Open Versus Closed Suctioning in Invasively Ventilated Critically Ill Patients for Sustainability of ICU Care: A Life-Cycle Assessment Comparison

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Introduction

Although care for critically ill patients can be lifesaving, it requires additional resources that generate a large amount of waste. For example, care for ~2,500 critically ill patients in one Dutch ICU for one year leads to 250,000 kg of waste. Care for a single ICU patient is accompanied by using materials and disposables that are responsible for approximately 17 kg of mass and 12 kg of CO_2 and consumes up 300 L of water per day.[1] The use of resources and disposables depends on the care received by critically ill patients and the local situation of the organization of care.

Disposable medical equipment carries significant environmental costs, encompassing material extraction, manufacturing, shipping, and waste management. Whereas opting for cheaper disposables may seem financially attractive, it can lead to increased staff time and labor costs due to more frequent replacements, negating the initial savings. It is crucial to carefully evaluate the total cost of ownership, including environmental impacts and staff resources, when making equipment choices to promote sustainability in health care practices.

As an example, critically ill patients in the ICU are often treated with invasive ventilation. During invasive ventilation, patients receive various airway care interventions to clear secretions in the upper and/or lower airways.[2,3] Endotracheal suctioning is the most commonly used airway care intervention.[4] Reported frequencies of endotracheal suctioning in patients are 8–17 times per day.[5] To perform endotracheal suctioning, disposable items are commonly used. During the so-called open suctioning, a sterile catheter connected to a suctioning system is inserted into the artificial airway. Alternatively, a closed suctioning system can be used that remains connected to the endotracheal tube and to a suctioning system. This catheter is sealed and designed for multiple uses over 1–3 d in a single patient.

There is no difference in important patient-centered outcome, including ventilator-pneumonia, between the use of open or closed systems.[6] Guidelines indicate that both techniques are safe to use.[7] Currently, the choice of a suctioning system is mainly driven by availability or preference of the practitioner. This choice could possibly be better substantiated by adding information about the sustainability of the intervention, that is, the impact of the intervention on the environment. The aim of this study was to analyze the environmental impact of a closed and open endotracheal suctioning system. We tested the hypothesis that a closed suctioning system is more environmentally sustainable than an open endotracheal suctioning system by performing a life-cycle assessment (LCA) comparison. This LCA is an example of the larger principle of incorporating environmental impact in the decisions regarding selection of disposable equipment.

Key words: endotracheal suctioning; open or closed system; intensive care; life cycle assessment; sustainability of care

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The authors have disclosed no conflicts of interest.

Research time for Dr Stilma was based on a personal grant from NWO Netherlands Organization for Scientific Research (number 023.011.016) during the conduct of the study and by Amsterdam University of Applied Sciences (Stimuleringsgelden 2023). Drs Stobernack and Touw worked on a ZonMw grant (number 80–86800-98-112).

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DOI: 10.4187/respcare.11189

Methods

Study Design

We conducted a single-center observational pilot study in an adult mixed medical-surgical ICU. No subject data were collected; the study focused exclusively on the use of medical products and their environmental impact determined by LCA. LCA is a method used to calculate the environmental impact of a product or service, taking into account all stages from cradle (raw material extraction) to grave (waste processing). The study was exempted from review by the medical ethics committee METC Oost-Nederland under the exemption number 2021–13265.

Materials

Two medical disposable products and their packaging were analyzed based on their material composition: (1) a closed suction system named TrachSeal (Intersurgical, Wokingham, United Kingdom) that needs to be replaced after 72 h; details are documented at https://www.intersurgical.com/products/critical-care/trachseal-closed-suction-systems-for-72-hour-use (*Accessed June 22, 2023*), and (2) an open suction system from Bicakcilar (Bicakcilar Medical Devices, Istanbul, Turkey) was analyzed. The closed suctioning system in our study costs about $13.73, whereas the single-suction catheter costs about $0.27 each.

Data Collection

Data were collected on the 2 systems mentioned above via the following workflow. Material types of the 2 systems were collected from patents and/or estimated by experts based on their physical properties. Different materials were separated and weighed on an accurate laboratory scale. Transport distances were based on the location of the production facility and calculated using Google Maps and searates.com. Data on the use of gloves, connection pieces, or other disposable accessories were not included in this study.

Life-Cycle Assessment Methodology

LCA was used to evaluate the environmental impact of the closed suction system TrachSeal and the open suction system by Bicakcilar over the entire life cycle, from raw material extraction to disposal. An LCA calculates the environmental impact based on all inputs and outputs to and from the environment during raw material extraction, manufacturing, transport, use phase, and waste processing. Using the ISO-14040 standards[8] of the International Organization for Standardization (Geneva, Switzerland), we defined the functional unit of our study as one suction device (open vs closed). The ISO-14040 standards for LCA system boundary define inclusions/exclusions. We have included the extraction of raw materials, the production of plastics and manufacturing processes such as injection molding and extrusion, transport processes, and end-of-life processes such as incineration. This method is comparable to previous LCA approaches performed by internationally recognized LCA researchers in the health care sector.[9]

We used SimaPro 9 LCA software (PRé Sustainability, Amersfoort, the Netherlands) to model the data. Our team created an inventory to measure the quantity of materials and energy consumed by using the ecoinvent Database (version 3.9) as described at https://ecoinvent.org/the-ecoinvent-database (*Accessed June 22, 2023*). ReCiPe 2016 at mid-point and end-point level with the hierarchist perspective was used as life-cycle impact assessment method.[10] Midpoint analyses illustrate the environmental impact on 18 different environmental categories (eg, global warming, toxicity), while end-point analyses summarize the impact in a more aggregated category, eg, damage on human health expressed in disability-adjusted life-years (DALYs).

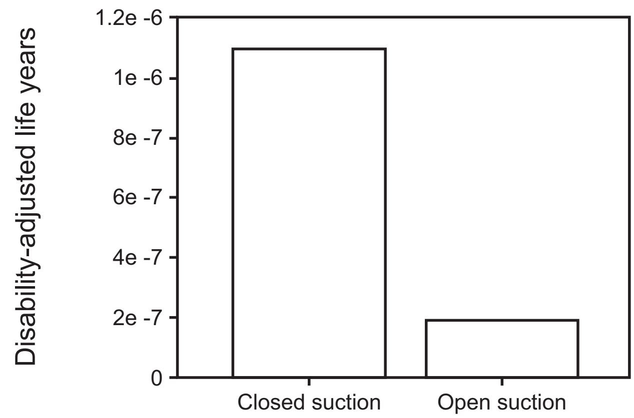

Fig. 1. Environmental impact of one closed versus one open suction system on human health. The y-axis illustrates the damage on human health expressed in disability-adjusted life-years, which summarize the overall environmental impact of the single impact factors (eg, global warming, toxicity).

Results

The closed suction system (total weight 67.38 g) consisted of a packaging of paper and low-density polyethylene, paper/vinyl stickers, a polyurethane catheter, polyethylene connectors, and polycarbonate connectors. The open suction system (total weight 11.82 g) consists of a paper and low-density polyethylene packaging, a polyurethane catheter, and a polycarbonate connector.

The environmental impact of the closed suction system was significantly higher compared to the open suction system (Fig. 1). Specifically, environmental impact expressed

Table 1. Comparison of Environmental Impact of Closed and Open Suction System on 18 Different Midpoint Indicators

Impact Category	Unit	Closed Suction System	Open Suction System
Global warming	g CO_2 eq	547.0	86.6
Stratospheric ozone depletion	ug CFC11 eq	328.0	172.0
Ionizing radiation	Bq Co-60 eq	14.8	4.4
Ozone formation, human health	g NOx eq	1.1	0.2
Fine particulate matter formation	mg $PM_{2.5}$ eq	669.0	111.0
Ozone formation, terrestrial ecosystems	g NOx eq	1.1	0.2
Terrestrial acidification	g SO_2 eq	1.6	0.3
Freshwater eutrophication	mg P eq	68.4	18.3
Marine eutrophication	mg N eq	11.1	7.7
Terrestrial ecotoxicity	g 1, 4-DCB	492.5	224.2
Freshwater ecotoxicity	g 1, 4-DCB	25.0	5.5
Marine ecotoxicity	g 1, 4-DCB	32.7	7.2
Human carcinogenic toxicity	g 1, 4-DCB	15.5	3.8
Human non-carcinogenic toxicity	g 1, 4-DCB	473.7	105.0
Land use	cm^2a crop eq	142.2	42.6
Mineral resource scarcity	mg Cu eq	777.0	172.0
Fossil resource scarcity	g oil eq	157.6	27.7
Water consumption	L	4.5	1.1

eq = equivalent
CFC11 = chlorofluorocarbon-11
Bq Co-60 = becquerel Cobalt-60
NOx = nitric oxide
$PM_{2.5}$ = particulate matter 2.5
SO_2 = sulfur dioxide
P = phosphate
N = nitrogen
DCB = dichlorobenzene
cm2a crop = cm^2 per year crop
Cu = copper
Stratospheric ozone depletion = Gradual thinning of Earth's ozone layer in the upper atmosphere caused by the release of chemical compounds containing gaseous chlorine or bromine from industry and other human activities.
Ionizing radiation = a type of high-energy radiation that has enough energy to remove an electron (negative particle) from an atom or molecule, causing it to become ionized. Ionizing radiation can cause chemical changes in cells and damage DNA.
Ozone formation = Ozone is a molecule made up of 3 oxygen atoms, often referenced as O_3. Ozone harms human health and the environment when it forms close to the Earth's surface.
Fine particulate matter formation = Fine particulate matter is an air pollutant that is a concern for people's health when levels in air are high (> 35 ug/m^3).
Terrestrial acidification = Terrestrial acidification is characterized by changes in soil chemical properties following the deposition of nutrients (namely, nitrogen and sulfur) in acidifying forms.
Freshwater/marine eutrophication = The gradual increase in the concentration of phosphorus, nitrogen, and other plant nutrients in an aging aquatic ecosystem such as a lake.
Terrestrial/freshwater/marine ecotoxicity = The ability of a chemical or physical agent to have an adverse effect on the environment and the organisms living in it, such as fish, wildlife, insects, plants, and microorganisms.

in damage to human health caused by the closed suction system was found to be 1.1 x 10^{-6} DALYs and for the open suction system 1.9 x 10^{-7} DALYs, which is approximately 6 times as much (Fig. 1). Further analysis showed that the closed suction system had the greatest impact on climate change, as evidenced by the high CO_2 emissions compared to the open suction system. Over the entire life cycle, the closed suction system emits 547 g of CO_2, whereas the open suction system only emits 86.6 g of CO_2, which is about 6 times as much (Table 1). In addition, the closed suction system had a greater impact on fine particulate matter formation and non-carcinogenic toxicity in humans. However, since one closed suction system can be used for several days, the use of 6 or more open systems within 72 h in one patient has more impact than the use of one closed system.

Discussion

The findings of this LCA of a closed suction system and an open suction system can be summarized as follows: The environmental impact expressed in terms of human health damage caused by the closed suction system was found to be 6 times greater than for a single open suction system. If a patient requires endotracheal suctioning more than 6 times within 72 h, closed suction systems are more sustainable than open suctioning systems.

To our knowledge, this is the first LCA performed for ICU airway care, and the results can help health care professionals and institutions identify the most environmentally friendly options for patient care. Currently, environmental impact plays an important role in how we organize our care and what materials we use.[11] Ultimately, by making informed choices, health care providers can help minimize the environmental impact of patient care without compromising the quality of care provided. The LCA is a robust method to compare the sustainability of products. Part of the LCA is the inclusion of transport distances and mode of transport. In the current study, the transportation impact was only between 4–6% of the total, as products are transported by ship or truck and not by air, which would have made a much larger contribution to the impact. The analysis in this study serves as a practical illustration of how an LCA can inform decisions regarding the selection of disposable equipment.

In addition to choices regarding environmental impact, a variety of clinical aspects related to the process of care are important when selecting suction systems because both systems have advantages and disadvantages. A recent review showed no difference in patient outcomes, including ventilator-associated pneumonia and mortality, between the 2 systems.[12] With closed suctioning, the ventilation circuit remains intact, preventing possible contamination from aerosols.[4] Ventilation and PEEP settings are believed to be maintained with a closed suctioning system, although this is not confirmed in a bench study.[13] However, open suction can penetrate deeper into the airways and is recommended to remove more mucus but can also cause damage and discomfort. It is known that patients remember endotracheal suctioning as one of the most painful experiences during their stay in the ICU.[14]

In addition to clinical aspects, there are practical issues to consider regarding the organization of care, in particular costs and nursing workload. Depending on local purchasing policy, it seems that closed suction systems have higher initial costs. On the other hand, a closed suctioning system is known to reduce the amount of nursing time by 40%.[12] More research is needed to further evaluate cost-effectiveness and workload of suctioning systems.

This report has limitations as we analyzed only 2 types of endotracheal suctioning disposables, and therefore, the results of these may be less generalizable. However, we focused our analysis on relevant, commonly used disposables. Another limitation is that we did not include additional materials used to perform the procedure, such as gloves and gowns. In current guidelines, the use of personal protection equipment is comparable between the 2 systems, and we do not expect a difference in additional disposables when using an open or closed suction system.

In general, the hierarchical 10R model[15] provides insight in how to contribute to a sustainable and circular economy. If “Refuse” is not an option, “Rethink” and “Reuse” follow the next steps in the hierarchy. With regard to suctioning systems, these data inform clinicians who consider a more sustainable option for the care they provide.

In this LCA, we found that when open suctioning catheters are used more than 6 times within 72 h the use of a closed suctioning catheter is more sustainable. However, open suctioning could be more sustainable in patients who are expected to be ventilated for < 24 h.

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