Review

Sustainable Ophthalmology Applications: From the Perspective of Strabismus and Pediatric Ophthalmology

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Abstract

Ophthalmology significantly contributes to the healthcare sector's carbon footprint. Despite recent increases in sustainability research in ophthalmology, there remains limited information on initiatives specific to pediatric ophthalmology and strabismus. This review aims to examine the existing literature and provide insights into sustainability and reducing carbon footprints in these areas. Although there has been no specific assessment of carbon emissions associated with congenital and developmental cataracts, measures related to cataract surgery and operating room practices remain relevant. Strabismus surgeries can be considered environmentally friendly, affordable, and energy-efficient procedures. Involving non-ophthalmologist personnel, expanding telemedicine applications, and restructuring outpatient services could reduce clinic congestion, lower costs, and improve sustainability. Some amblyopia examinations requiring long-term follow-up could be performed at local healthcare centers. While compliance and effectiveness are primary concerns in patching treatment, it is crucial to acknowledge that the patches generate significant waste and carbon footprints. Therefore, exploring alternative solutions is essential. Anesthesia poses an additional challenge for pediatric examinations, and various strategies have been suggested to reduce carbon dioxide emissions. Additionally, artificial intelligence is promising and its integration into pediatric ophthalmic examinations could further enhance sustainability. In brief, although pediatric ophthalmology and strabismus are considered environmentally friendly subspecialties of ophthalmology, especially in the operating room, there are many steps that can be taken for "sustainable ophthalmology," from anesthesia to amblyopia treatment and outpatient clinic services.

Keywords: Sustainability, carbon footprint, climate change, strabismus, pediatric ophthalmology

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Introduction

Climate change and increased greenhouse gas emissions are among the greatest threats to health worldwide.[1] Healthcare services contribute significantly to the climate crisis due to their broad scope and specific requirements. World Bank and World Health Organization data indicate that as of 2020, the health sector was responsible for approximately 4%-5% of global carbon dioxide equivalent (CO_2eq) emissions.[2]

Sustainability has become a major priority in health care, with numerous initiatives being taken globally, most notably the United Nations Sustainable Development Goals.[3] Sustainability and "green" health care involve practices that minimize environmental impact through waste reduction, energy efficiency, and resource conservation with the aim of creating a sustainable environment for future generations. Numerous studies conducted in various fields have started to raise awareness of this important issue in recent years.[4]

Ophthalmology is one of the largest healthcare sectors, with millions of outpatient services and surgeries performed worldwide every year. As the world population and average life expectancy continue to increase, the demand for ophthalmological care is also growing. Important steps can be taken to achieve sustainability goals in this area, such as the widespread use of reusable instruments, reduction of drug waste, and optimization of energy and resource use in operating rooms. Recently, there has been an increase in publications and studies on sustainability in ophthalmology practices.[5] A closer investigation of the literature demonstrates that current research has primarily focused on surgical procedures, especially cataract surgery. This is not surprising, as cataract surgery is one of the most commonly performed surgical procedures, not only in ophthalmology, but among all medical specialties.[6] In addition to cataract and cataract surgery, there are also a few reports concerning vitreoretinal, corneal, and glaucoma surgery and outpatient services.[7,8,9,10]

Pediatric ophthalmology and strabismus are subspecialties that encompass both the anterior and posterior segments of the eye, as well as central nervous system connections such as the afferent and efferent visual pathways. A wide range of diseases such as amblyopia, cataract, nystagmus, retinopathy of prematurity, and strabismus fall within this field of study. Both outpatient services and surgical procedures generate significant resource utilization.[11] However, research on sustainability in this area is limited. This review aims to analyze the existing literature and provide insight into sustainability and carbon footprint reduction in pediatric ophthalmology and strabismus.

Literature Review

A comprehensive literature review on sustainability and carbon footprint reduction in ophthalmology was conducted using the PubMed and Google Scholar databases. The initial screening was performed using the keywords sustainability, carbon footprint, greenhouse gas, CO_2eq emission, telemedical, teleophthalmology, climate change, eye health, ophthalmic surgery, cataract, travel, artificial intelligence, strabismus, amblyopia, and pediatric ophthalmology. No restrictions were imposed in terms of time, language, or geography. Article titles and abstracts were screened, and publications on pediatric ophthalmology and strabismus were selected for full-text review. Only English abstracts were used for articles that were not written in English or had no English translation available.

A Brief Review: The Core Principles of Sustainability

To facilitate applicability and understanding, the principles of sustainability can be summarized as the 5R rule: Reduce, Reuse, Recycle, Rethink, and Research.[12] In ophthalmology, these principles can be applied both in the operating room and in the outpatient clinic. The rest of this review will focus on actions specific to strabismus and pediatric ophthalmology.

Measures to Take in the Operating Room

The operating room is a large workspace where various sustainability measures can be implemented. Cataract surgery is responsible for a significant portion of ophthalmology's carbon footprint because of the high patient circulation, overuse of disposable instruments and equipment, and reliance on devices with high energy consumption.[13] Morris et al.[14] estimated that the total carbon footprint of 343,782 cataract surgeries performed in England in 2011, including building and energy use, travel, and supply factors, was approximately 63,000 tons of CO_2eq. The carbon footprint of a single cataract surgery was reported to be 151.9 kg CO_2eq in New Zealand, 86.62 kg in Spain, and 81.13 kg CO_2eq in France.[15,16,17]

Several strategies have been proposed to make these procedures more environmentally friendly without compromising patient safety. These strategies primarily include simple, practical solutions to reduce energy consumption in operating rooms, such as turning off lights and ventilation when the room is not in use, and powering down equipment when not needed.[18] Another strategy is to reuse equipment or choose equipment designed to be reusable. Kallay et al.[19] found that a phacoemulsification device with specially designed reusable cassettes provided a 75.3% reduction in plastic waste production compared to conventional devices with disposable cassettes, without posing any risk to patient safety. Noteworthy studies on equipment reuse have been conducted in 11 regional eye hospitals within the Aravind Eye Care System in South India. In this region, surgical gloves, gowns, irrigation/aspiration probes, irrigation bottles, scalpels, and cannulas are widely reused to reduce costs and minimize waste generation, with post-cataract endophthalmitis rates similar to or below global rates.[20,21] Another measure that can be taken is to improve waste management. Most operating room waste consists of recyclable materials such as paper, plastic packaging, metal, and glass.[14] Khor et al.[22] reported that approximately 57% of the waste generated in cataract surgery can be classified as clinical waste, 38% as general waste, and 6% as sharps waste. Fifty-one percent of the general waste produced can be recycled, which would reduce CO_2eq emissions from 0.421 kg to 0.282 kg per operation.

There are no studies in the current literature evaluating carbon emissions related to congenital and developmental cataracts specifically. However, the above-mentioned carbon emission sources and solutions also apply. Nevertheless, when implementing these measures, it should be kept in mind that pediatric patients may be more prone to infection and inflammatory conditions and can have different outcomes than adults.

We also found no study specifically examining measures that can be taken in strabismus surgery. However, economic analyses have shown that strabismus surgery is cost-effective.[23,24] Beauchamp et al.[24] conducted a cost-benefit analysis of adult strabismus surgeries and found that the estimated total cost per case was $4254 according to the model they developed. When evaluated according to quality-adjusted life year (QALY) gains, adult strabismus surgery costs $1632/QALY. This is very cost-effective compared to other ocular procedures such as cataract surgery ($2093/QALY for the first eye, $2863/QALY for the second eye), pars plana vitrectomy for diabetes-related vitreous hemorrhage ($2038/QALY), and amblyopia treatment ($2395/QALY).[25,26,27]

In a study on waste production in ophthalmic surgeries, Lever et al.[28] reported that intraocular procedures produced approximately 80% more waste than extraocular procedures. A very recent study conducted at Ann & Robert H. Lurie Children's Hospital in Chicago examined CO_2eq emissions produced during strabismus surgery. The CO_2eq emissions of the materials used were calculated using the Sustainability Index tool of the European Society for Cataract and Refractive Surgery, and the average total CO_2eq emission per case was determined as 4.80 kg. The largest component in this average was surgical drapes, which produced an average of 2.54 kg CO_2eq and represented 53% of the average emissions per case. This was followed by unused operating room towels (1.51 kg CO_2eq) and cotton-tipped applicators (0.33 kg CO_2eq).[29] Although it varies by country and the metrics used, strabismus surgery is an efficient and environmentally friendly procedure, considering that the CO_2eq emissions associated with a single cataract surgery range from 81.13 to 151.9 kg.

Reorganizing Polyclinic Services

Advances in telemedicine and the continuation of practices that originated as COVID-19 measures have led to increased usage of local health centers and virtual clinics as an alternative to traditional face-to-face visits.[30] These approaches are also time- and labor-efficient, making them an attractive option in the restructuring of outpatient clinic services. With the growing awareness of sustainability in ophthalmology, it is increasingly recognized that these methods not only save time and effort, but also support sustainability by reducing transport, building, and energy use and decreasing waste production. However, telemedicine services create their own carbon footprint, especially in terms of server and digital device use. Holmner et al.[31] compared CO_2eq emissions generated during telemedical appointments and routine services and determined that telemedicine services became carbon cost-effective when the transportation distance was more than 7.2 km.

Pediatric ophthalmology and strabismus practice involves a large team of pediatric ophthalmologists, strabismus specialists, opticians, nurses, and other staff.[32] Reorganizing outpatient clinic services to include non-physician personnel in the system can reduce clinical intensity, reduce costs, and increase sustainability. An interesting study on this topic was conducted by Francis et al.[33] at NHS Sheffield Teaching Hospitals in the United Kingdom. The study team has implemented virtual strabismus clinics since January 2015 and further developed these outpatient clinics during the COVID-19 pandemic. They provide an environmentally friendly and sustainable service that reduces travel, parking costs, energy consumption, and waste while ensuring that patients are served in a timely manner. Studies conducted in other countries have also reported favorably on the integration of non-physician personnel into the system. In Spain, 90% of 42 pediatric ophthalmologists and strabismus specialists supported the inclusion of orthoptists in the team because they believed it would alleviate the patient burden.[34]

Amblyopia Management: Another Major Challenge in Pediatric Ophthalmology

A 2020 meta-analysis evaluating a total of 16,385 cases from 60 studies indicated an amblyopia prevalence of 1.44%. In 2019, there were approximately 99.2 million amblyopes worldwide, with this number expected to increase to 175.2 million by 2030 and 221.9 million by 2040.[35] Amblyopia treatment usually requires repeated examinations over a long follow-up period. Considering the increasing prevalence of amblyopia, this suggests substantial carbon emissions from transportation.

Thomas et al.[36] compared the transportation distance, time in clinic, and treatment costs of amblyopic children followed up in a hospital versus local health centers and found that all three parameters were lower in local health centers (Table 1). Therefore, performing post-diagnosis follow-up and control examinations at local health centers can be considered as a safe, cost-effective, time-saving, and environmentally friendly option.

Table 1. Average transportation, waiting times, and treatment costs for amblyopic children treated in hospitals and local health centers

	Hospital	Local health center (n=71)
Mean transportation distance (miles)	(n=92)	3.7
Mean time in clinic (minutes)	(n=71)	20
Mean examination cost (pounds)	100	55

Another problem in amblyopia management is the waste produced by disposable patches. Although the literature on occlusion therapy mainly focuses on compliance and efficacy, the patches used are also thought to cause significant waste and carbon footprint production. Despite various alternative treatments such as penalization, pharmacotherapy, and levodopa, occlusion therapy still remains the gold standard for amblyopia.[37,38] Aside from patches, various products such as opaque spectacles, Doyne occluders, Bangerter filters, and contact lens occluders have been developed and marketed specifically to address compliance problems.[39] As an affordable and eco-friendly option, patches made of fabric and foam fixed to the head with an elastic strap may be a good alternative. Moreover, a study by the Pediatric Eye Disease Investigator Group (PEDIG) found that Bangerter filters provided vision gains equivalent to 2 hours of occlusion per day in children with moderate amblyopia (20/40-20/80).[40] PEDIG also reported that atropine and occlusion provided similar visual gains in children with moderate amblyopia.[41] These alternative treatment options can be considered in children with mild to moderate amblyopia especially, both to increase compliance and reduce the environmental impact of treatment. Furthermore, Abu-Ain and Watts[42] emphasized that occlusive contact lenses had an acceptable side effect profile and may offer an alternative treatment for amblyopia.

Ophthalmologists' Carbon Footprint: Analysis of the 2021 and 2022 AAPOS Annual Meetings

In addition to the known sources of greenhouse gas emissions in health care, the carbon footprint associated with professional conferences have also become a subject of research.[43] A noteworthy study conducted by West and Hunter[44] examined the carbon footprint of pediatric ophthalmology meetings. The authors compared the CO_2eq emissions of the 2021 and 2022 AAPOS Annual Meetings, which were held virtually due to the pandemic, with the CO_2eq emissions of face-to-face meetings. The study team found that in 2021, the virtual meeting format saved 1,282 tons of CO_2eq emissions, which is equivalent to the emissions of 264 vehicles used for a year. Although face-to-face meetings offer advantages such as facilitating interaction, business partnerships, and workshop and course participation, they create a significant transportation and accommodation burden worldwide, leading to a serious carbon footprint.

Anesthesia: An Added Problem in Pediatric Examinations

Datta et al.[45] randomized 50 children aged 1-5 years undergoing ophthalmological examination under anesthesia into two groups. Both groups received 8% sevoflurane in O_2:N_2O (40:60), followed by a standard 2% sevoflurane regimen with 1 L/min fresh gas flow (50:50) in one group (Group S), while in the other group (Group L), sevoflurane was discontinued and the fresh gas flow was reduced to 0.5 L/min. Effective anesthesia time showed no difference between the groups (median 14-15 minutes), whereas Group L used 2 mL less sevoflurane ($p<0.001$, 95% confidence interval: 0.96-3.04) and 3.75 mL less nitrous oxide per case. In addition, laryngeal mask removal time was shorter in Group L compared to Group S (86 s vs. 131 s; $p=0.002$, 95% confidence interval=19.85-70.15). This anesthesia approach produced an average of 11,327 L less carbon dioxide per day. The study team concluded that this method can reduce the negative environmental impact without affecting the duration and quality of anesthesia.[45]

Pediatric patients are a high-risk group for hypothermia due to the lower capacity of the central nervous system to regulate body temperature, the different body weight/surface area ratio than adults, and lower amount of subcutaneous adipose tissue.[46] Rather than addressing this by heating the entire operating room, forced-air heating has been recommended as a sustainable measure to maintain adequate body temperature throughout the procedure.[47]

Finally, the laryngeal airway mask (LMA) has been used for many years in ophthalmic surgery and offers advantages over tracheal intubation in terms of intraocular pressure and cardiovascular stability.[48] In a study of pediatric patients, the LMA was also found to be advantageous over conventional intubation in terms of both anesthesia time and awakening time.[49] This should be taken into account in terms of anesthesia efficiency, especially the efficiency of the operating room.

Artificial Intelligence in Pediatric Ophthalmology and Strabismus

Artificial intelligence has started to play a role in the diagnosis and management of various anterior and posterior segment pathologies, optic nerve diseases, strabismus, and pediatric diseases. With improvements in diagnostic accuracy, it has become particularly valuable in reducing workload and costs related to screening.[50] Chen et al.[51] introduced a deep learning-based screening method that can diagnose 16 common eye pathologies in children, including strabismus. In another study, Long et al.[52] developed a system that successfully identified abnormal patterns (area under the curve: 86.4%-93.0%) by analyzing the behavioral phenotypes of 4,196 infants. Shu et al.[53] reported that an artificial intelligence model they developed effectively detects myopia, strabismus, and ptosis (with 84%, 73%, and 85% sensitivity, respectively) using mobile phone photographs.

In addition, mobile photo-supported applications have been developed that can quantitatively measure strabismus deviation. These programs may be useful for both orthoptists and strabismus specialists in teleophthalmology examinations, diagnosis, and even surgical decision-making.[54,55] Several other studies report similarly successful results, and it is believed that artificial intelligence will become an important part of examinations once standardization is achieved.[56,57,58] Such advances will help conserve resources and promote sustainability in many areas such as transportation, waste management, and energy consumption.

In summary, although research on sustainability practices has increased in recent years, there is still limited information on what can be done in pediatric ophthalmology and strabismus. In addition to the general principles of sustainability that can be applied in outpatient clinics and operating rooms, certain measures related to the core areas of pediatric ophthalmology and strabismus can help reduce its carbon footprint, such as involving non-physician personnel (e.g., optometrists), performing amblyopia examinations in local health centers, integrating artificial intelligence, and modifying anesthesia protocols. However, it should be kept in mind that the existing literature stems from very different health systems, and results may vary in countries with different levels of development and different practice patterns.

Declarations

Authorship Contributions

Concept: M.P., E.D.B., Design: M.P., E.D.B., Literature Search: Z.A., Writing: Z.A., E.D.B., M.P.

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