believed to have wide-ranging effects on the body and various organ systems through inflammation, immune dysfunction, altered metabolism, impaired cell development, and carcinogenicity.[6,7] Worldwide, around 30% of healthcare waste generated is plastic, and the U.S. healthcare system is estimated to contribute more than 1.7 million tons of plastic waste annually.[8]

Submitted: August 7, 2025 | Final revision submitted: August 27, 2025 | Accepted: September 2, 2025

From the Altos Eye Physicians, Los Altos, California (Chen, Chang); Vision Innovation Partners, McLean, Virginia (Baveja); San Francisco Veterans Affairs Healthcare System, San Francisco, California (Chen).

Corresponding author: David F. Chang, MD, Altos Eye Physicians, 762 Altos Oaks Drive, Los Altos, CA 94024. Email: dceye@earthlink.net.

0886-3350/$ - see frontmatter
https://doi.org/10.1097/j.jcrs.0000000000001784

In the U.S., most cataract surgical supplies are labeled for single use, and current regulations do not allow surgeons to reuse them off-label.[9] Transitioning to multiuse products and devices presents a practical and meaningful way to reduce the considerable waste and economic burden of cataract surgery. Potentially reusable items needed for every case include surgical knives and the phacoemulsification tubing and cassette. For instance, diamond keratomes and paracentesis knives are specifically designed to be repeatedly cleaned and autoclaved for reusability. In the U.S., multiuse phacoemulsification tubing and cassettes that are processed and resterilized in-between uses were previously more common but are now only approved for a single phacoemulsification platform, the Compact Intuitiv (Johnson & Johnson Vision). Some phacoemulsification machines provide the option of day cassettes, which allow continuous, sequential, same-day reuse without removing, autoclaving, or replacing the cassette each time. Although phacoemulsification day cassette options are available in more than 60 countries, none are commercially available in the U.S. at this time.

Studies assessing the cost, waste, and carbon footprint reduction that can be achieved by switching from specific, single-use phacoemulsification products to reusable alternatives are limited. Surgeons at our single-specialty ambulatory surgery center (ASC) use both diamond surgical blades and the Compact Intuitiv's reusable phacoemulsification tubing/cassette. To analyze the potential benefits of adopting these approved reusable options currently available to U.S. surgeons, we compared the cost, waste, and carbon emissions attributed to the reusable products against those of their single-use counterparts. Cost and surgical volume for phacoemulsification tubing/cassettes were assessed over a 1-year period, while diamond blades data were evaluated over a 10-year period.

METHODS

Part 1: Single-Use vs Reusable Phacoemulsification Tubing/Cassette Analysis

Before 2024, our multisurgeon, ophthalmology-only ASC (Peninsula Eye Surgery Center, Mountain View, CA) was exclusively using the Whitestar Signature Pro (Johnson & Johnson Vision) phacoemulsification machine. Each of the 2 ORs had this machine, which uses single-use tubing/cassettes as the only option. In June of 2024, our ASC purchased 2 Compact Intuitiv phacoemulsification machines (Johnson & Johnson Vision) to provide the option of a second machine in each OR. The Compact Intuitiv offers the option of either a single-use tubing/cassette or a multiuse system that is approved for reprocessing and sterilization for up to 20 times. By July 1, 2024, the 2 highest volume surgeons at our ASC—including one of the authors (D.F.C.) and both from the same practice—had transitioned to using the Compact Intuitiv routinely, while remaining surgeons at the ASC continued to use the Signature Pro machine. The same phacoemulsification handpieces and settings can be used on both Johnson & Johnson Vision phacoemulsification machine models.

At the conclusion of each same-day case, the reusable Compact Intuitiv phacoemusification tubing and cassette was processed in adherence with the manufacturer's instructions-for-use (IFU). The tubing was flushed using a quick rinse system, consisting of 2 cycles of a 15-second sterile water rinse (equivalent to 120 mL) followed by a 15-second air blast. The tubing was then wiped down with a wet 4 × 4 gauze pad before being placed in the cataract instrument tray along with the cassette. For sequential same-day surgeries, the unwrapped instrument trays were sterilized with a short steam sterilization cycle using the STAT*IM* tabletop autoclave system (SciCan Ltd.). At the end of the surgical day, the reusable tubing/cassettes were cleaned in the same way, air dried, and then placed in peel packs for terminal sterilization and overnight storage. A tracking system was used so that the multiuse tubing/cassettes were discarded after 20 cases. A new bottle of balanced salt irrigation solution was used for each case.

Because the actual negotiated pricing of phacoemulsification cassette products for our ASC is confidential, we used the manufacturer suggested baseline pricing for this analysis. This is U.S. $45 each for both the Signature Pro and the Compact Intuitiv single-use tubing/cassette packs. The reusable tubing/cassette pack for the Compact Intuitiv is priced at $300, or $15 per use when used 20 times.

To estimate the cost savings and reductions in waste and carbon emissions by switching from single-use to reusable phacoemulsification tubing/cassettes, we quantified the cataract surgery volume of our 2 busiest surgeons over a 1-year period (July 1, 2024, to June 30, 2025). Other cases where an irrigation/aspiration tubing/cassette was used—such as an intraocular lens (IOL) exchange or secondary IOL implantation—were included as well. Immediate sequential bilateral cataract surgeries (ISBCS) did not affect the cost or waste calculations because a new set of instruments and a different sterilized cassette were opened and used for the second eye. We then compared the estimated tubing/cassette costs of performing this surgical volume using either the $45/procedure or $15/procedure options. We performed a life cycle analysis (LCA) of a new, single-use phacoemulsification tubing/cassette for both the Signature Pro and the Compact Intuitiv, according to the methodology explained below. Because the multiuse Compact Intuitiv tubing/cassette is virtually identical in size, weight, components, and packaging to the single-use counterpart, a separate LCA for this reusable product was not repeated.

Part 2: Single-Use vs Reusable Surgical Blade Analysis

We evaluated the savings in cost and carbon emissions from the routine use of diamond surgical knives in lieu of single-use metal alternatives over a 10-year period, from July 1, 2015, through June 30, 2025. During this decade, between 12 and 16 different cataract surgeons operated at our single-specialty ASC each year. All surgeons used communal sets of diamond surgical keratomes and paracentesis blades while operating in either of the ASC's 2 ORs. The diamond knives were separated from the main surgical instrument trays and kept in smaller, dedicated instrument trays for storage and sterilization. Multiple sets of diamond blades were used per OR so that one set could be cleaned and processed while another set was being used. The knives were either repaired or discarded if the surgeons determined that their cutting performance became impaired. None of the surgeons at our ASC used metal keratomes or paracentesis blades during the study period.

All diamond blades were purchased from and repaired by a single vendor during this period. That company, Accutome, was later acquired by Microsurgical Technology, but the diamond surgical blade product line remained unchanged throughout. Invoices from the ASC were reviewed to determine the frequency and cost for purchasing new blades or repairing existing blades during the study period. If the diamond blade was rehoned or replaced using the same handle, this was considered a repaired blade. The number of items purchased or repaired was independently verified by cross-checking with internal company records provided by the manufacturer. This analysis was limited to cataract surgeries, IOL exchanges, secondary IOL implantations, and endothelial keratoplasties where both a keratome and paracentesis blade were routinely used. The total number of these procedures during the 10-year study period was tabulated from ASC records. Assuming that a diamond keratome and a diamond paracentesis blade were used for every case, the average amortized cost per case for each type of blade was calculated. This was then

Table 1. Summary of diamond knife usage and cost over 10-year period with 50 100 procedures

	No. used[a]	Total cost	Per case cost	No. of cases per unit
Diamond keratome	34	$43 370.00	$0.87	1474
Diamond paracentesis	60	$27 200.00	$0.54	835

[a]Includes the initial 10 knives in use at start of study period plus number of blades newly purchased, repaired, or replaced to provide a more conservative estimate of use

compared with the current noncontracted price from a representative manufacturer (Johnson & Johnson Vision) for single-use metal keratomes ($115 for a box of 6) and paracentesis knives ($76 for a box of 6). We assumed that the cost of these knives was not substantially lower in 2015; however, the manufacturer could not provide specific cost data for each year of the study period to confirm this.

A standardized protocol for handling and processing diamond keratomes and paracentesis blades was followed at the ASC. All diamond knives were kept in a smaller instrument container that was separate from the larger, main instrument tray. The scrub technician always handled diamond knives with the actual blade retracted inside the metal handle, including when passing it to the surgeon. The surgeon extended the blade and after each use, immediately rinsed it off with sterile water from a large syringe. After rinsing off all visible ophthalmic viscosurgical device, blood, and/or mucus, the surgeon retracted each blade before handing the knife back to the scrub technician, who in turn placed it back into its container. At the conclusion of surgery, an instrument technician cleaned all the surgical instruments before the autoclave cycle but did not extend or clean the diamond blades. The general instrument tray and the separate small diamond knife tray then underwent unwrapped, short cycle sterilization for the subsequent same-day case. At the end of the surgical day, the instrument technician extended each diamond blade for cleaning with distilled water and pressurized steam. The small diamond knife tray underwent wrapped, terminal sterilization before overnight storage. No additional cleaning steps, such as physical wiping, ultrasonic baths, or enzymatic solutions, were used.

Carbon Footprint Analysis

LCA, or LCA-equivalent analysis, was conducted by an independent company, Zasti, using an artificial intelligence–based software platform called ATOM for estimating and analyzing carbon metrics. A cradle to grave LCA boundary was used to calculate the environmental impact of each product studied. The LCA included sourcing of the raw materials, material composition and manufacturing, packaging analysis, product distribution, and finally disposal. Each study item was evaluated for its material composition using the Zasti software with benchmarking data from published patents. These materials were then matched with values from emission factor datasets that adhered to international standards. The emission factors accounted for raw material extraction, manufacturing processes, transportation/distribution, and disposal. These values were combined with the calculated carbon emissions for packaging and waste disposal to estimate the total carbon footprint of each study product. The contribution of distribution costs to carbon emissions was estimated based on publicly available data. Because the reusable tubing/cassettes were autoclaved alongside other cataract instruments, emissions related to steam sterilization were not included in this comparison. Because of the outsized impact plastic waste has on the environment and health when compared with paper or metal waste, we separately quantified the total weight of plastic waste from each phacoemulsification tubing/cassette system based on the estimated percentage of plastic in each component. For the surgical blades analysis, LCA calculations conservatively assumed that each knife would be used 500 times before disposal.

No financial support from industry was received for any part of this study.

RESULTS

Phacoemulsification Tubing/Cassettes

From July 2024 through June 2025, approximately 2700 cataract and IOL-related surgeries were performed using the Compact Intuitiv with the reusable cassettes by the 2 highest volume surgeons at our ASC. Of these, 590 eyes (295 patients) were ISBCS, typically with light adjustable IOLs. At the manufacturer's baseline cost, this would have amounted to approximately $40 500 spent on the reusable phacoemulsification tubing/cassettes over the 1-year period. Had the same number of procedures been performed using either the disposable Signature Pro or Compact Intuitiv tubing/cassettes, the total cost would have been $121 500. Transitioning to the reusable phacoemulsification packs therefore resulted in an estimated 66.7% cost savings. There were no cases of toxic anterior segment syndrome or endophthalmitis among the 2700 cases performed with the reusable tubing/cassettes, and the surgeons reported no decline in phacoemulsification machine performance by instituting these changes. Although the tubing/cassettes were processed and resterilized rather than discarded after each use, there was no reduction in the average number of surgeries performed per day by the 2 surgeons in the study.

Table 2. Carbon emission and waste analysis of phacoemulsification (phaco) tubing/cassette packs

Phaco machine	Phaco handpiece	Phaco pack	Carbon footprint per 1000 cases ($kgCO_2eq$)	Distance driven per 1000 cases (miles)	Km equivalent	Weight of total waste per 1000 cases, kg[a]
Whitestar Signature Pro	Ellips FX	Single-use	974.61	2371.30	3816.24	358 (333)
Compact Intuitiv	Ellips FX	Single-use	725.18	1764.44	2839.59	239 (203.5)
		Multiuse (20 cases)	36.26	88.22	141.98	11.95 (10.18)

[a]Weight of plastic waste per 1000 cases, kg

Table 3. Component life cycle analysis of single-use and multiuse phacoemulsification tubing/cassette packs

Packs	Carbon emissions ($kgCO_2eq$)
Compact Intuitiv	
Manifold and tubing assembly	5083.75 e^{-4}
Test chamber	96.28 e^{-4}
Packaging	1741.56 e^{-4}
Disposal	330.25 e^{-4}
Total single-use	7251.84 e^{-4}
Total multiuse (20 times)	362.59 e^{-4}
Signature Pro	
Manifold and tubing assembly	5912.27 e^{-4}
Mayo stand drape cover	1397.02 e^{-4}
Test chamber	48.14 e^{-4}
Packaging	1972.77 e^{-4}
Disposal	415.86 e^{-4}
Total	9746.06 e^{-4}

Blades

Over the course of 10 years, approximately 50 100 cataract, IOL-related, and lamellar keratoplasty procedures were performed. All diamond knives performed well throughout their usable lifetimes with no reported wound complications related to the blades. According to ASC invoices and the manufacturer's database, 34 diamond keratomes and 60 diamond paracentesis knives were used during this same period, including the 10 communal diamond knife sets (keratome and paracentesis) already in circulation at the beginning of the study period in July 2015. We included the capital cost of acquiring those blades in the total cost calculations. Because the 10 sets currently in circulation at the end of June 2025 still have unrealized remaining lifespan, we discounted the capital costs by 50%. Amortized over the number of procedures performed, this amounts to a per case cost of $0.87 for the diamond keratome and $0.54 for the diamond paracentesis blade (Table 1). On average, each keratome was used for nearly 1500 cases, and each paracentesis blade for more than 800 cases. This is significantly lower than the current representative unit cost of a single-use metal keratome at $19.17 and single-use metal paracentesis blade at $12.67. For 1000 procedures, the savings would have been approximately $18 300 from using the diamond keratomes, and $12 130 from using the diamond paracentesis blades. Over 10 years, this amounted to over $1.5 million in cost savings at our ASC by using diamond keratomes and paracentesis knives rather than single-use metal blades.

Carbon Footprint Analysis

Based on our LCA-equivalent analysis, the total weight of each single-use pack for the Compact Intuitiv was 0.239 kg, and the estimated total carbon footprint was 0.725 $kgCO_2eq$ per case (Table 2). With the reusable system of 20 cases, these estimates are reduced by a factor of 20 to 0.012 kg and 0.0363 $kgCO_2eq$, respectively, per case. The single-use cassette pack for the Signature Pro had a higher total weight of 0.358 kg and carbon footprint of 0.975 $kgCO_2eq$ per case. Compared with the single-use Signature Pro tubing/cassette system, the reusable Compact Intuitiv system would save approximately 322.8 kg of plastic and 938.3 $kgCO_2eq$ per 1000 procedures. The increased CO_2 emissions from the single-use system would be equivalent to driving a car 2283 miles (3674 km). Table 3 details the component analysis of each tubing/cassette pack. Figure 1 illustrates the physical amount of waste generated from 20 cases using the Signature Pro phacoemulsification pack that was reduced by switching to the multiuse Compact Intuitiv tubing/cassettes.

Figure 1. Twenty single-use Signature Pro phacoemulsification cassettes/tubing (above) and packaging containers (below). These were replaced by a single multiuse cassette/tubing set when using the Compact Intuitiv.

For reusable diamond blades, the carbon emissions and amount of waste produced are <1% that of disposable metal blades (Table 4). Based on the LCA, the plastic handle contributed the most to carbon emissions for surgical knives, followed by the manufacturing and packaging processes. This LCA was calculated with a conservative estimate of 500 reuses for each diamond blade. However, our ASC averaged nearly 1500 cases for each diamond keratome and more than 800 cases for each diamond paracentesis blade, suggesting that the actual environmental savings at our ASC were much higher.

DISCUSSION

In the U.S., most cataract surgical supplies are labeled single-use in the manufacturers' IFU. For a surgical product to be labeled reusable, the U.S. Food and Drug Administration (FDA) requires the manufacturer to validate the safety and efficacy of reuse in their submission. To be able to specify that a phacoemulsification tubing/cassette pack can be reused 20 times in the IFU, the manufacturer must demonstrate that it can be safely reused 40 times. In addition to the added expense for this testing and documentation, such validation may delay or complicate regulatory approval of

Table 4. Component life cycle analysis and waste analysis of single-use metal knives and multiuse diamond knives

	Keratome		Paracentesis	
	Single-use (metal)	Multiuse (diamond)[a]	Single-use (metal)	Multiuse (diamond)[a]
Carbon emissions ($kgCO_2eq$)				
Blade	1.638 e^{-4}	3.675 e^{-4}	0.546 e^{-4}	1.225 e^{-4}
Handle[b]	238.596 e^{-4}	839.265 e^{-4}	239.532 e^{-4}	979.755 e^{-4}
Manufacturing and packaging	142.153 e^{-4}	297.294 e^{-4}	142.138 e^{-4}	311.098 e^{-4}
Transportation	13.000 e^{-4}	37.000 e^{-4}	13.000 e^{-4}	39.000 e^{-4}
Disposal: blade (plastic + metal)[c]	44.737 e^{-4}	NA	44.912 e^{-4}	NA
Disposal: packaging landfill[c]	35.870 e^{-4}	NA	35.870 e^{-4}	NA
Total emissions	475.994 e^{-4}	1177.234 e^{-4}	475.998 e^{-4}	1331.078 e^{-4}
Emissions per use[a]	475.994 e^{-4}	2.354 e^{-4}	475.998 e^{-4}	2.662 e^{-4}
Emissions per 1000 cases	47.60	0.2354	47.60	0.2662
Equivalent distance driven (miles/km)	115.8/186.4	0.573/0.922	115.8/186.4	0.647/1.042
Waste analysis (g)				
Weight per unit without packaging	9	25	9	25
Weight per use	9	0.05	9	0.05
Weight of waste per 1000 cases	9000	50	9000	50

[a]Assumed 500 reuses for diamond knives
[b]Handle for the single-use blade is made of plastic. Handle for the multiuse blade is made of metal
[c]Disposal for the diamond knives was not included given its minimal contribution when averaged over 500 reuses

the product. Considering this, the potential increased liability, and the fact that manufacturers sell more products if they are discarded each time, there are few business incentives to develop and commercialize phacoemulsification tubing/cassette packs approved for multiple uses.

Unless the manufacturer validates multiple uses in their FDA submission, the product must be labeled single-use by default.[9] "Single-use" in the IFU therefore does not mean that the manufacturer has demonstrated or claimed that reuse is dangerous—only that the safety of reuse has not been validated. This nuance, as it applies to ophthalmic surgery, may not have been appreciated when the Centers for Medicare and Medicaid Services (CMS) issued a new set of ASC Conditions for Coverage in 2009, including many mandatory infection-control measures.[10] CMS surveyors were instructed to "Determine whether the ASC reuses devices marketed for single use, and if so, does it send them to an FDA-approved vendor for reprocessing?" The new guidelines specified that only devices approved by the FDA for reprocessing could be reused. For many cataract surgical supplies, such as phacoemulsification tubing/cassettes and metal surgical knives, this ruling effectively assumed any off-label reuse of single-use products to be unsafe, without any scientific evidence to support this determination.

Off-label reuse of single-use phacoemulsification tubing/cassettes is commonly practiced in many countries. At the Aravind Eye Care System (AECS), a network of 15 regional eye hospitals in Southern India, surgeons routinely reuse the single-use phacoemulsification tubing/cassette from a leading manufacturer's machine all day for approximately 25 to 30 cases without removal, cleaning, or resterilization.[11] Despite this off-label practice, the previously published postoperative endophthalmitis rate at AECS was only 0.01% in 335 000 consecutive phacoemulsification surgeries.[12] Recent analysis found an identical 0.01% postoperative endophthalmitis rate in 1 133 959 consecutive phacoemulsification cases performed at AECS from 2016 to 2024 while routinely reusing single-use cassettes all day.[13] Moreover, an AECS microbiologic study failed to find bacterial or fungal contamination of tubing that was reused all day.[11]

Table 5. Phacoemulsification machines with approved multiuse tubing/cassette options in the U.S. or EU.

Manufacturer/ model	Autoclavable tubing/ cassette?	"Day" cassette?	No. of countries with multiuse option	Available in the U.S. (FDA)?	Available in EU (CE)?
J&J Compact Intuitiv	20 cases	NA	18	Yes	No
Oertli CataRhex 3/ Faros	6 cases	6 cases	21	No	Yes
Rayner Sophi	NA	10 cases	60+	No	Yes
Zeiss/DORC EVA NEXUS	NA	20 cases	50+	No	Yes
Geuder Megatron S4 HPS	NA	Max 6 h	65	No	Yes
Ruck Qube Pro	NA	Max 16 h	45	No	Yes

In a large North American survey on surgical waste, most cataract surgeons felt that manufacturers specify single use of products to limit liability and to increase profits, and should offer more reusable instruments and supplies along with greater surgeon discretion to reuse products in their IFU.[3] Ten times as many respondents would prefer reusable over disposable instruments of comparable functionality and cost. Most also wanted regulatory bodies to allow surgeons more discretion to reuse surgical supplies and devices. Only 17% of respondents were unwilling to reuse phacoemulsification tubing/cassettes, and only 18% were unwilling to reuse metal blades.

Although it is intuitive that multiuse phacoemulsification tubing/cassette systems generate less environmental waste than single-use systems, we found only 1 other study that attempted to quantify this impact. This 2024 European study compared waste generation from a single-use phacoemulsification cassette (Whitestar Signature, Johnson & Johnson Vision) with a multiuse day cassette approved for 10 consecutive cases (Sophi, Rayner Intraocular Lenses Ltd.) by using product weights as a proxy for environmental impact.[14] The reusable system produced 306.7 kg less waste per 1000 cataract procedures, representing a 75.3% reduction. Although estimating carbon footprint based on product weight is a simple and inexpensive calculation, it may be inaccurate and misleading for small items such as surgical knives. For example, the carbon footprint of 1 kg of plastic, metal, or paper varies significantly despite having the same weight.

By contrast, we undertook a rigorous LCA to calculate carbon emissions of both single-use and multiuse products. This was conducted by an independent environmental consulting company. Despite their small size, a precise and accurate calculation of the environmental impact of these products is important because of their high-volume usage. This comprehensive LCA separately determined the carbon footprint contributions from the manufacturing process (including raw material acquisition, production, and packing), as well as the distribution and disposal processes (Tables 3 and 4). This highlighted that compared with the metal blade itself, the plastic handle contributed far more to the carbon footprint of a single-use knife. A single-use metal blade that could be inserted into an autoclavable metal handle would therefore decrease emissions and plastic waste (handle and packaging) at large scale while still optimizing cutting performance.

Instead of comparing phacoemulsification cassettes from 2 different machine platforms, our study compared the reusable and single-use cassette options available for the same machine, as well as a single-use cassette for a different model of machine from the same manufacturer. These were the 3 phacoemulsification cassette options available to our surgeons, and we believe this direct comparison more accurately quantifies the waste reduction (346 kg per 1000 cases) from adopting the multiuse option. The single-use cassettes for other phacoemulsification machines are often larger than those from the 2 Johnson & Johnson Vision platforms, and this would have further increased the differences in waste and carbon footprint.

Scientific and public concern about the health effects of plastics, and MNPs in particular, has surged in recent years.[15,16] The healthcare industry in the United States generates approximately 2800 to 3500 tons of plastic waste daily, 91% of which is neither recycled nor reused.[17] Of the total weight of waste produced from the phacoemulsification tubing/cassettes we studied, a significant percentage is plastic (93% for the Signature Pro pack and 85% for the Compact Intuitiv pack). Reusing the Compact Intuitiv phacoemulsification tubing/cassette 20 times reduced the amount of plastic waste generated by approximately 90% compared with the single-use Signature Pro tubing/cassette.

In addition to reducing cost, emissions, and waste per case, switching from single to multiuse tubing/cassettes also reduced the facility storage space needed for phacoemulsification packs (Figure 1). Although it did not reduce our average daily case volume per OR, additional staff time was required to process and sterilize the reusable phacoemulsification tubing/cassettes after each use. At least 5 manufacturers currently offer the approved option of a phacoemulsification "day" cassette in the European Union (Table 5). These cassettes can be left in the machine and used for multiple consecutive same-day surgeries without removal for sterilization between cases. Each manufacturer specifies either the allowable number of cases for reuse or the number of hours during which cases can be performed with the same-day cassette. These day cassette options improve OR efficiency and turnover time and may not require changing the irrigation bag after every case, thereby also decreasing fluid and irrigation bag or bottle waste. None are available in the U.S. at this time.

The option of reusable diamond surgical blades has existed for decades, but a detailed cost, LCA, and waste generation comparison with single-use metal blades has not been reported to our knowledge. Many facilities have been reluctant to purchase diamond knives because of the potentially high repair or replacement costs in the event of damage. We are aware of 1 manufacturer (Microsurgical Technologies) that offers a diamond blade warranty program to cover repairs or replacements due to damage. We demonstrated considerable cost savings of more than $1.5 million in a real-world setting with multiple surgeons sharing communal sets of blades over the course of a decade. The carbon emissions and waste differences were also significant when multiplied by the 50 000+ operations performed during the past decade at our ASC. Single-use metal knife packaging is mostly nonrecycled plastic, and the knives themselves are usually incinerated following disposal in contaminated sharps containers. Some manufacturers sell autoclavable metal keratomes and paracentesis knives. Although we did not study those specific products, one could estimate the per case emissions and waste of reusing a metal knife 5 times, for example, by dividing the single-use values in Table 4 by 5. For surgeons who prefer new metal blades for every case, our analysis showed that pairing a reusable handle with single-use metal blades would also significantly reduce carbon emissions compared with discarding the entire knife each time. We urge manufactures to develop and offer such options.

Considering the global mandate for sustainability in health care, our study highlights the compelling and unmet need for

all manufacturers to offer multiuse phacoemulsification tubing/cassette options. Phacoemulsification machines with day cassette options already exist in more than 60 countries. However, this sensible and feasible option is not available in the U.S. at this time and has not been commercialized by the largest phacoemulsification machine manufacturers that account for the majority of global market share. Ultimately, meaningful progress will require coordinated action from all stakeholders. For instance, in 2022, the United Kingdom's National Health Service became the first health system to commit to net-zero carbon emissions through legislation.[18] Based on the AECS data, off-label reuse of single-use phacoemulsification cassettes should not be prohibited and should instead be left to the surgeon's discretion.[9] Manufacturers should prioritize development and approval of multiuse phacoemulsification tubing/cassettes and other surgical products. Because the U.S. is one of the few major global markets without an approved multiuse phacoemulsification day cassette, the FDA should reduce unnecessarily burdensome regulatory barriers. Finally, the significant cost and waste reduction from reusable phacoemulsification products in this study were determined from actual implementation of these strategies in our ASC. Therefore, surgeons should strongly consider adopting multiuse products when available, such as diamond surgical knives and multiuse phacoemulsification tubing/cassettes.

WHAT WAS KNOWN

- Most cataract surgical products are labeled "single-use" by default in the United States without evidence that reuse is unsafe.
- The majority of North American and European surgeons believe that cataract surgical waste is excessive and would like the option of more reusable surgical instruments and supplies.
- A previously published analysis showed that switching from a single-use phacoemulsification cassette pack to a multiuse pack reduced waste by 75%.

WHAT THIS PAPER ADDS

- A formal life cycle analysis provides the most accurate estimate of carbon footprint. To the authors' knowledge, this is the first published study using life cycle analysis to compare the environmental impact of single-use and reusable surgical products.
- Compared with single-use systems, multiuse phacoemulsification tubing/cassettes lowered plastic waste by 323 kg and carbon emissions by 938 kgCO_2eq for every 1000 procedures performed. Over a 1-year period, cost was reduced by 67%.
- Compared with disposable metal knives, surgical diamond knives reduced plastic waste and carbon emissions by 99% and saved more than $30 000 for every 1000 procedures performed.

REFERENCES

1. Eckelman MJ, Huang K, Lagasse R, Senay E, Dubrow R, Sherman JD. Health care pollution and public health damage in the United States: an update. Health Aff (Millwood). 2020;39(12):2071–2079
2. Health Care Without Harm: Health Care's Climate Footprint. 2019. Accessed July 10, 2025. https://noharm-global.org/documents/health-care-climate-footprint-report
3. Chang DF, Thiel CL; Ophthalmic Instrument Cleaning and Sterilization Task Force. Survey of cataract surgeons' and nurses' attitudes toward operating room waste. J Cataract Refract Surg. 2020;46(7):933–940
4. Chang DF, Elferink S, Nuijts RMMA. Survey of ESCRS members' attitudes toward operating room waste. J Cataract Refract Surg. 2023;49(4):341–347
5. Chang DF. Needless waste and the sustainability of cataract surgery. Ophthalmology. 2020;127(12):1600–1602
6. Gopinath PM, Parvathi VD, Yoghalakshmi N, Kumar SM, Athulya PA, Mukherjee A, Chandrasekaran N. Plastic particles in medicine: a systematic review of exposure and effects to human health. Chemosphere. 2022;303(pt 3):135227
7. Ali N, Katsouli J, Marczylo EL, Gant TW, Wright S, Bernardino de la Serna J. The potential impacts of micro-and-nano plastics on various organ systems in humans. EBioMedicine. 2024;99:104901
8. Rizan C, Mortimer F, Stancliffe R, Bhutta MF. Plastics in healthcare: time for a re-evaluation. J R Soc Med. 2020;113(2):49–53
9. Chang DF. Tackling the challenge of needless surgical waste in ophthalmology. J Cataract Refract Surg. 2023;49(4):333–338
10. Centers for Medicare & Medicaid Services. State Operations Manual (SOM) Appendix L, Ambulatory Surgical Centers (ASC) Comprehensive Revision. Center for Medicaid and State Operations/Survey and Certification Group; 2009. Accessed July 31, 2025. https://www.cms.gov/Medicare/Provider-Enrollment-and-Certification/SurveyCertificationGenInfo/Downloads/SCLetter09_37.pdf
11. Shukla AG, Chang DF, Dhanaseelan T, Vivekanandan VR, Gubert J, Robin AL, Venkatesh R. Reusing surgical materials for cataract surgery: an assessment of potential contamination. J Cataract Refract Surg. 2024;50(10):993–999
12. Haripriya A, Chang DF, Ravindran RD. Endophthalmitis reduction with intracameral moxifloxacin in eyes with and without surgical complications: results from 2 million consecutive cataract surgeries. J Cataract Refract Surg. 2019;45(9):1226–1233
13. Chang DF, Haripriya A. Postoperative endophthalmitis rate associated with routine off-label reuse of single-use phacoemulsification cassettes in more than 1,000,000 consecutive cataract surgeries. Asia Pac J Ophthalmol (Phila) 2025 (in press).
14. Kallay O, Sadad R, Zafzafi A, Motulsky E. Cataract surgery and environmental sustainability: a comparative analysis of single-use versus reusable cassettes in phacoemulsification. BMJ Open Ophthalmol. 2024;9(1):e001617
15. Marfella R, Prattichizzo F, Sardu C, Fulgenzi G, Graciotti L, Spadoni T, D'Onofrio N, Scisciola L, La Grotta R, Frigé C, Pellegrini V, Municinò M, Siniscalchi M, Spinetti F, Vigliotti G, Vecchione C, Carrizzo A, Accarino G, Squillante A, Spaziano G, Mirra D, Esposito R, Altieri S, Falco G, Fenti A, Galoppo S, Canzano S, Sasso FC, Matacchione G, Olivieri F, Ferraraccio F, Panarese I, Paolisso P, Barbato E, Lubritto C, Balestrieri ML, Mauro C, Caballero AE, Rajagopalan S, Ceriello A, D'Agostino B, Iovino P, Paolisso G. Microplastics and nanoplastics in atheromas and cardiovascular events. N Engl J Med. 2024;390(10):900–910
16. Nihart AJ, Garcia MA, El Hayek E, Liu R, Olewine M, Kingston JD, Castillo EF, Gullapalli RR, Howard T, Bleske B, Scott J, Gonzalez-Estrella J, Gross JM, Spilde M, Adolphi NL, Gallego DF, Jarrell HS, Dvorscak G, Zuluaga-Ruiz ME, West AB, Campen MJ. Bioaccumulation of microplastics in decedent human brains. Nat Med. 2025;31(4):1114–1119
17. Jain N, LaBeaud D. How should US health care lead global change in plastic waste disposal? AMA J Ethics. 2022;24(10):E986–E993
18. Delivering a 'Net Zero' National Health Service. 2020. Accessed July 17, 2025. https://www.england.nhs.uk/greenernhs/a-net-zero-nhs/

Disclosures: *D.F. Chang is a consultant for Alcon Laboratories, Inc., Johnson & Johnson Vision, and Carl Zeiss Meditec AG. G.B. Baveja is an advisory board member for Zasti. S.P. Chen has no financial disclosures. There are no other financial or proprietary interests in any material or method mentioned.*

First author:
Stephanie P. Chen, MD

Altos Eye Physicians, Los Altos, California