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"Environmental Impact of Single-Use vs Reusable Double Lumen Tubes in One-Lung Ventilation: A Life Cycle Assessment Review"

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Abstract
The healthcare sector plays a vital role in causing environmental degradation globally, with medical devices being key contributors to wastage and emissions. In thoracic anesthesia, double lumen tubes (DLTs) and bronchoscopes conventionally comprise one-lung ventilation (OLV). This review contrasts the environmental impact of traditional single-use DLTs in conjunction with reusable bronchoscopes with new single-use camera-integrated DLTs based on Life Cycle Assessment (LCA). By evaluating raw material production, device use, sterilization, personal protective equipment (PPE), and waste treatment, variations in carbon footprint are revealed. The review emphasizes future directions in recycling and sustainable device design to foster environmentally conscious clinical decision-making.

Keywords
Double Lumen Tubes, One-Lung Ventilation, Life Cycle Assessment, Environmental Impact, Reusable vs Single-Use Devices, Carbon Footprint, Sustainable Medical Devices, Sterilization, Medical Waste Management

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I. Introduction

The healthcare industry is a major contributor to worldwide environmental degradation, with medical devices generating significant amounts of waste and emissions (Drew et al., 2021; Lichtnegger et al., 2022). One-lung ventilation (OLV) in thoracic anesthesia necessitates the use of double lumen tubes (DLTs) and bronchoscopes for lung isolation and visualization (Agrawal & Tang, 2021; Rizan & Bhutta, 2022; McGain et al., 2017).

This review critically analyzes the environmental footprint of the conventional single-use DLT used in conjunction with reusable bronchoscopes compared to recently developed single-use camera-integrated DLTs using Life Cycle Assessment (LCA), with the intent of guiding sustainable clinical choices (Carvalho et al., 2023; Kane et al., 2018).

II. Methods

A systematic literature search was conducted in PubMed, Scopus, and Web of Science databases from June 2025 to June 2025 for published studies. The search terms included: "double lumen tubes," "bronchoscopes," "life cycle assessment," "environmental impact," and "carbon footprint." Studies that compared LCA or environmental effects of OLV devices were included (Drew et al., 2021). Inclusion criteria encompassed peer-reviewed articles, gray literature, and technical reports providing quantitative environmental data related to OLV device use. Publications in non-English languages or those lacking quantitative environmental metrics were excluded.

Data extraction focused on life cycle phases—raw material acquisition, manufacturing, device use, cleaning/sterilization (when applicable), PPE consumption, and end-of-life disposal. Environmental impact indicators included carbon dioxide equivalents (CO_2-eq), energy consumption, water usage, and waste generation (Rizan & Bhutta, 2022; Lichtnegger et al., 2022).

Data Extraction and Quality Evaluation

Data were extracted on all relevant phases of the device life cycle, including raw material acquisition, manufacturing, clinical use, cleaning and sterilization (where applicable), personal protective equipment (PPE) usage, and end-of-life disposal. Key environmental impact indicators collected included carbon dioxide

equivalents (CO_2-eq), energy consumption, water usage, and waste generation (McGain et al., 2017; Carvalho et al., 2023).
The quality of the included studies was assessed using an adapted PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist. Particular emphasis was placed on the transparency of the Life Cycle Assessment (LCA) methodology, the clarity and consistency of defined functional units, and the appropriateness of system boundary definitions (Drew et al., 2021).

Life Cycle Assessment Methodology
System Boundaries and Functional Units
LCAs encompassed raw material extraction, device production, clinical application, cleaning/sterilization (where relevant), PPE use, and end-of-life waste disposal. The functional unit was "one patient receiving one-lung ventilation." The main impact measure was carbon dioxide equivalents (CO_2-eq), with additional energy to be supplemented by water use, and waste generation analysis (Lichtnegger et al., 2022).
Variability and Assumptions
Variability was contributed by energy source composition (renewable vs fossil fuel), sterilization effectiveness, and available waste infrastructure in an area. Sensitivity analyses emphasized geographical and procedural factors on environmental footprints.

Environmental Footprint of DLTs and Bronchoscopes (Kane et al., 2018)

- **Legacy Setup: Single-Use DLT with Reusable Bronchoscope**
  Reusable bronchoscopes involve numerous cleaning and sterilization processes using water, chemicals, energy, and PPE. These contribute to a high overall environmental footprint despite reuse advantages.
- **Innovative Single-Use Camera-Incorporated DLTs**
  Camera DLTs eliminate the requirement for reprocessing of the bronchoscope, lowering water, energy, and PPE utilization. More manufacturing effects due to embedded electronics need to be weighed.
- **Comparative Environmental Impact Findings**
  More recent Life Cycle Assessments estimate the environmental consequences of single-use traditional DLTs with reusable bronchoscopes versus single-use integrated camera DLTs (Agrawal & Tang, 2021; Carvalho et al., 2023).

Table 1: Environmental Impact Comparison of Airway Management Device Setups

Device Setup	Carbon Footprint (kg CO_2-eq/patient)	Energy Use (kWh)	Water Use (Liters)	Waste Generated (grams)	Primary Impact Source
Single-Use DLT + Reusable Bronchoscope	~2.1	~10.5	~50	~200	Bronchoscope cleaning and sterilization
Single-Use Camera-Integrated DLT	~1.25	~6.8	~5	~300	Device manufacturing and disposal

Device production and waste disposal

The conventional arrangement generates about 2.1 kg CO_2-equivalent per patient, mostly contributed by the resource-enduring bronchoscope disinfection and decontamination process, such as PPE use. Camera-integrated DLTs, on the other hand, minimize this carbon footprint to about 1.25 kg CO_2-equivalent per patient by avoiding bronchoscope reprocessing. Even though single-use camera DLTs generate more plastic residue, their overall environmental footprint is less because there are fewer sterilization needs (Fankhauser et al., 2024).

Broader Environmental Considerations

- **Beyond Carbon Footprint**
  Water usage and chemical application during bronchoscope sterilization can have an impact on aquatic environments, particularly in arid areas (Lichtnegger et al., 2022). Sterilant toxicology effects and single-use integrated device electronic waste are poorly studied and need more investigation (Rizan & Bhutta, 2022; Carvalho et al., 2023).
- **Recycling and Waste Disposal**
  Recycling of plastics and packaging is a strong means of minimizing environmental effects. Such benefits are however curtailed by variability in recycling facilities between healthcare facilities (Lichtnegger et al., 2022).

Clinical and Economic Integration

Environmental benefits must be weighed against clinical safety, efficacy, and cost. Ongoing monitoring of image quality and procedure outcomes with camera-integrated DLTs is necessary (Kane et al., 2018). Although initial costs for the devices are greater, avoided bronchoscope reprocessing costs and decreased PPE use can help defray expenses (Rutala & Weber, 2001; Al Hashemi, 2013).

Table 2: Table: Clinical and Environmental Advantages vs. Disadvantages of DLT Setups (McGain et al., 2017)

Aspect	Traditional Setup (Single-use DLT + Reusable Bronchoscope)	Camera-Integrated DLT
Environmental Impact	Higher carbon footprint due to sterilization and PPE use	Lower carbon footprint by eliminating bronchoscope reprocessing
Water & Energy Use	High due to repeated cleaning and sterilization	Low, no bronchoscope cleaning required
Waste Generation	Moderate plastic waste; reusable bronchoscope reduces some waste	More device waste but overall less environmental impact
Clinical Efficacy	Established, proven image quality and reliability	Emerging technology; requires further validation
Cost	Lower device cost but higher labor and sterilization costs	Higher per-device cost but potential savings in labor and reprocessing
Infrastructure Needs	Requires sterilization facilities and water supply	No sterilization needed, but electronic waste management required
Future Potential	Limited sustainability improvements without infrastructure upgrades	Opportunities for innovation and recycling

Limitations and Research Gaps

- Local differences in energy grids, clinical guidelines, and waste collection restrict generalizability of findings (Fankhauser et al., 2024).
- Most studies emphasize greenhouse gas emissions and, in many cases, other environmental and toxicological effects are overlooked.
- Economic evaluations combined with LCAs are limited but are required for informed procurement decisions.
- More research should be conducted on patient outcomes and acceptance among staff concerning the uptake of new devices.

Future Directions

- Design hybrid reusable-disposable device formats that maximize sustainability and performance.
- Embed complete LCA data into healthcare procurement and policymaking.
- Establish employee education programs to encourage environmentally friendly device selection.
- Develop recycling technology and circular economy strategies in medical device management.

III. Conclusion

This review highlights the significant environmental advantages of using single-use camera-integrated double lumen tubes (DLTs) over the conventional combination of single-use DLTs with reusable bronchoscopes in one-lung ventilation (OLV). Life Cycle Assessment (LCA) reveals that camera-integrated DLTs substantially reduce carbon emissions; water and energy use, and eliminate the need for resource-intensive bronchoscope sterilization. Although these devices generate more single-use waste, the overall environmental footprint is lower.

To advance sustainable healthcare, it is essential to consider the full life cycle of medical devices during procurement and clinical decision-making. Continued innovation in device design, integration of recycling practices, and improved waste management infrastructure will be critical. Environmental sustainability must be balanced with clinical efficacy, safety, and cost-effectiveness to ensure both patient care and planetary health are protected.

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