



Cataract surgery and environmental sustainability: Waste and lifecycle assessment of phacoemulsification at a private healthcare facility

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Purpose: To measure the waste generation and lifecycle environmental emissions from cataract surgery via phacoemulsification in a recognized resource-efficient setting.

Setting: Two tertiary care centers of the Aravind Eye Care System in southern India.

Design: Observational case series.

Methods: Manual waste audits, purchasing data, and interviews with Aravind staff were used in a hybrid environmental lifecycle assessment framework to quantify the environmental emissions associated with cataract surgery. Kilograms of solid waste generated and midpoint emissions in a variety of impact categories (eg, kilograms of carbon dioxide equivalents).

Results: Aravind generates 250 grams of waste per phacoemulsification and nearly 6 kilograms of carbon dioxide-equivalents in

greenhouse gases. This is approximately 5% of the United Kingdom's phaco carbon footprint with comparable outcomes. A majority of Aravind's lifecycle environmental emissions occur in the sterilization process of reusable instruments and materials. Electricity use in the operating room and the Central Sterile Services Department (CSSD) accounts for 10% to 25% of most environmental emissions.

Conclusions: Surgical systems in most developed countries and, in particular their use of materials, are unsustainable. Results show that ophthalmologists and other medical specialists can reduce material use and emissions in medical procedures using the system described here.

J Cataract Refract Surg 2017; 43:1391–1398 © 2017 ASCRS and ESCRS

Supplemental material available at www.jcrsjournal.org.

In most developed countries, surgery in general uses a significant amount of single-use disposable instruments and generates large quantities of waste.^{1–3} The resulting emissions contribute directly and indirectly to public health impacts, including respiratory impacts and global warming or climate change.^{4–6} The National Health Services are responsible for 5% of the United Kingdom's greenhouse gases,⁷ and in the United States, the healthcare sector produces 10% of total greenhouse gases and 9% of criteria air

pollutants.⁶ Climate change is already having a profound effect on public health, resulting in increased frequency and severity of flooding and droughts, greater insecurity of food systems, and an increase in disease vectors such as mosquitoes and ticks.⁸ A larger proportion of these impacts fall on developing countries such as India where environmental and economic conditions make it difficult to mitigate the effects of climate change and where emissions from material production or electronic waste treatment

Submitted: July 6, 2017 | Final revision submitted: August 22, 2017 | Accepted: August 27, 2017

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Supported by a Fulbright-Nehru Academic and Professional Excellence Award through the United States – India Educational Foundation, New Delhi, India. Dr. Saeedi is supported by a Career Development Grant (No. K23 EY025014) from the U.S. National Institutes of Health, Bethesda, Maryland, USA. The sponsor or funding organization had no role in the design, conduct, or reporting of this research.

The employees of Aravind Eye Care System helped collect data for this project.

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result in emissions such as air particulates, heavy metals, and toxic compounds that directly affect health.^{8,9}

Cataracts are the leading cause of blindness and visual impairment worldwide, making cataract surgery one of the most commonly performed surgical procedures.¹⁰ Cataract surgery in the U.K. emits 180 kilograms (kg) of carbon dioxide (CO₂)-equivalents per eye, with more than one half of those emissions originating from the procurement of largely disposable medical equipment.¹¹ Globally, the cost of cataract surgery frequently impedes access for those who need it most.^{12,13} In its mission to eradicate unnecessary blindness, the Aravind Eye Care System, in the southern Indian state of Tamil Nadu, has developed an innovative and effective model of care centered on time efficiency and resource efficiency. Aravind performs 1000 surgeries per working day. Sixty percent of these surgeries are delivered at minimum or no cost to the patient and with better outcomes and lower complication rates than the U.K.^{13,14} The Aravind model is recognized for its financial and social success,^{15,16} although it has not yet been studied for its environmental footprint.

As healthcare professionals worldwide become more aware of and concerned for the public health implications of climate change and excessive resource use, efficient care delivery models must be better understood and promoted.^{8,17–19} Aravind, with its assembly-line model for surgery and its use of reusable instruments, serves as an example of more sustainable, efficient cataract surgery. This study analyzes Aravind's material use from phacoemulsification cataract surgery and quantifies the resulting environmental effects and costs through environmental lifecycle assessment (LCA).

MATERIALS AND METHODS

Data Collection

Data were collected at Aravind Eye Hospital in Pondicherry, India, between November 2014 and February 2015. This project obtained institutional review board exemption because no individual patient data were collected. Material flow analysis was performed by observing the flow of materials through the operating room. Lists of the materials used in surgery, their prices, quantities, and estimated lifespans were obtained from Aravind's purchasing department and interviews with midlevel ophthalmic personnel. The weight of each surgical instrument and tool was measured directly. Data on waste disposal routes and associated costs or profits were obtained from Aravind's housekeeping department and direct observation, and information on the sterilization processes was obtained from Aravind's CSSD. Waste audits, in which waste from each stream was separated by material type and weighed, were performed on all phacoemulsification cases from 1 operating room on the same day with a typical caseload (93 cases). An on-site visit to the regional biomedical waste incinerator confirmed treatment and disposal of waste from this specific waste stream. Surgical demographics, including number of surgeries and staffing levels, were obtained from Aravind's surgical database and the midlevel ophthalmic personnel administrator.

Data on the hospital's overall use of water and electricity were obtained from Aravind's engineering department. Water consumption and treatment was allocated to a single phacoemulsification based on floor area of the operating rooms and the CSSD, and then by total number of all surgeries performed in a single year. Electricity use was calculated using the power ratings from all

equipment and lighting found in the operating room, and an average duration of 9 minutes, from a patient entering the operating room to the patient leaving the operating room. Ventilation and air conditioning was calculated by subtracting the per-operating room electricity use from Aravind's total annual records and allocating the remainder to the total floor area of air-conditioned space. These assumptions will likely overestimate the actual water and electricity consumption in the operating room for a single phacoemulsification. Electricity use for sterilization of reusable items was calculated using power ratings of sterilization and laundry equipment in the CSSD and the duration of equipment's treatment cycles. These were allocated to the quantity of linens or trays treated per load. Aravind uses diesel generators to overcome gaps in the electrical grid. On-site emissions from the burning of diesel fuel were allocated as a percentage of total electricity use based on the amount of energy generated by the diesel generators (4% of Aravind's kilowatt hours [kWh] per year).

Lifecycle Assessment

Lifecycle assessment is a tool used to quantify the emissions of a product or process throughout its lifecycle, from raw material extraction through use and disposal. Emissions to air, water, and soil are typically sorted into related categories (eg, greenhouse gases) and converted into similar units (eg, kg of CO₂-equivalents) in what is known as midpoint reporting. In the case of cataract surgery, emissions include indirect sources (upstream might include emissions to water and air caused by the production of plastics for surgical materials, whereas downstream might include emissions to soil and water for landfilling of waste) and direct sources (eg, burning diesel fuel in generators onsite at Aravind).

The International Organization for Standardization²⁰ has established guidelines for LCAs that are performed in 4 stages as follows: (1) goal and scope definition, (2) lifecycle inventory, (3) impact assessment, and (4) interpretation. For this LCA study, the functional unit, an essential component of stage 1, was the removal of cataract in 1 eye using phacoemulsification. The study boundaries encompass only the perioperative period, including preoperative cleaning and anesthesia of the eye and all activities performed within the operating room. The study boundaries do not include the patient preparation before entering the operating area or postoperative follow-ups. The production, use, and disposal of all surgical instruments and supplies are included in the LCA; however, capital equipment such as the phacoemulsification machine, operating microscope, and the building construction were not included because the effect of these items when allocated to a single case are typically negligible.^{4,5,16}

The lifecycle inventory is a list of all the emissions associated with a single product. The lifecycle inventory for Aravind's phacoemulsification surgeries was created by matching the collected material, energy, and water-use data with global-based and Indian-based unit processes in the Ecoinvent database,²¹ an international emissions database containing thousands of products. Ecoinvent is known for its comprehensiveness and robustness and it has been used in previous studies of medicine.^{4,5,21,22} Aravind's Pondicherry location constructed an on-site wetland to treat wastewater. However, this study did not model this system as is because most medical facilities do not use this wastewater treatment method, wastewater treatment is a tertiary concern of cataract care, and decentralized wastewater treatment systems are not well documented in existing LCA databases and literature. This system was modeled instead as a standard wastewater treatment plant with primary and secondary settlers, activated sludge aeration, and anaerobic digestion. A detailed list of the materials inventory and matching lifecycle inventory databases can be found in [Supplemental Tables 1 and 2](http://jcrjournal.org), available at <http://jcrjournal.org>.

These emissions were characterized and combined into midpoint impact categories using the lifecycle impact assessment (LCIA) method, the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (version

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