The Laryngoscope

A Comparison of Environmental Impacts Between Reusable and Disposable Flexible Laryngoscopes

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Introduction: There is increasing prevalence of single-use flexible laryngoscopes in Otolaryngology. This study aims to quantify and compare the environmental outcomes of single-use disposable flexible laryngoscopes (SUD-Ls) and reusable flexible laryngoscope (R-Ls).

Methods: The ISO 14040 standardized Life Cycle Assessment (LCAs) was utilized to estimate the environmental footprint of SUD-L and R-L. Product and packaging material composition, energy and water consumption, and high-level disinfection products were tabulated from on-site observation, manufacturer data, and the Ecoinvent database. Global warming impacts were defined by greenhouse gas emissions (GHGs) quantified by kilograms of carbon dioxide equivalents ($kgCO_2$-eq) and analyzed using the US EPA's TRACI and SimaPro software. Monte Carlo sensitivity analyses were additionally performed.

Results: Assuming a 6-year lifespan and 218 laryngoscopies/year, the R-L saves 804 $kgCO_2$-eq compared to SUD-L (1816 vs 2619 $kgCO_2$-eq). Notably 63% of the R-L total GHGs were due to personal protective equipment (PPE) production and disposal used in reprocessing, whereas 79% of SUD-L total GHGs were attributed to scope manufacturing and production. In a break-even analysis, a R-L produces fewer lifespan GHGs than SUD-Ls after 82 uses.

Conclusion: Reusable flexible laryngoscopes pose an environmental benefit over SUD-Ls across several impact categories when used in high frequency. SUD-Ls have significant advantages in various situations: low utilization settings, in-patient/ED consults, and urgent need for sterile instrumentation. Providers should assess laryngoscope use frequency, site of use, and available resources to balance the environmental consequences. Further areas of sustainable optimization include reducing disposable PPE used in R-L reprocessing.

Key Words: clinical practice guidelines, clinical research, clinical research health policy, comprehensive otolaryngology.
Level of Evidence: N/A

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INTRODUCTION

The flexible fiberoptic laryngoscope, first described by Sawashima and Hirose in 1968,[1] has undergone several evolutions and is a pivotal tool in the Otolaryngologist's practice. Recently, the introduction of miniature electronic image sensors manufactured on silicon wafers has allowed for mass production of single-use, disposable flexible laryngoscopes that feasibly perform laryngoscopy.[2,3] Postulated benefits of disposable endoscopic tools include remedying supply–demand mismatch, avoiding reprocessing time, and associated labor and repair costs. Furthermore, clinical practice guidelines have adapted their utilization to minimize infection risk and disease transmission especially during the COVID-19 pandemic.[4,5] Additionally, increasing reprocessing standards and subsequent labor demands from accrediting organizations such as JCAHO have influenced health care providers and systems to use disposable alternatives.

However, increasing prevalence of single-use medical devices has raised concern surrounding their carbon footprint and adverse environmental health impacts. A total of 8.55%–10% of the domestic United States greenhouse gas emissions (GHGs) have been estimated to be from the US health care sector,[6–10] and if the US health care were, itself, a country, it would be the 13th largest emitter of GHGs in the world. To determine appropriate climate action pathways, researchers have employed life cycle assessments (LCAs), a scientific methodology that quantifies the environmental impacts associated with the life

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cycle stages of the health care products from material sourcing to waste disposal.

To date, there are no reported studies assessing flexible laryngoscopes and comparing the environmental impacts between reusable and disposable of flexible options. Prior LCAs of similar endoscopes include bronchoscopes,[11,12] cystoscopes,[13] duodenoscopes,[14,15] and ureteroscopes[16] but have conflicting results due to varied methodology, depth of analysis, and key assumptions. The aim of this study is to conduct a detailed LCA of reusable and single-use disposable flexible laryngoscopes (SUD-Ls) that quantify carbon emissions and associated environmental health impacts.

MATERIALS AND METHODS

This study was conducted at the University of California, San Francisco (UCSF), and did not include human subjects. It was determined to be institutional review board review exempt. A process-based LCA approach was utilized, according to ISO 14040 standards.[17]

LCA Goal and Scope

The goal of the LCA was to compare the environmental impacts between SUD-Ls and reusable flexible laryngoscope (R-L) and their packaging. The analysis encompasses raw material extraction, manufacturing, transportation, use, and end-of-life stages of each product, known as the cradle-to-grave approach. The SUD-L and R-L analyzed is the aScope 4 RhinoLaryngo Slim (Ambu A/S, Coppenhagen, Denmark) and Olympus ENF-V2 laryngoscope (Olympus Manufacturing, Tokyo, Japan), respectively. The functional unit, the quantified reference unit for comparative analysis, was determined to be 1308 flexible laryngoscopy examinations–1308 uses of one R-L compared to 1308 SUD-L used and disposed. The functional unit was approximated by totaling the number of CPT Billing Codes "31575" and "31579" for laryngoscopy examination recorded at the UCSF Voice & Swallowing Center in 2022 divided by the number of laryngologists in practice. It was assumed that each laryngologist had four laryngoscopes used in consecutive rotation and that the average life span of each scope was 6 years (Supplementary Information I). For the study, the clinical performance of SUD-Ls and R-Ls were assumed to be equal and that multiple SUD-L laryngoscopies were not needed to equate to a laryngoscopy using a R-L, or vice versa. The boundaries of the LCA are illustrated in Figure 1 and include the stages aforementioned, as well as the reprocessing/sterilization and repair of the R-L.

Life Cycle Data Collection and Inventory

Data to perform the LCA were collected from on-site observation, flexible laryngoscope manufacturers, and the Ecoinvent v3.10 database.[18] Ecoinvent is a leading comprehensive and commonly used life cycle inventory database, providing estimates of emissions associated with specific materials and processes. Material composition of SUD-L and R-L, and its associated primary packaging, was provided by the manufacturer of each scope. Manufacturers provided information on the distance (km) from factory to medical center, distribution routes, carriers, and transport modes (truck, air freight, and sea shipment) for the finished products. For the R-L, the manufacturer also provided distribution modes and distances from their suppliers to their factory. For the SUD-L, we utilized Ecoinvent industry-average estimates for upstream distribution emissions.

The reusable Olympus ENF-V2 laryngoscope (R-L) is connected to a "tower" that houses its illumination source, image processor, and external display monitor necessary for function. Because the image processor and external display monitor can be used by multiple reusable scopes for many more laryngoscopies than a scope, the manufacturing of these elements was not included in this study. However, the study included their electricity usage while the scope was in use. Electrical energy consumption of the Olympus ENF-V2 laryngoscope was observed and captured with a voltmeter (Hobo Plug Load Data Logger UX120-018) connected to the "tower" during both active use and idle time for four patient encounters.

The Ambu® Ascope™ 4 Rhinolaryngo Slim (SUD-L) is powered through its aView external monitor (the manufacturing of which was also not included in this study). Its electrical consumption was derived from the maximum battery capacity, assuming 12 uses per charge. For the LCA model, this study determined the average time of 5 min for active use and 79 min for idle time per patient.

After R-L use, two pathways of scope reprocessing occur at UCSF, with two different methods of high-level disinfection (Supplementary Information I). One pathway provides high-level disinfection through manual submersion of the flexible laryngoscope in Cidex™ OPA (Advanced Sterilization Products, Irvine, California) and the second involves high-level disinfection via an automated ultrasonic washer. The second option of reprocessing was decided to be included in the study. The reprocessing protocol was independently observed by two members of the study team (JK and KY). Disinfection procedures, type and volume of reagents used, their packaging and likely distribution routes, and volume of water consumed were recorded. The baseline LCA uses an average washer loading scenario of 30 scopes cleaned in 5 days. Electricity consumption of the automated ultrasonic washer was estimated using machine specifications (Olympus OER-Pro Endoscope Reprocessor).

For reusable scope reprocessing, personal protective equipment (PPE) and waste generated were counted and weighed. Findings were then compared, and discrepancies were resolved by reprocessing center managers. PPE required for R-L reprocessing was determined to be 2 exam gloves, 1 gown, and 1 surgical mask weighing 131.6 g in total. Their manufacturing was included, but not their packaging or distribution to UCSF.

It was assumed that both laryngoscopes, and any consumables associated with R-Ls, would be disposed via landfilling via regular municipal solid waste, collected via municipal waste collection service (garbage truck), and transported 50 km from UCSF.

All input data were mapped to emissions estimates using Ecoinvent v3.10 allocation, cut-off by classification, unit model.[18] A full list of model inputs and associated Ecoinvent unit process can be found in Supplementary Information II.

Life Cycle Impact Assessment

Measured and tabulated data were analyzed using the SimaPro software v. 9.6 (PRé Consultants, Amersfoort, Netherlands). Emissions inventory data were converted into environmental impacts using the US Environmental Protection Agency's The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) 2.1 V1.08/US 2008).[19] The primary outcome of this LCA is GHGs using carbon dioxide equivalents (CO_2 – equivalents) to quantify environmental impact. In addition, nine other environmental impact categories were quantified including acidification, carcinogenics,

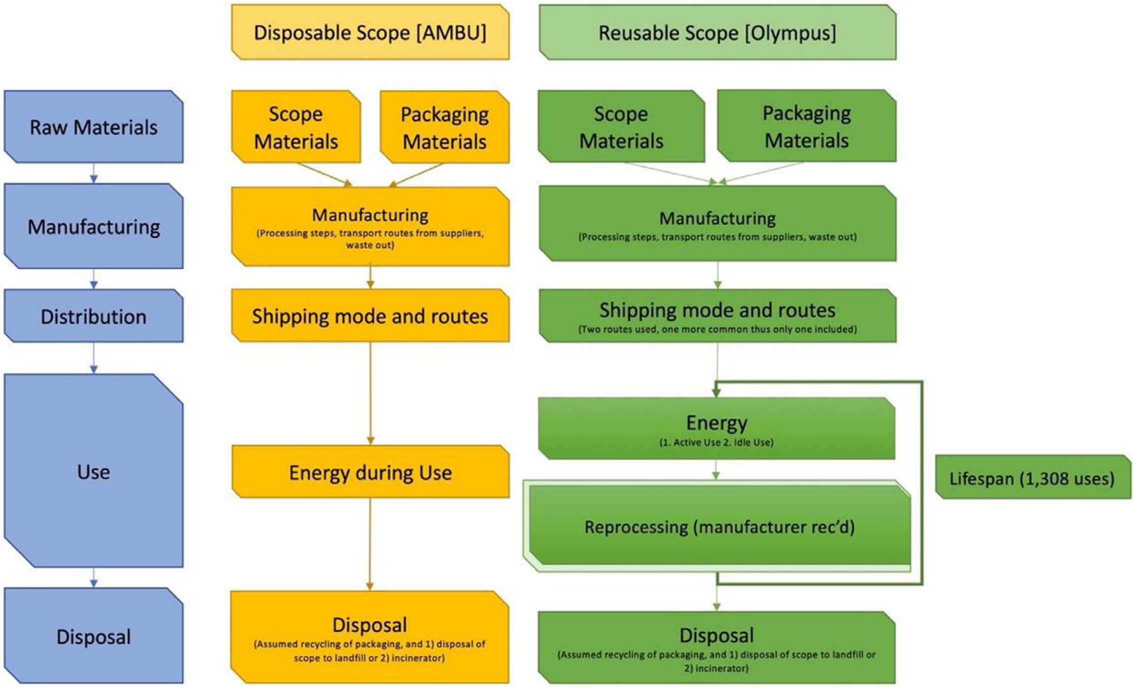

Fig. 1. System boundaries and scope of the life cycle assessment for single-use disposable (SUD) and reusable flexible laryngoscopes. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

noncarcinogenics, ecotoxicity, eutrophication, fossil fuel depletion, ozone depletion, respiratory effects, and smog, explained in Table I.

Sensitivity Analysis

LCAs involve many estimates and assumptions. To assess the impact of different electric grids on the outcomes of this study, results were modeled with the baseline (the Western Electricity Coordinating Council or WECC electric grid), the US average electric grid, and solar photovoltaic (PV) system.

In addition, we modeled multiple disposal pathways including landfilling (or municipal solid waste) and incineration. Though the manufacturer of the disposable scope engages in a recycling or 'take back' program, we are using a 'cut-off' allocation approach in which the environmental burdens of the original product remain with that product and are not allocated onto any secondary uses. This decision was further justified in that the

TABLE I.
Impact Categories, Descriptions, and Comparison of Performance after 1308 Laryngoscopies Between One Reusable Laryngoscope and Individual Single-Use Disposable Laryngoscopes (SUD-Ls).

Impact Category	Indicator Description	Unit	Reusable Laryngoscope (1 Lifetime = 1308 Uses)	Disposable Laryngoscope	% Difference
Global warming	Greenhouse gas emissions	kg CO_2 eq	1.82×10^3	2.73×10^3	50%
Ozone depletion	Emissions destructive to the stratospheric ozone layer	kg CFC-11 eq	4.30×10^{-5}	4.12×10^{-3}	9463%
Smog	Photochemical smog trapped at ground level	kg O_3 eq	90.1	1.88×10^2	109%
Acidification	Soil and water acidification due to release of sulfur dioxide	kg SO_2 eq	6.31	12.5	99%
Eutrophication	Aquatic nutrient enrichment and ecosystem disruption	kg N eq	6.32	12.5	54%
Carcinogenics	Production of cancer-causing toxic substances	CTUh	5.96×10^{-4}	6.77×10^{-4}	14%
Noncarcinogenics	Production of non- cancer-causing toxic substances	CTUh	5.85×10^{-4}	2.63×10^{-3}	349%
Respiratory effects	Release of microscopic particles toxic to the respiratory tract	kg PM2.5 eq	1.64	2.29	40%
Ecotoxicity	Release of environmentally toxic substances	CTUe	3.96×10^4	2.11×10^5	434%
Fossil fuel depletion	Depletion of natural fossil fuel resources	MJ surplus	2.98×10^3	4.09×10^3	37%

recycling program offered by the SUD vendor is presently not used at our institution.

Sensitivity analysis also included the effect of lifespans on results and described in the break-even analysis described below.

Monte Carlo Analysis

To account for the uncertainties of the life cycle inventory emissions data, a Monte Carlo Assessment (MCA), or random number sampling to account, was used in the R-L and SUD-L LCA comparison. Here, we use MCA to compare one reusable scope vs. one disposable scope with 1000 runs and a 95% confidence interval.

Break-Even Analysis

As there is natural variability in the lifespan of reusable items, a 'break-even analysis' is used to assess the point the baseline GHG emissions from the R-L would be equivalent to the SUD-L. The break-even analysis assumes linear impacts for SUD-Ls (where 10 scopes are 10 times the emissions of a single scope). The R-L has two calculation components; The first is linear, and these are all elements that accrue with each use of the R-L including electricity and reprocessing. The second are the lifetime impacts of the scope which decrease with each use which includes its manufacturing and disposal. The break-even analysis was conducted only on the baseline LCA. Error range was estimated using the 5% and 95% confidence intervals in per-device impacts from the MCA.

RESULTS

Laryngoscope Material Composition and Materiality Assessment

Material composition of the R-L and SUD-L were provided by both manufacturers for analysis and reported in broad categories to maintain confidentiality (Fig. 2). The R-L weighed 799.9 grams(g) composed of metals (58%), plastics (25%), electronic circuit board (10%), rubbers (6%), and other materials (1%). The SUD-L weighed 147.8 g made primarily of plastics (96%), metals (2%), electronics (1%), and other materials (1%). Across its lifespan the reusable scope uses 175 kg of materials. Approximately 98% (172 kg) of this is from the PPE required to reprocess the scope between uses, estimated at 132 g per use. Alternately, the disposable scope uses 41 kg of materials over the same number of uses (1308). This is 77% less material over this timeframe than the R-L.

Electricity Consumption

During on-site observation, electrical consumption of the R-L during four patient examinations were recorded from one tower. Those examinations were conducted over 317.5 min of which 13.5 min were during active use (4%), or 3.38 min per case. The R-L consumed on average 0.046 kWh while in active use and 0.351 kWh in idle use, or 927 kWh and 111,479 kWh when extrapolated over its

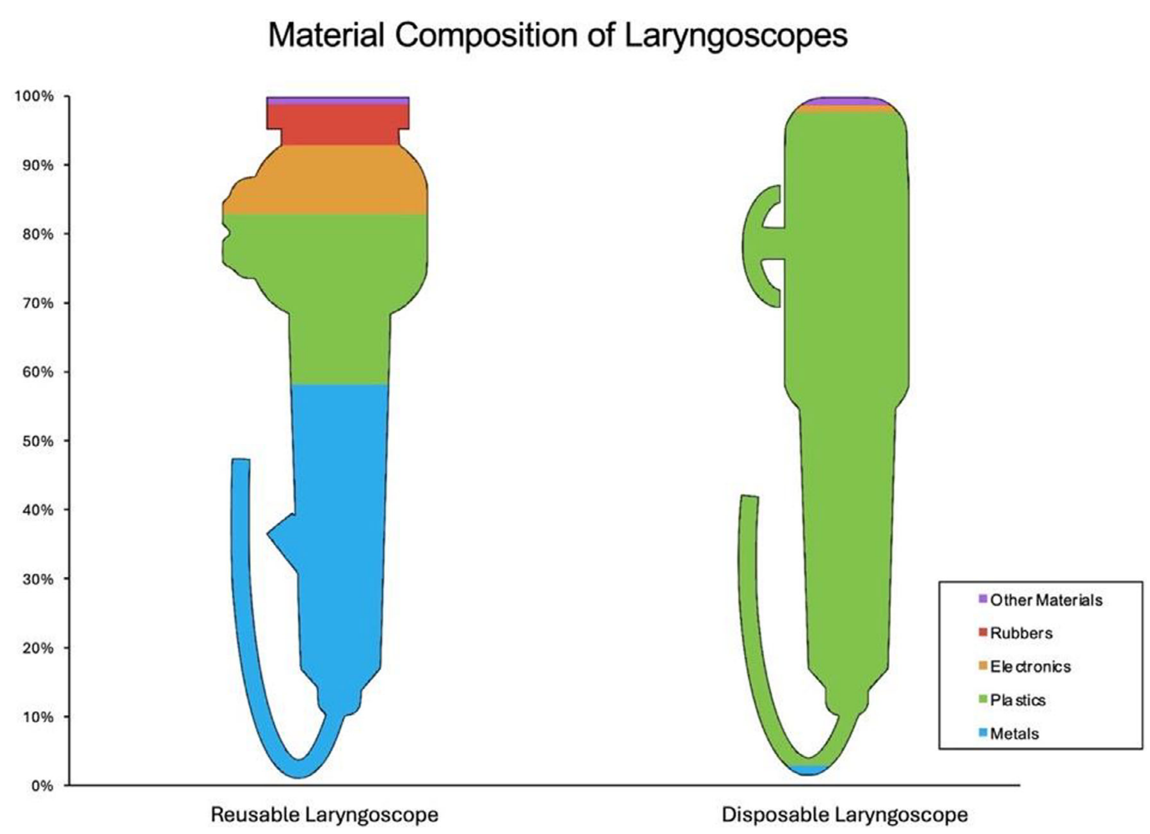

Fig. 2. Comparison of material composition between the reusable laryngoscope (Olympus ENF-V2) and single-use disposable laryngoscope (SUD-L) (aScope 4 RhinoLaryngo Slim). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

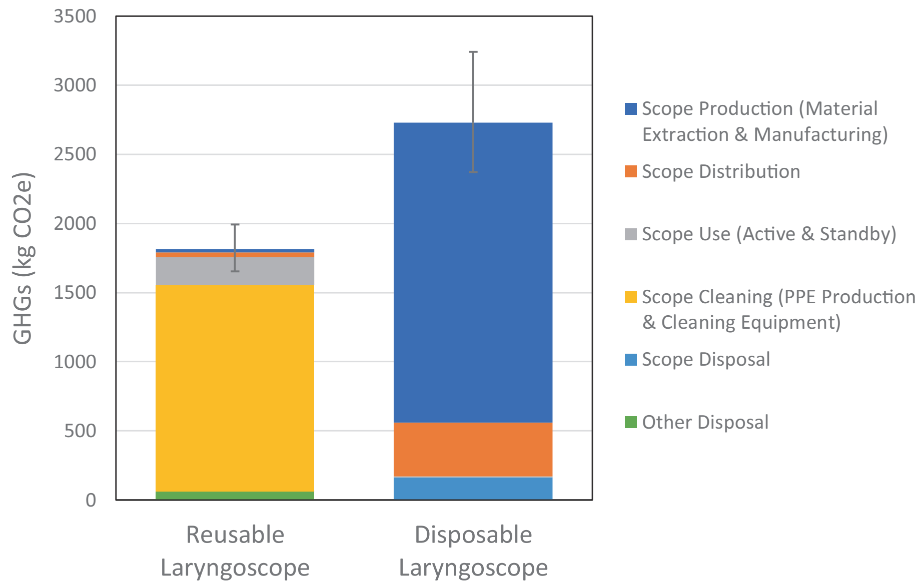

Fig. 3. Greenhouse Gas Emissions (kg CO_2 eq) per flexible laryngoscopy by a reusable (with an assumed 1308 use lifespan) and single-use disposable laryngoscope (SUD-L). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

lifetime, respectively. Power consumption of the SUD-L was approximated by assuming 3 h of use from its 93.6 Wh battery. Assuming 15 min per patient encounter, it was determined SUD-Ls consume 0.0078kWh per use.

Reprocessing, PPE Usage, and Storage

Electricity, water, and materials consumed during high-level disinfection of the R-L were identified and tabulated during on-site observation. Immediately after use, the R-L is wiped down with a detergent-laden sponge, placed in a bin and transported to reprocessing center. Reprocessing of the R-L produced 128.9 L total of waterwaste during pre-rinsing, leak testing, and enzymatic rinsing (43.5 L) and during high-level disinfection in the automatic reprocessing machine (85.4 L) where R-Ls undergo six separate rinse cycles. Power consumption was 0.173kWh by calculating the reported maximum electric current of the reprocessing machine, 3.33 A, over 120 V outlet over a 26-min cleaning cycle.

After high-level disinfection, the R-L is transferred onto a drying mat with the flexible portion wrapped in a plastic sheath and placed in a bin for return to clinic. During this process, two sets of gloves, one gown, and one mask were used to reprocess each scope. One set of bouffant and shoe covers were used per shift.

LCA Results

Assuming a 6-year lifespan and 218 laryngoscopies/year, the R-L saves 804 kgCO_2-eq compared to SUD-L (1816 vs 2619 kg CO_2-eq), or a 31% reduction. A composition analysis of GHGs revealed that 62% of the R-L total GHGs were due to PPE production and disposal used in reprocessing. Notably, 80% of SUD-L total GHGs were attributed to scope manufacturing and production (Fig. 3). In a break-even analysis of GHGs, a R-L produces fewer lifespan kgCO_2-eq than SUD-Ls after 82 uses (Fig. 4).

SUD-Ls had an increased environmental footprint across nine other impact categories (Fig. 5, Table I) when compared to R-Ls. After 6 years of use (1308 laryngoscopies), SUD-Ls were shown to produce about 14% more emissions in the impact category of carcinogenic human health impacts and 40%–50% more emissions in the categories of global warming, eutrophication, respiratory impacts (particulate matter), and fossil fuel depletion. SUD-Ls produced double the impact (around 100% more) in smog formation and acidification, and at least 4.5 times more impact in noncarcinogenic and ecotoxicity categories. Lastly, SUD-Ls produced 96 times more (9500%) ozone-destructive emissions than the R-L over 1308 uses.

Sensitivity Analyses

As the WECC grid has more renewable energy sources, switching to the US average electric grid would increase the emissions from both R-L and SUD-Ls (Figs 6 and 7). The sensitivity analyses also revealed that incinerated waste treatment pathways emit more GHGs than waste to landfill for the SUD-L (Fig. 7).

DISCUSSION

Disposable laryngoscopes, and disposable products more broadly, are the hallmark of the burgeoning linear economy or “take-make-waste” pipeline that often discounts its global impact on natural systems. This study is the first to examine, quantify, and compare the environmental impact of disposable and reusable flexible laryngoscopes. In this study, it was revealed that R-L produce 1816 kg of carbon emissions over its lifetime whilst

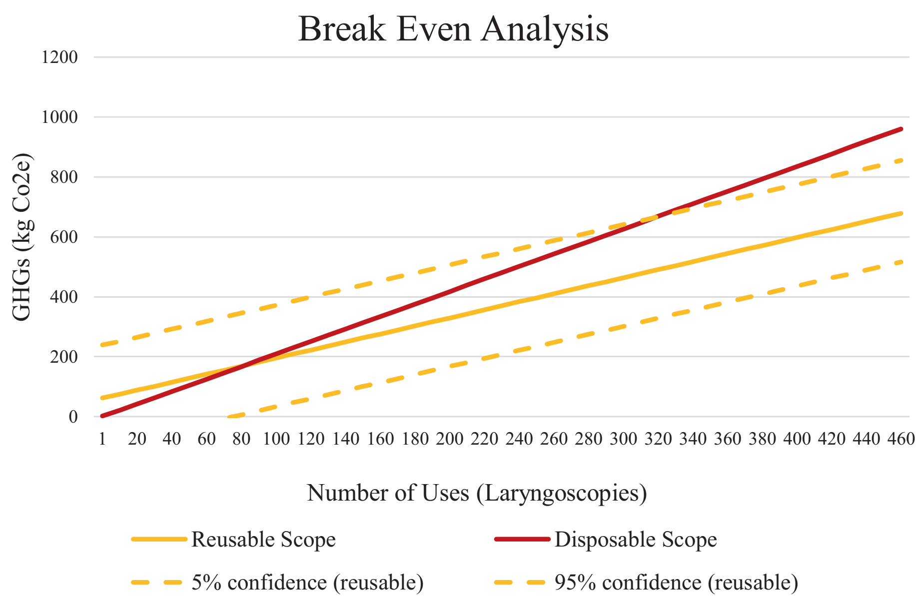

Fig. 4. Break even analysis of greenhouse gas emissions (kg CO_2 eq) between single-use disposable (SUD) and reusable laryngoscopes. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

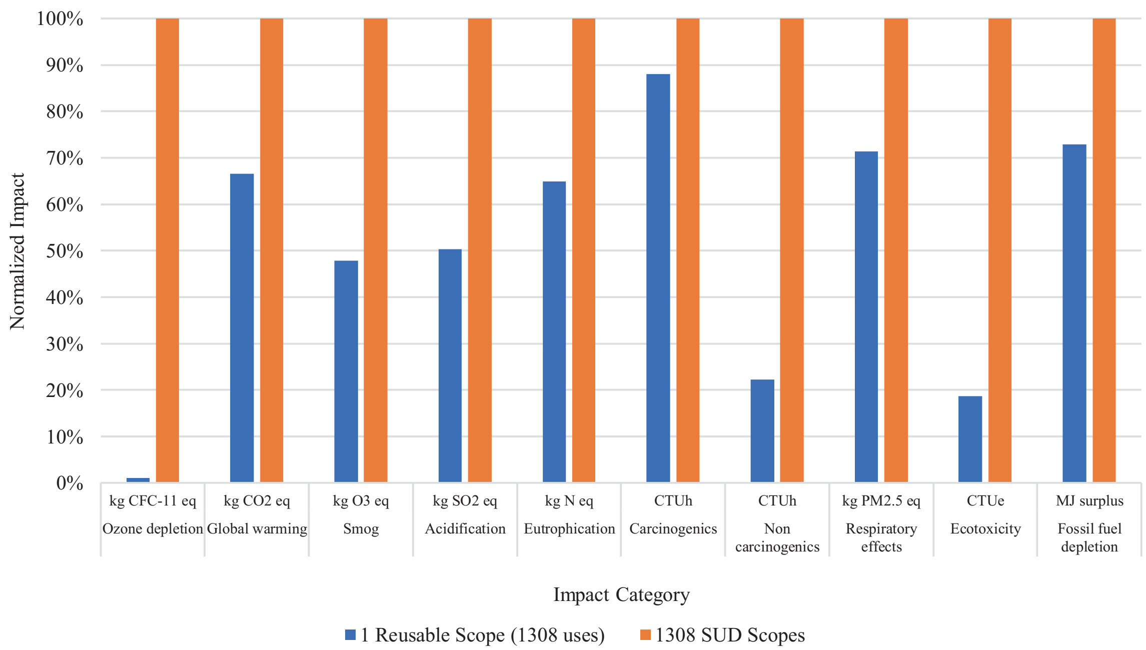

Fig. 5. LCA results comparing the environmental impact from 1 reusable laryngoscope over 6 years (1308 uses) compared to 1308 single-use disposable laryngoscopes (SUD-Ls). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

disposable laryngoscopes produce 2619 kg CO_2-eq. Moreover, the SUD-L performed worse in nine other environmental impact categories. The absolute difference in harmful emissions and eco-toxicity are magnified when the per-scope emissions are multiplied by the projected 645,000 annually billed flexible laryngoscopies in the US.[20]

Findings of this study concur with existing environmental studies on various endoscopes that reusable options produce less GHGs over their lifetime when used instead of their disposable alternatives. Prior "cradle-to-grave" LCAs bronchoscopes and duodenoscopes yielded similar results.[11,14] This study further validates their findings as scope material composition and distribution routes were directly disclosed and not indirectly measured or assumed. Findings differ from a prior LCA that concluded reusable and disposable bronchoscopes have equivocal greenhouse emissions, but this methodology was more limited in scope (excluding transportation, production, and manufacturing or reusable bronchoscope) and disproportionally attributes high GHGs from PPE usage.[12] Davis et al. similarly found that reusable and disposable cystoscopes have comparable environmental footprints, but their data were taken indirectly and assumed identical composition of reusable and disposable cystoscopes.[16] Finally, our study model determined a greater functional unit and scope lifetime use between R-Ls and SUD-Ls.

After 82 uses, the R-L produced less carbon emissions than using individual SUD-Ls, suggesting that SUD-Ls can be advantageous in lower utilization settings such as an in-patient/emergency department consult service as opposed to an outpatient Otolaryngology clinic. In addition, disposable laryngoscopes in prior studies have shown to be cost-effective options in very low-resource settings and negates the wages and costs for staff and reprocessing facilities.[3,21] SUD-Ls can also be used as adjuncts to increase efficiency in times of staffing shortages, emergent consults, or malfunctions in reprocessing systems.[22] SUD-L also have the advantage of being sterile as opposed to high-level disinfected, and there are situations that this difference maybe important.

Results are purposed not only to inform a dichotomous decision, but to also identify major contributors to carbon emissions in each product life cycle. Manufacturing and production contributed the majority of total carbon emissions produced the SUD-L– a consistent finding in several LCAs of disposable medical products, including blade laryngoscopes,[23] laryngeal mask airways,[24] surgical drapes,[25] and isolation gowns.[26] A recent study found that disposable surgical equipment used in adult tonsillectomies led to a significant impact of GHG across three different operative techniques, advocating for reduction of disposable instrumentation.[27]

Moreover, our results further corroborated prior evidence that disposable PPE used in reprocessing is a marked contributor to GHGs in the reusable laryngoscope life cycle and a significant source of material consumption across the R-L's lifespan. Other investigators have studied the impact of reducing PPE consumption and transitioning to reusable alternatives. A LCA on isolation gowns found that conversion to reusable isolation gowns would result in 30% reduction in GHG emissions.[26] A separate report that modeled switching to non-sterile gowns during direct laryngoscopy resulted in 15% reduction of total GHGs produced.[28]

From a broader perspective, emissions from both disposable and reusable life cycle stages can be minimized

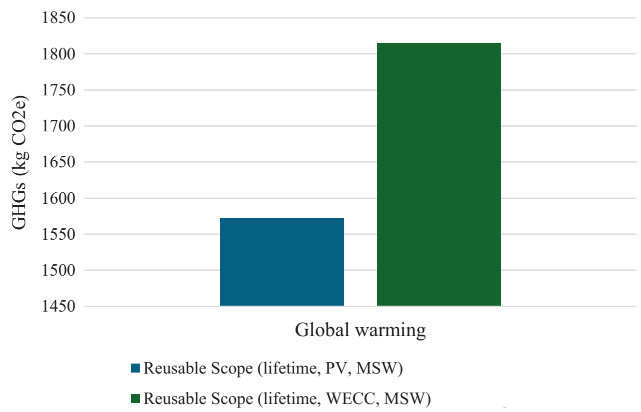

Fig. 6. Sensitivity analyses for reusable scope, illustrating GHG emissions from changes to waste treatment pathways and electricity grid. MSW = municipal solid waste (landfilling); PV = photovoltaic; WECC = Western Electricity Coordinating Council. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

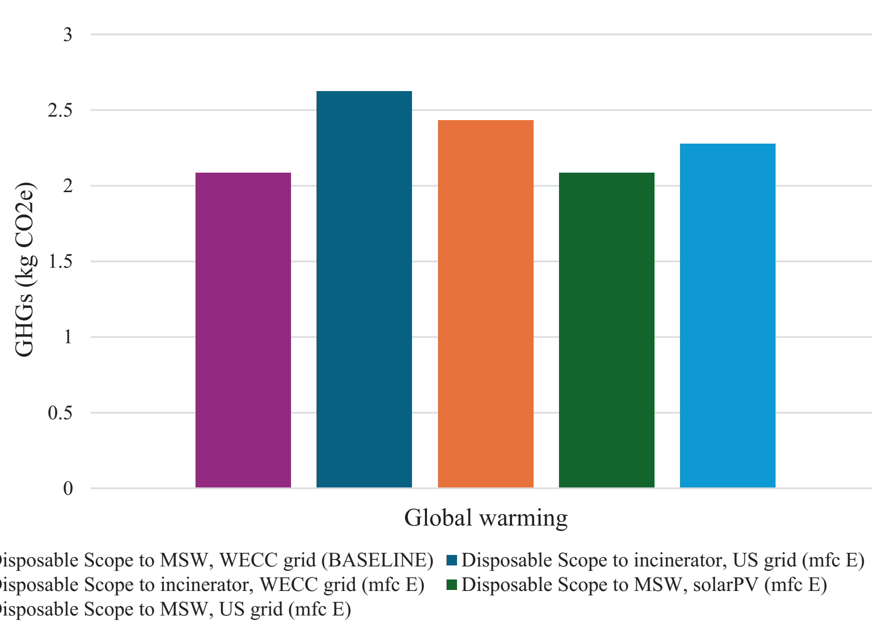

Fig. 7. Sensitivity analyses for disposable scope, illustrating GHG emissions from changes to waste treatment pathways and electricity grid. MSW = municipal solid waste (landfilling); PV = photovoltaic; WECC = Western Electricity Coordinating Council. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

by transitioning to "decarbonized" energy sources that can provide power in laryngoscope production, use, reprocessing, and more. Currently, 20% of US energy sources are carbon-free including wind, solar, hydropower, geothermal, and biomass sources whereas the rest are traditionally from fossil fuel and power plants.[29] Advocating and sponsoring policy and research in carbon deintensification will reduce our footprint on a global level.

Limitations in this study do exist. SUD-L "recycling" programs, R-L repairs, and overhead facility- and labor-associated emissions (such as commuting) were not included in the LCA model, skewing results in favor of the R-L. Additionally, we modeled automated high-level disinfection which is one avenue of flexible laryngoscope reprocessing. Other institutions and facilities can either use manual high-level disinfection without an automated reprocessor or use gas sterilization; neither of these methods were included. Lastly with a majority of health care LCAs, many manufacturing and processing data are not directly measured but collected from reputable databases. Future studies can include different models and sensitivity analysis to evaluate these scenarios.

CONCLUSION

Reusable laryngoscopes produce less carbon emissions and pose an environmental benefit over SUD-Ls across several impact categories when used in at least mild frequency. Single-use disposable laryngoscopes can be advantageous in various situations: low utilization settings, in-patient/emergency department consults, need for sterile instrumentation and when scopes cannot be reprocessed properly or timely. Providers should carefully consider the use frequency of the scope to balance the environmental consequences. Further areas of sustainable optimization include reducing disposable PPE used in R-L reprocessing and moving toward carbon-neutral energy sources.

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