Article

Rethinking Environmental Sustainability in the Operating Room: Beyond the Reusability Assumption for Surgical Instruments

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Abstract: Addressing the climate crisis is an urgent global priority, yet the healthcare sector continues to face significant challenges in implementing long-term green solutions. The sector accounts for 4.4% of global carbon emissions, with an even greater impact of 7% in the Netherlands. The latest Dutch report- Barometer Groene OK- proposes ten key measures to reduce the healthcare carbon footprint, including a shift from disposable to reusable materials. Although reusable instruments are often promoted as a sustainable alternative, their environmental impact within healthcare is contentious due to resource-intensive sterilization procedures. This critical commentary evaluates the environmental implications of reusable versus disposable surgical instruments, drawing on insights from the existing literature. Although further research is necessary, the initial findings suggest that, under current sterilization practices, disposable instruments may still have a lower environmental impact. At present, the assumption that reusable instruments are inherently more sustainable is overly simplistic. The adoption of sustainable packaging and the optimization of sterilization processes are essential steps to significantly reduce the carbon footprint of reusable instruments; however, these advancements may require several years to develop and to achieve widespread implementation. Switching prematurely to reusable surgical instruments can inadvertently increase the environmental footprint of the sector. Instead, a gradual transition-emphasizing sustainable manufacturing of disposable instruments - alongside advances in sterilization procedures - offers a more balanced and effective pathway toward sustainability in healthcare.

***K*eywords** Carbon Emission · Environmental Sustainability · Reusable · Disposable · Surgical Instruments

1 Introduction

In recent decades, the urgency of the climate crisis has driven industries worldwide to prioritize the pursuit of sustainable solutions. A key aspect of this effort is measuring the compound greenhouse gases emitted by a sector, also known as carbon footprint since generally reported in CO2 equivalents [1]. Despite the efforts, the healthcare sector remains a significant contributor to global CO2 emissions, accounting for an average of 4.4% of the global net carbon emissions [2, 3]. In the Netherlands, this figure is even higher, with healthcare responsible for 7% of the country's total CO2 emissions [4].Sustainability requires taking deliberate actions to reduce emissions through practices like recycling, using renewable energy, and minimizing the release of CO2 and other greenhouse gases.

To address these concerns, 36 Dutch healthcare centers collaborated on the "Barometer Groene OK" report, a strategic initiative designed to formulate action points for reducing CO2 emissions within the sector [5]. One of the key recommendations of the report is to shift from disposable to reusable materials in healthcare settings. The report notes that disposable surgical gowns are among the largest contributors to CO2 emissions. It emphasizes that while single-use materials are still predominant, many operating rooms are transitioning to reusable alternative. The report advises prioritizing the shift towards reusable gowns before expanding to other materials [5]. While the focus of the report is largely on items like gowns and gloves - which are well-documented contributors to CO2 emissions - advising towards a universal reusable shift may be premature, since the environmental impact of other surgical instruments, such as blades and needles, remains less understood. The complex life-cycle of such reusable surgical instruments—including transportation, sterilization, and potential issues like damage and inadequate sterilization—complicates the assessment of their true environmental impact [6].

Although the principle of reusability is often seen as environmentally advantageous, in the case of medical instruments like needles, this assumption may be overly simplistic. In this commentary, we posit that the environmental sustainability of reusable instruments within the healthcare sector is not unequivocally superior to disposable ones. The inefficiencies and high carbon emissions associated with current sterilization processes suggest that the environmental benefits of reusable instruments may not be as clear-cut as assumed. In fact, disposable options, particularly those produced by manufacturers with green policies, may present a lower carbon footprint. Given these complexities, it is crucial to reevaluate the environmental impact of reusable versus disposable surgical instruments.

2 Problem Statement

One often-overlooked aspect of reusable surgical equipment is its extensive life-cycle, which significantly contributes to its overall environmental footprint [6]. This life-cycle includes material extraction, production, sterilization, quality testing, and transportation—each of which adds to the cumulative environmental impact. Therefore, a comprehensive evaluation is necessary to truly determine the sustainability of reusable surgical equipment.

While reusable equipment may initially seem to offer environmental benefits by reducing waste, a deeper analysis may reveal that the cumulative CO2 emissions from its life-cycle are substantial. In contrast, disposable equipment, particularly when produced by manufacturers committed to sustainable practices, may have a lower environmental impact. These manufacturers often adhere to green policies that emphasize efficient production processes and recycling programs, thereby reducing the overall carbon footprint. Jansen et al. (2020) measured a reduction in carbon footprint amounting to 23% when procedures are implemented by manufacturers to optimize disposable procedure trays by simply removing one extra sterile coat in the tray [1].

In this commentary, we gather and analyze data on the environmental impact of both reusable and disposable surgical equipment. While reusable instruments align with waste reduction goals, the associated CO2 emissions from material extraction, production, sterilization, and transportation must also be carefully considered. Our findings suggest that, under current conditions, certain disposable equipment might still represent a greener solution from an environmental standpoint. Further research and development are needed to improve the sustainability of both reusable and disposable healthcare materials, ensuring a holistic approach to reducing the sector's carbon footprint.

3 Full Life-cycle Assessment of Reusable Equipment

The life-cycle of reusable surgical instruments is far more complex and environmentally impactful than that of disposable ones. Leiden et al. (2020) identify five key stages in the life-cycle of surgical equipment: material extraction and production, transportation, sterilization, hospital use, and final disposal [6]. For disposable instruments, the most

significant environmental impact occurs during production. The use of less durable materials and a simpler life-cycle production, single sterilization, use, and disposal—leads to increased waste generation compared to the cyclical use of reusable instrument. While the production of reusable instruments still remains impactful, the primary environmental footprint comes from the energy-intensive sterilization processes necessary to maintain safety and hygiene standards between uses [6]. Reusable instruments undergo repeated sterilization cycles throughout their lifespan, typically lasting about five years before their end-of-life [6, 7].

Although transitioning from disposable to reusable solutions is seen as a key strategy to reduce the carbon impact of surgical rooms, this does not eliminate the high emissions associated with sterilization and packaging. In fact, optimizing sterilization and packaging processes is essential to making reusable instruments a truly sustainable option. Jansen et al. (2020) found that by fully implementing optimized cleaning and sterilization processes, the CO2 footprint could be reduced by 30%. This optimization involves streamlining hospital-wide the washing and disinfecting of surgical sets, which in turn decreases the consumption of energy, electricity, chemicals, water, and steam [1].

3.1. Ideal Solutions Compared to Real-World Challenges

Current calculations of the environmental impact of reusable surgical instruments often rely on ideal scenarios—such as sterilization machines operating at full capacity, using the greenest energy options, with minimal transportation impact. However, these assumptions do not reflect real-world conditions, where inefficiencies in sterilization and transportation can significantly increase the carbon footprint of reusable instruments. A clear example of this discrepancy is seen in the packaging systems used to sterilize surgical instruments [8].

Despite the preference for reusable instruments, the most common method for packaging during sterilization remains single-use blue wrap, contributing approximately for 115 million kilograms of waste annually in the United States alone [8]. This reliance on single-use packaging raises important questions about the true environmental benefits of transitioning to reusable instruments. Friedericy et al. (2022) explored the environmental and cost advantages of shifting from single-use packaging to reusable sterilization containers (RSCs), revealing that these benefits materialize after 98 to 228 use cycles, depending on hospital size and usage volume [8]. In their study, the environmental and economic advantages of switching to reusable RSCs are calculated under the assumption that the machines are fully loaded during each sterilization cycle –crucial for achieving the mentioned break-even points. However, these advantages are contingent on optimal conditions, such as fully loaded sterilization machines, which are often not achieved in practice. Until sterilization processes, including packaging systems and machine utilization, are optimized to ensure maximum environmental and economic efficiency, choosing disposable instrument may still be the more sustainable choice.

The lack of comprehensive data on CO2 emissions further complicates comparisons between reusable and disposable instruments, suggesting that a nuanced approach is needed to ensure that the switch to reusable options genuinely reduces environmental impact. For example, Eckelman et al. (2012) performed a full life-cycle assessment of reusable versus disposable laryngeal mask in a US hospital, demonstrating a reduction on CO2 emission for the reusable alternative [9]. However, Leiden et al. (2020) found that disposable instrument sets in a German hospital had a significantly lower environmental impact compared to reusable sets [6].

While comparing the outcomes of these two studies is not straightforward, due to their differences in study designs and contexts, their contrasting views on the environmental impact of reusable over disposable alternatives are noteworthy. This highlights the importance of careful consideration and context-specific analysis before making decisions between reusable and disposable alternatives. For instance, in Liang (2019), a similar study on the use of disposable and reusable laryngeal mask airways in Sweden, the author concludes that the overall lower environmental footprint of reusable equipment is dependent on the use of renewable energy for sterilization and cleaning, as well as on the minimum number of sterilization cycles required to match a single-use equivalent [10]. If either of these conditions are not met - due to wear and tear, improper cleaning, safety concerns or reliance on fossil-based electricity- then the impact of

reusable equipment becomes significantly higher than projected. Until there is a comprehensive understanding of the carbon footprint of each surgical instrument, it should not be automatically assumed that reusable alternatives are the most sustainable solution.

Additionally, the carbon footprint assessment is also dependent on the geographical region, as different countries use diverse energy sources to produce electricity, which can significantly influence the overall environmental impact. For example, switching from disposable to reusable anesthetic equipment would reduce the CO2 emission by 84% in the UK, while it would increase by 9% in Australia [11].

4 Proposed Solutions

4.1. Comprehensive and Contextual Life-cycle Assessment

Conduct a detailed and context-specific life-cycle assessment (LCA) of both reusable and disposable surgical instruments. This assessment should encompass all stages from raw material extraction, production, transportation, sterilization, usage, and final disposal, as reported by Leiden et al. (2020), Liang (2019), and Eckelman et al. (2012) [6, 9, 10]. Additionally, the LCA should consider regional variations in energy sources, transportation logistics, and hospital practices to provide a more accurate comparison of environmental impacts across different geographical locations. If conducting a full life-cycle assessment and context-specific analysis is not feasible, results from other publications should be taken with extreme caution, as outcomes from one hospital in a specific geographical location may vary significantly from those in another. By doing so, healthcare facilities can make informed decisions that account for local factors, ensuring that the chosen solutions genuinely minimize environmental footprints.

4.2. Optimization of Sterilization and Operational Efficiency

Improve the efficiency of sterilization processes and operational practices within healthcare facilities to reduce the carbon footprint of reusable surgical instruments. This can be achieved by optimizing the loading of sterilization machines to ensure they operate at full capacity, thereby minimizing energy and waste.

4.3. Innovation in Sustainable Packaging and Materials

Develop and implement sustainable packaging solutions for sterilization that reduce reliance on single-use plastics and prioritize the use of recyclable or biodegradable materials. This could involve the transition from single-use blue wraps to reusable sterilization containers (RSCs) that have demonstrated environmental and economic benefits under optimal conditions.

4.4. Sustainable Production and Disposal

Fostering innovations in medical equipment and healthcare technologies could have a significant impact on reducing the carbon footprint of both reusable and disposable instruments. An eco-design approach to medical equipment involves designing and producing new technologies with durable yet easily recyclable materials - a simple yet effective way to save energy when still ensuring patient safety [12, 13]. Collaboration with manufacturers to create a circular economy for disposable surgical instruments—wherein materials are continuously reused and recycled—can also contribute to reducing the sector's overall carbon footprint.

Furthermore, effective disposal of recyclable materials is crucial for mitigating the carbon footprint of operating rooms and preventing loss of raw materials [1]. Despite the common practice of recycling in daily life, its implementation in hospital settings faces significant barriers. A survey of anesthesiologists revealed that the primary obstacles include inadequate recycling facilities and negative staff attitudes, suggesting the necessity for better infrastructure and education to support recycling efforts. The lack of information regarding effective recycling practices highlights the need for

targeted training and awareness programs to bridge the gap [14].Therefore, it is imperative that local manufacturers and hospitals establish collaborations to create comprehensive recycling procedures, thereby minimizing waste and enhancing the sustainability of medical equipment design and usage.

5 Conclusion

While reusable instruments align with the goal of waste reduction, their sustainability is contingent upon optimizing sterilization and operational processes. In some cases, disposable instruments, particularly those produced by manufacturers with strong green policies, may actually present a lower environmental impact. However, the development of innovative, sustainable packaging and materials, coupled with efficient sterilization and comprehensive life-cycle assessments, offers a pathway to reducing the carbon footprint of both reusable and disposable instruments.

The healthcare sector's responsibility to reduce its environmental impact is critical, and achieving this requires a nuanced approach that considers the complexities of both reusable and disposable options. Moving forward, the integration of advanced technologies and sustainable practices will be essential in driving the sector toward genuine sustainability.

In conclusion, the prevailing assumption that reusable surgical instruments are inherently more sustainable than disposable alternatives is overly simplistic and may not hold true in all scenarios. Regional differences in energy sources, hospital practices, and transportation logistics significantly influence the carbon footprint of these instruments. A comprehensive analysis of their full life-cycle reveals that, under current conditions, disposable instruments still have a lower environmental impact. Moving forward, it is essential to enhance the sustainability of both reusable and disposable healthcare materials to effectively reduce the sector's carbon footprint. While optimizing sterilization processes may still present challenges for many hospitals, fostering communication with local manufacturers to implement greener policies for manufacturing, recycling, and reducing waste could be a swift and effective solution. This collaborative approach can significantly enhance the sustainability of surgical instruments, ultimately leading to a more environmentally responsible healthcare sector.

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