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PERSPECTIVES

Advancing Sustainability in Ophthalmic Surgeries and Interventions: A Narrative Review of Environmental Impact and Best Practices

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Abstract: Healthcare is a significant contributor to global greenhouse gas (GHG) emissions, and the field of ophthalmology, particularly through high-volume surgeries such as cataract, glaucoma, and retina interventions, has a considerable environmental impact. This review explores the environmental consequences of ophthalmic surgeries, emphasizing recent research on carbon emissions, waste production, and resource use. It also examines current sustainable practices and suggests evidence-based recommendations to mitigate the carbon footprint of ophthalmic care. Sustainability has become a critical priority in healthcare, particularly in high-volume specialties like ophthalmology, which generate significant environmental impact through resource-intensive surgical procedures. This review examines the carbon footprint of key ophthalmic surgeries—cataract, glaucoma, and retina—and identifies primary sources of emissions, including single-use disposables, energy consumption, and the use of potent greenhouse gases such as sulfur hexafluoride (SF_6) in retina surgery. Strategies to mitigate these impacts are proposed, focusing on transitioning to reusable instruments and supplies, reducing pharmaceutical waste, optimizing energy use in surgical facilities, and considering air tamponade as a viable alternative to high global warming potential (GWP) gases in retina procedures. Case studies, such as the sustainable practices at Aravind Eye Hospital, illustrate the feasibility of combining high-quality ophthalmic care with environmental responsibility. By adopting evidence-based solutions, the field of ophthalmology can significantly reduce its ecological footprint, aligning with global sustainability initiatives while maintaining patient safety and surgical efficacy.

Keywords: sustainability, carbon footprint, ophthalmology

Introduction

Sustainability has become a critical priority in healthcare, aligning with global initiatives such as the United Nations Sustainable Development Goals (SDGs).[1] Sustainability in healthcare refers to the responsible use of resources to meet present needs without compromising the ability of future generations to meet theirs, encompassing environmental, economic, and social factors.[2] Similarly, the term "green" healthcare denotes practices that minimize environmental impact through waste reduction, energy efficiency, and resource conservation.[2] The SDG framework, particularly Goal 3 (Good Health and Well-Being) and Goal 12 (Responsible Consumption and Production), calls for efficient, resource-conscious practices that minimize waste, reduce emissions, and promote environmentally sustainable healthcare systems.[1]

In ophthalmology—a high-volume specialty performing millions of procedures worldwide annually—the environmental impact is significant yet often overlooked. The demand for ophthalmic procedures is rapidly increasing due to aging populations and the rising prevalence of vision-threatening conditions such as cataracts, glaucoma, and diabetic retinopathy.[3] Studies have shown that ophthalmic surgeries, particularly phacoemulsification and vitrectomy, generate significant carbon emissions, raising concerns about long-term sustainability.[4–6]

Despite these challenges, ophthalmology has a unique opportunity to lead in sustainable surgical practices. Existing research highlights potential interventions, such as transitioning to reusable instruments, reducing pharmaceutical waste,

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optimizing energy use in surgical facilities, and modifying surgical techniques to be less resource-intensive.[7–11] However, comprehensive, evidence-based strategies tailored to ophthalmology remain underexplored. This review aims to synthesize current knowledge on the environmental impact of ophthalmic procedures and present practical, evidence-based solutions to enhance sustainability. By addressing these issues, ophthalmologists can align their practices with global sustainability goals, ensuring long-term environmental and public health benefits.

Environmental Impact of Ophthalmic Surgeries

Carbon Footprint

The carbon footprint of healthcare, particularly in surgical specialties, is a growing environmental concern.[2] Ophthalmic surgeries, including high-volume cataract procedures, vitreoretinal repairs, and glaucoma surgeries, contribute significantly to greenhouse gas emissions through energy-intensive equipment, single-use disposables, and high-impact gases like SF_6 and C_3F_8.[4–6,12–14] Studies have documented the environmental impact of these procedures, highlighting the need for sustainable practices within ophthalmology to mitigate emissions while maintaining patient care quality.[4–6,12–14] The following sections will delve into the carbon footprint of cataract, vitreoretinal, and glaucoma surgeries, and proposes strategies to enhance sustainability in ophthalmic care.

Environmental Impact and Sustainable Practices in Cataract Surgery

Overview of Cataract Surgery's Carbon Footprint

Cataract surgery, one of the most frequently performed procedures globally, has a significant carbon footprint due to its reliance on energy-intensive equipment, single-use instruments, and disposable supplies. Studies reveal that the carbon footprint of cataract surgery varies considerably between countries and healthcare settings. For example, in France, a single cataract procedure emits approximately 81 kg of CO_2 equivalent (CO_2e), driven primarily by disposable materials and patient transportation.[13] In the UK, the carbon emissions per cataract surgery can reach 181.8 kg CO_2e, largely due to procurement and building energy use.[6] These studies underline the necessity for sustainable practices in cataract care to minimize environmental impact (Table 1).

Table 1 Per-Case CO_2 Emissions in Ophthalmic Surgeries

Study	Country, Year	Procedure	CO2 Emissions	Primary Source of CO2 Emissions
Morris DS et al[6]	UK, 2014	Phacoemulsification	181.8kg of CO_2e	Procurement of surgical consumables
Thiel CL et al[14]	India, 2017	Phacoemulsification	6kg of CO_2e	Sterilization process of reusable instruments
Latta et al[15]	New Zealand, 2021	Phacoemulsification	152kg of CO_2e	Procurement of disposable material
Power et al[16]	Ireland, 2021	Intravitreal injection	13.68kg of CO_2e	Patient travel
Chandra et al[17]	New Zealand, 2022	Intravitreal injection	14.1kg of CO_2e	–
Ferrero et al[13]	France, 2022	Phacoemulsification	81.13kg of CO_2e	Procurement of disposable medical devices
Moussa et al[5]	UK, 2022	Rhegmatogenous-retinal-detachment (RRD) and macular hole repair	60 and 32kg of CO_2 e respectively	-

Notes: *CO_2e: Carbon dioxide equivalent. This table summarizes the estimated CO_2 emissions per procedure for various ophthalmic surgeries, highlighting the primary sources of emissions and relevant references from the literature.

Sources of Emissions in Cataract Surgery

The carbon footprint of cataract surgery is predominantly associated with four main factors:

1. Procurement and Disposal of Disposable Supplies: The procurement and life cycle of single-use items—such as gowns, drapes, and instrument packs—constitute the largest source of emissions, accounting for up to 73% of the carbon footprint in some cases.[7,13,15]
2. Energy Use in Surgical Facilities: Building energy consumption, particularly in heating, ventilation, and sterilization processes, contributes significantly to the carbon footprint. In the UK, building energy alone accounted for around 36% of total emissions per procedure.[6]
3. Pharmaceutical and Medical Waste: Unused pharmaceuticals and sterile supplies generate considerable waste. Studies from the United States have shown that 21.3% to 65.8% of prepared medications were discarded, costing up to $195,200 annually per site and generating significant environmental impact, with monthly emissions from wasted drugs reaching up to 2498 kg CO_2-equivalent adding both financial and environmental costs.[18]
4. Patient and Staff Travel: Patients often travel multiple times for assessments, surgery, and follow-ups, which increases fossil fuel consumption and adds to the carbon footprint. Studies indicate that patient travel accounts for about 10% of healthcare's carbon emissions, especially in cases requiring multiple follow-ups.[6]

Strategies for Reducing Environmental Impact in Cataract Surgery

Several strategies have been proposed to reduce the environmental impact of cataract surgery while maintaining high standards of patient safety:

1. Transition to Reusable Instruments and Supplies: Transitioning to reusable instruments and supplies can significantly reduce waste in cataract surgery, but this shift must be balanced with patient safety considerations. Two studies highlighted the risks associated with reusing single-use devices, such as phacoemulsification packs and incisional knives.[19–21] While reuse can lower costs, the study found that residual materials left on reused instruments may increase the risk of postoperative infections like endophthalmitis.[19,20] However, it remains unproven that these debris directly cause infections, and the authors recommend prospective studies to confirm this potential link. Meanwhile, they advocate for stringent reprocessing protocols and suggest that healthcare institutions establish oversight committees to ensure reusability practices meet safety standards. Another study demonstrated that repeated use of phaco tips labeled for single use did not result in significant ultrastructural damage, suggesting these tips could withstand multiple uses under controlled conditions.[11]

Given these risks, the reuse of certain surgical instruments may require careful evaluation. However, transitioning to sterilizable surgical gowns, which has been shown to decrease waste, remains a feasible and effective strategy to enhance sustainability in ophthalmic surgery.[10]

On the other hand, while recycling in surgical settings can reduce waste, its impact may be limited compared to other factors like energy-intensive processes. For example, waste segregation during cataract surgeries in Malaysia could cause a 30% reduction in carbon footprint, 0.139 kg CO_2e saving per case, is not revolutionary, as it is less than 1% of the total carbon costs of a cataract case.[19] There are calls for focusing on more impactful measures beyond recycling alone.[20]

Additionally, modifications to surgical draping techniques can further reduce waste without compromising sterility. The routine use of full-body surgical drapes contributes to unnecessary waste, while a face drape alone may provide sufficient coverage for cataract surgery. Notably, over 20% of the waste by weight in cataract surgery comes from surgical draping during the procedure.[14] Reducing excess draping, in combination with the use of intracameral antibiotics, can help maintain low infection rates while significantly reducing carbon emissions.

2. Optimizing Pharmaceutical Usage: Reducing the amount of unused pharmaceuticals by adopting multidose vials for multiple patients or allowing patients to take home partially used medications to reduce waste.[18] The UK's

surgical colleges developed a "Green Theatre Checklist" in 2023 to guide practices that reduce emissions, including minimising drug waste during the anaesthetic preparation, and switching to low carbon alternatives (eg topical anaesthesia for cataract rather than sub-tenons).[21]

3. Streamlining Energy Use in Operating Rooms: Implementing efficient HVAC systems, using LED lighting, and optimizing energy use during non-operating hours can decrease emissions associated with building operations.[22]
4. Surgical Technique Modifications: Adopting techniques with lower resource requirements, such as Manual Small Incision Cataract Surgery (MSICS), which has a lower environmental impact compared to phacoemulsification, can significantly reduce overall emissions. MSICS is more sustainable because it requires less energy, uses fewer disposable supplies, and does not rely on high-resource-consuming phacoemulsification machines. These factors make it particularly relevant in low-resource settings, where reducing waste and optimizing resource use are critical for sustainable eye care.[23]
5. Implementing Bilateral Cataract Surgery: Bilateral cataract surgery, where both eyes are treated in the same visit, can minimize patient travel, reduce clinic visits, and lower energy use. This approach is particularly beneficial in reducing emissions in remote and underserved regions, where patient travel often represents a significant portion of the environmental burden.[24] A key concern with bilateral sequential cataract surgery has been the risk of bilateral endophthalmitis, though this remains extremely rare.[24] The use of intracameral moxifloxacin has dramatically reduced the incidence of endophthalmitis, making the procedure safer while potentially supporting more sustainable practices in ophthalmology.[25]
6. Reduction in fossil fuel use: outpatient appointments can be either avoided or conducted via other means (eg telephone consultation).[25]

Key Insights for Sustainable Eye Care

Unequal Environmental Costs in Different Regulatory Settings

- A key finding from a study by Buchan et al,[20,26] was the stark difference in environmental costs between high- and low-income countries. For instance, a cataract procedure in the UK generates over 20 times the emissions of the same procedure in India, despite both achieving high patient satisfaction and similar clinical outcomes. This suggests that the regulatory environment in high-income countries often drives resource-heavy practices that may not provide proportionate safety or quality benefits, making a case for streamlined, sustainable alternatives.

Balancing Safety and Environmental Costs

While new healthcare interventions must demonstrate cost-effectiveness, safety practices do not always require similar justification. As a result, practices introduced for theoretical safety gains often have high financial or environmental costs with limited benefit. There is currently no metric to evaluate the CO_2 emissions per quality-adjusted life year (QALY) gained, a gap that has been suggested to be addressed to balance environmental and patient safety impacts effectively.[19].

Leveraging Ophthalmology's Market Influence

As a large specialty with substantial purchasing power, ophthalmology can influence sustainable practices beyond its field by encouraging eco-friendly manufacturing, packaging, and energy solutions. By prioritizing research and strategic planning, the eye care sector has the potential to drive significant improvements in healthcare's environmental footprint and contribute positively to global climate goals.[19].

Education in Sustainable Healthcare

- Sustainability principles are increasingly integrated into medical education. The Medical Schools Council in the UK has endorsed a curriculum on sustainable healthcare, and the NHS supports programs to train healthcare professionals in environmentally sustainable practices.[20]

Case Study: Aravind Eye Hospital as a Model of Sustainable Cataract Surgery

Aravind Eye Hospital in India serves as a global model for sustainable ophthalmic care.[14] By implementing a high-efficiency model that minimizes waste and reduces emissions, Aravind has achieved a low per-surgery carbon footprint.

Aravind's approach includes several innovative practices:

- Reusable Instruments and Supplies: Aravind uses reusable surgical tools, including stainless steel instruments, gowns, and drapes, which are cleaned and sterilized using efficient autoclave cycles. Surgical gloves are reused multiple times after being sterilized with antiseptic gel, while gowns and drapes are laundered daily.
- Streamlined Surgical Workflow: Surgeons at Aravind operate with two tables, allowing for continuous flow from one patient to the next. This model enables them to perform between 750 and 1500 surgeries per day, optimizing resources and reducing per-patient emissions.
- Water and Energy Conservation: Aravind has invested in sustainable energy solutions, including solar power, and uses water-saving devices to minimize water consumption.
- Decentralized Vision Centers: With numerous vision centers in rural and underserved regions, Aravind minimizes patient travel. Staffed by mid-level personnel and connected to the hospital via telemedicine, these centers provide local screenings, significantly reducing emissions associated with patient travel.

This model is both sustainable and effective. Aravind's endophthalmitis rate is 0.01%, lower than many global benchmarks, showing that high-quality care and environmental responsibility can coexist.[14,25] Compared to a cataract surgery in the UK, which generates emissions equivalent to driving 700 kilometers,[6] Aravind's approach emits only 0.25 kg of solid waste and around 6 kg of CO_2, roughly equivalent to a 25-kilometer drive. Aravind's model exemplifies how sustainable practices can enhance quality care while reducing environmental impact.

Environmental Impact and Sustainable Practices in Glaucoma Surgery

Environmental Burden of Glaucoma Procedures

Although we did not find a study measuring and calculating the carbon footprint of glaucoma surgery, we did find a study by Namburar et al[12] which examined the waste generated during glaucoma surgery and compared it between two institutions: the Aravind Eye Hospital in India and a community hospital in the United States. The study found that the average waste produced per trabeculectomy was significantly lower at Aravind (0.5 kg) than at the US hospital (1.4 kg). This difference highlights variations in waste generation due to institutional practices, with Aravind's practice of reusing certain sanitized materials leading to reduced waste without compromising patient safety.

Strategies for Reducing Environmental Impact in Glaucoma Surgery

1. Selective Laser Trabeculoplasty (SLT) as a First-Line Treatment: The LiGHT trial demonstrated that SLT can effectively manage intraocular pressure (IOP) in newly diagnosed glaucoma patients, offering a drop-free alternative to traditional medication.[26] This reduces reliance on single-use drug packaging and decreases patient visits, ultimately lowering the environmental impact.
2. Implementing Reusables in Trabeculectomy and Tube Shunt Procedures: Surgical teams can adopt sterilizable instruments, drapes, and gowns in trabeculectomy and tube shunt surgeries. A shift to reusable materials has shown potential for considerable reductions in waste and costs.[27]

Environmental Impact and Sustainable Practices in Retina Surgery and Injections Clinic

Overview of Environmental Impact in Retina Surgeries

Retina surgery, particularly vitreoretinal procedures, contributes significantly to healthcare's carbon footprint, largely due to the use of fluorinated gases for tamponade, such as sulfur hexafluoride (SF_6), hexafluoroethane (C_2F_6), and octafluoropropane (C_3F_8).[4,5] These gases have extremely high global warming potentials, with SF_6 producing CO_2-

equivalent emissions up to 23,500 times greater than the same amount of CO_2.[5] A study by Moussa et al[5] quantified the emissions generated by various types of vitreoretinal surgery across multiple UK hospitals, finding that procedures using SF_6 accounted for 68.8% of total emissions, despite SF_6 being used in only 38.6% of cases. Rhegmatogenous retinal detachment (RRD) and macular hole surgeries were the highest contributors, averaging 60.0 kg and 32.0 kg of CO_2-equivalent emissions per surgery, respectively.[5]

A separate study explored the environmental benefits of using air tamponade instead of fluorinated gases for RRD repairs.[4] The findings indicated that air tamponade could reduce CO_2 emissions by up to 47% compared to SF_6, offering a viable alternative with minimal environmental impact while maintaining surgical efficacy. The research underscores the potential for adopting air or other low-impact alternatives in vitreoretinal surgeries to decrease the environmental burden of these procedures.[4]

Relevant to the macula intravitreal service, a single intravitreal injection emits around 13 to 14 kg CO2e,[16,17] 77% of which is accounted for by patient travel.[16] With macula conditions requiring repeated attendances by patients to have these injections results in a significant accumulation of GHG emissions.[16]

Strategies for Reducing Environmental Impact in Retina Surgery

1. Air Tamponade as an Alternative: Air tamponade is a viable, low-impact alternative to fluorinated gases in specific retinal surgeries, such as macular hole repair and some cases of retinal detachment.[28,29] Two recent studies have evaluated the efficacy of air tamponade as an alternative to gas tamponade in ophthalmic surgeries, particularly in macular hole repair and rhegmatogenous retinal detachment (RRD) procedures. The first study retrospectively analyzed 211 eyes undergoing pars plana vitrectomy for idiopathic full-thickness macular holes.[29] Of these, 171 eyes received gas tamponade (primarily sulfur hexafluoride [SF_6]), while 40 eyes underwent fluid-air exchange without gas placement. The results indicated no statistically significant difference in hole closure rates between the two groups, suggesting that air tamponade is as effective as gas tamponade for macular hole repair.[29]

The second study conducted a prospective examination of the effectiveness of air tamponade in rhegmatogenous retinal detachment (RRD) repairs.[28] This study included 194 eyes that underwent pars plana vitrectomy with air tamponade. The findings were promising, with a high primary success rate of 97.9%, indicating that air tamponade achieved retinal reattachment in nearly all cases without the need for subsequent procedures.[28]

2. Diluting High-GWP Gases: When air tamponade is not suitable, diluting fluorinated gases like C_2F_6 or C_3F_8 can reduce their environmental impact while maintaining therapeutic duration.[5] By using diluted concentrations, surgeons can achieve effective tamponade with a lower emission profile than undiluted gas, contributing to a decrease in greenhouse gas emissions.
3. Long-acting intravitreal injections: Research must focus on developing longer-acting agents to reduce the number of repeated injections required by patients in managing macula diseases.[28]
4. Research and Technology in Teleophthalmology: Teleophthalmology is described as a promising approach for sustainable ophthalmic care, allowing real-time examinations without the need for patient travel. Some innovations, including smartphone-assisted examinations, can enable virtual diagnostics and treatment monitoring, particularly for chronic diseases like diabetic retinopathy and glaucoma.[30]

Limitations

This review provides a broad overview of sustainability challenges and potential solutions in ophthalmic surgery; however, several limitations must be acknowledged. As a narrative review, it is subject to selection bias, as the included literature was chosen based on relevance rather than a systematic methodology. Additionally, the lack of standardized metrics for measuring the environmental impact of ophthalmic procedures limits direct comparisons between studies.

Future Research Directions

Future studies should focus on identifying scalable, evidence-based strategies to enhance sustainability in ophthalmology while considering variations in healthcare infrastructure. Comparative life cycle assessments of ophthalmic procedures could provide clearer insights into the environmental impact of reusable versus disposable instruments. Research on resource-efficient surgical workflows, including optimized sterilization protocols and low-waste surgical packs, could inform practical hospital-level interventions. Additionally, evaluating the effectiveness of sustainability policies and manufacturer-led waste reduction efforts would help shape industry standards. Given the disparities in healthcare resources, it is also essential to explore how sustainable practices can be adapted to low-resource settings, ensuring feasibility and equity across different regions.

Conclusion

- In conclusion, the healthcare sector, and ophthalmology in particular, is increasingly focused on aligning with global sustainability goals. This review highlights the substantial carbon footprint of high-volume ophthalmic surgeries, such as cataract, glaucoma, and retina procedures, and identifies sources of emissions across surgical equipment, disposables, pharmaceuticals, and energy use. The findings underscore the importance of adopting sustainable practices, including the transition to reusable supplies, optimized pharmaceutical usage, energy-efficient surgical environments, and alternative surgical techniques such as air tamponade in retina surgeries. Notably, models like Aravind Eye Hospital showcase how institutions can balance high-quality care with minimal environmental impact.
- Collaboration between high- and low-income countries could foster resource-efficient models that are both safe and environmentally sustainable. Additionally, incorporating environmental costs into healthcare policies may drive broader adoption of green practices.
- By integrating evidence-based sustainable practices, ophthalmology can significantly reduce its ecological footprint while ensuring patient safety and high standards of care, paving the way for a more responsible and resilient healthcare future.

Disclosure

The authors report no conflicts of interest in this work.

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