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REVIEW

Sustaining Ophthalmic Practices for the Future: A High-Value Care Approach to Environmental Responsibility

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ABSTRACT

Ophthalmology, like all medical specialities, is continuously evolving to adapt to emerging challenges and advancements. The evidence-based medical practices that previously guided policies and regulations may no longer be sufficient or sustainable in the context of an ageing population, increasing healthcare demands, and the urgent need for sustainability. As the global burden on healthcare systems grows, sustainability must be considered from multiple perspectives, including financial and environmental aspects, without compromising patient outcomes. While financial sustainability is essential to ensure cost-effective resource allocation, accessibility, and affordability for both healthcare providers and patients, environmental sustainability is becoming an increasing priority. Efforts to minimise the carbon footprint associated with medical procedures, transportation, and the production and disposal of ophthalmic equipment and materials are necessary. This paper highlights key examples of areas within ophthalmology where sustainability can be enhanced by practicing high-value care. We describe targeted opportunities that demonstrate how sustainable practices can be successfully integrated into ophthalmology without compromising patient care or operational feasibility.

Keywords: High value care; Sustainability; Efficient healthcare; Artificial intelligence; Ophthalmology greenhouse gases

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Key Summary Points

Challenges to traditional practices: Traditional evidence-based medical approaches may no longer be sufficient due to an ageing population, increasing healthcare demands, and the growing need for sustainability.

High-value care: High-value care focuses on improving health, preventing harm, and eliminating waste while ensuring that treatments and screenings remain evidence-based, accessible, cost-effective, and sustainable.

Financial and environmental sustainability: Healthcare systems must balance financial efficiency with environmental responsibility.

Innovating for sustainable eye care: In ophthalmology, adopting new patient care models, leveraging technological advancements, and addressing regulatory challenges are crucial for ensuring long-term sustainability and effectiveness.

INTRODUCTION

Ophthalmology is one of the busiest outpatient specialties, with demand for services outpacing capacity due to the ageing population [1, 2]. Data from the United Kingdom (UK) National Health Service in 2019/20 indicate that individuals aged 75 and over accounted for 36.4% of all ophthalmic outpatient visits [3]. The number of cataract procedures had already increased by 21% in England in 2021 (compared to 5 years earlier) and is projected to rise by 50% between 2015 and 2035 [4]. *The Lancet Global Health* predicts that by 2050, approximately 895 million people will have uncorrectable distance vision impairment, with 61 million expected to be blind. Addressing these conditions often requires promotional, preventive, and rehabilitative interventions, along with significant financial investment, to prevent millions from experiencing unnecessary visual impairment [5, 6].

The term "high-value care", as described by the American College of Physicians, is to improve health, avoid harm, and eliminate wasteful practices [7]. While clinicians must prioritise the best evidence-based treatment for patients, it is equally important to ensure that screening and treatment services are not only accessible and cost-effective but also sustainable in the long term [8–10]. This sustainability should be considered not only from a financial standpoint, ensuring efficient resource allocation and affordability for healthcare systems and patients, but also from an environmental perspective, minimising the carbon footprint associated with medical procedures, transportation, and the production of healthcare materials while maintaining patient safety with evidence-based data.

Healthcare is responsible for 4.4–5% of global greenhouse gas (GHG) emissions, with higher-income countries like the USA and Australia being major contributors [11]. Without dedicated interventions, ophthalmology, as a busy outpatient and surgical specialty, will see a significant rise in GHG emissions [12]. This presents a valuable opportunity for a strong public–private partnership, multilevel efforts, and collaboration with pharmaceutical companies, as well as the role of advocacy and global policies in addressing sustainability in healthcare [13]. The World Health Organization [14] developed guidance on improving sustainability in healthcare, leading to the emergence of green organisations such as Healthcare Without Harm [15] and Practice Greenhealth [16]. Regulatory bodies may argue that 'sustainable use of resources' could compromise patient safety, though this claim lacks supporting evidence. Countries in the Global North are drawing insights from the high-volume approach of the Aravind Eye Care System in Tamil Nadu, India [17–19]. Aravind generates approximately 5% of the United Kingdom's cataract surgery carbon footprint with comparable outcomes. However, emulating their practices is often constrained by strict regulations in developed nations, particularly regarding the reuse of surgical equipment [20]. Striking a balance between high-quality patient care, economic feasibility, and environmental responsibility is essential for the future of ophthalmic services and broader healthcare provision. To address healthcare's carbon footprint, hospitals and health systems must reduce emissions across Scope 1 (direct emissions), Scope 2 (indirect emissions from energy), and Scope 3 (indirect emissions from the supply chain). The approach to achieve these reductions have focused on reducing waste for procedures and office visits. However, practicing "high value care" by re-evaluating how and when we do procedures, surgery and office visits has not been explored in ophthalmology. This review aims to highlight innovative strategies and key considerations essential for ensuring long-term success in sustaining eye care. We will explore patient care models and technological advancements, along with the associated regulatory challenges in their implementation. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

IMMEDIATE SEQUENTIAL BILATERAL CATARACT SURGERY (ISBCS)

Cataract surgery, as one of the most common surgical procedures globally, is a key target for carbon reduction. It is estimated that 20 million surgeries are performed worldwide each year [21]. The Global Burden of Disease Study in 2020 reported cataract as the leading cause of blindness, affecting 45% (15.2 million) cases worldwide [22]. Considering carbon emissions and cost implications arising from (i) building energy consumption, (ii) patient and staff travel, and (iii) procurement related to the production, consumption, and disposal of goods and services in industrial supply and waste management chains, these factors are duplicated in delayed sequential bilateral cataract surgery (DSBCS) [23]. It is therefore logical that immediate sequential bilateral cataract surgery (ISBCS) would significantly reduce resource use, minimise operating time, and enable more efficient scheduling of surgical procedures, while also being more cost- and energy-efficient [23, 24]. ISBCS has been shown to enhance the productivity of cataract surgery within the National Health Service (NHS) in the United Kingdom, across both low- and high-volume surgical models, reducing costs to public healthcare without compromising patient safety [25–27]. Productivity increase and cost savings of over 30% have been observed in ISBCS when compared to DSBCS [25, 26, 28]. Malcolm and colleagues also found that more patients are willing to undergo ISBCS if given the choice, whereas surgeon attitudes remain a significant barrier to its wider adoption [29]. In 2020, the Royal College of Ophthalmologists, in collaboration with the UK and Ireland Society of Cataract and Refractive Surgeons (UKISCRS), issued guidance on best practices and the safe delivery of ISBCS in response to the COVID-19 pandemic [30]. The approach was initially introduced to reduce hospital visits, minimise clinical contact time, and shorten binocular visual rehabilitation for vulnerable patients who still required cataract surgery to improve poor vision. However, mixed reactions persist among clinicians due to concerns regarding post-operative endophthalmitis, the risk of refractive surprise, and medico-legal implications [31–33]. In the USA, ISBCS was common for refractive lens exchange (RLE) but not cataract surgery due to the reduced reimbursement rate of 50% for the second eye under the US CMS federal Medicare system, impacting doctors and surgical centres in private practice [25]. The government policy should be more pragmatic by covering at least 80% of the cost for the second eye, rather than 50%. This would result in substantial savings for the government, alongside the added benefit of reducing emissions. Patients would have an appealing option, which some may choose to take up while others may not. This is one of the most straightforward ways to make cataract surgery more economically and environmentally sustainable on a global scale in the long run [34].

To date, a small number of case reports have documented bilateral endophthalmitis following ISBCS, though none adhered to the gold standard established by the International Society of Bilateral Cataract Surgeons (*i*SBCS) [35, 36]. Despite these concerns, ISBCS has been demonstrated to be a safe approach to cataract surgery in various centres [25, 37–40]. A UK teaching hospital reported 0% endophthalmitis rate in 3402 cataract surgeries performed between July 2020 and July 2021 [41].

Similarly, a high-volume Canadian tertiary care centre reported zero cases of toxic anterior segment syndrome or endophthalmitis while reducing patient visits by 50% and increasing surgical volume by 25% [42]. Furthermore, data from Exeter show a high acceptance rate of 71.56% of eligible patients favouring ISBCS [43].

Service redesign to increase the adoption of ISBCS should be encouraged while addressing misinformation about the procedure. This could involve incorporating information leaflets and trained counsellors in clinics to support patients' decision-making, helping to reduce the carbon footprint while ensuring patient safety [29]. Specified consent forms should be available for ISBCS, with strict policies and clinical governance in place to uphold the standards and quality of surgical procedures, with oversight to ensure compliance. Clinical audits should be conducted to ensure transparency and provide data, highlighting areas for improvement to promote best practice. Every cataract operation should be treated as a refractive procedure, utilising the latest-generation formulas for intraocular lens (IOL) calculations to minimise the risk of a refractive surprise, similar to patients undergoing laser refractive surgery or RLE, who also face this risk but still undergo bilateral procedures. To minimise the unlikely risk of equipment contamination, different batches of equipment can be used for each eye. While the patient remains in theatre, the surgeon should de-robe, re-scrub with a new pair of gloves and gown, re-prep, and drape for the second eye as if it were the only eye being operated on. Theatre efficiency can be improved by having one scrub nurse assisting while another prepares a clean tray for the second eye. These measures would help optimise theatre capacity without requiring the patient to be moved in and out of theatre. Ultimately, the decision to proceed with ISBCS is jointly made by both the surgeon and the patient, with the well-informed patient making the final choice. Of course, careful patient selection is essential, and contraindications to ISBCS should be strictly followed as per the standards set by the *i*SBCS. Each eye should be treated as an independent procedure utilising prophylactic antibiotics, whilst practicing caution in eyes with high risk of refractive surprise and those with high risk of complications due to ocular co-morbidities [40].

COMBINING CATARACT SURGERY WITH MINIMALLY INVASIVE GLAUCOMA DEVICES

With the growing safety profile of minimally invasive glaucoma surgery (MIGS), the question arises—should more patients with glaucoma requiring cataract surgery undergo a combined procedure? Dr Richard L. Lindstrom shared his insights that every patient presenting for cataract surgery with treated ocular hypertension or mild to moderate glaucoma should be offered MIGS during cataract surgery due to its increasingly safe profile. However, he feels that MIGS is not performed as often as it should be [44]. The USA and European countries have already shown significant interest in MIGS, adopting these procedures soon after receiving respective regulatory approvals. Despite a lesser trend in the Asia–Pacific region, the adoption of MIGS is steadily increasing [45].

This approach could be a sensible strategy to reduce reliance on multiple topical anti-glaucoma drops, minimise local and systemic side effects, and potentially delay or avoid the need for further interventions like tube shunts or trabeculectomy. As the second leading cause of blindness worldwide [46], glaucoma patients often depend on topical anti-glaucoma drops, which can aggravate or contribute to ocular surface disease, impacting their quality of life and adherence to medication. This, in turn, leads to issues with compliance and, ultimately, a worsening of their eye condition [47]. Glaucoma remains the third leading cause of blindness in the US, as about half of patients do not take their prescribed medications, leaving their condition fundamentally untreated [48, 49]. In England, the number of glaucoma prescriptions issued by the National Health Service increased from 4.76 million in 2000 to 7.96 million in 2012. Over the same period, the cost of glaucoma medications rose from £55.2 million to £103.7 million [50].

Beyond the financial burden, there are also environmental concerns, particularly for patients with ocular surface disease who require preservative-free eye drops, leading to significant plastic waste disposal on a daily basis. Iordanous and colleagues conducted a cost-effectiveness analysis in Canada and concluded that incorporating the iStent during phacoemulsification is a cost-effective strategy for patients with mild to moderate open-angle glaucoma (OAG) and cataracts [51]. Similarly, Nieland and colleagues in France found that, in addition to being cost-effective, combined phaco-MIGS offers superior intraocular pressure (IOP) control, reduces the need for glaucoma medications over a patient's lifetime, and enhances overall quality of life [52]. As with any ocular procedure, there are potential, albeit uncommon, complications associated with MIGS, including microhyphaema, hyphaema, malposition, damage to adjacent structures, corneal decompensation, and pigment dispersion [53]. A recent systematic review and meta-analysis provided strong evidence supporting the benefits of combined phaco-MIGS for patients with OAG, demonstrating that it does not increase the incidence of vision-threatening complications. The study included various MIGS techniques and, based on current evidence, irrespective of the mechanism of action or MIGS type, combined phaco-MIGS not only lowers IOP but also reduces medication dependency and improves quality of life compared to cataract surgery alone [54]. Emerging evidence also demonstrates the efficacy of STREAMLINE canaloplasty combined with phacoemulsification in reducing IOP and the need for IOP-lowering medications in eyes with mild to moderate OAG [55]. Similarly, 6-year efficacy and safety data have shown significant IOP reduction and a decrease in the number of glaucoma medications at 6 years following iTrack ab-interno canaloplasty, both as a standalone procedure and when combined with cataract surgery [56]. Patient selection remains crucial, and individuals with rapidly progressive glaucoma or advanced cases requiring a filtering procedure should not be considered for phaco-MIGS [53, 54].

SELECTIVE LASER TRABECULOPLASTY

While glaucoma drops are still the first-line treatment in many countries for patients with glaucoma, the UK healthcare system introduced a paradigm shift in 2022 by recommending SLT as the first-line treatment for OAG and ocular hypertension (OHT) [57]. This follows the LiGHT trial, which indicates that SLT can provide drop-free intraocular pressure (IOP) control for 78.2% of eyes at 3 years and nearly 70% of eyes at 6 years following initial treatment [58, 59]. In fact, it also reduces IOP fluctuation for at least 6 months postoperatively, thereby lowering the risk of glaucoma progression [60]. For patients with non-pigmentary, newly diagnosed OAG and OHT who do not yet require cataract surgery, selective laser trabeculoplasty (SLT) as a first-line treatment not only reduces long term cost implications associated with drop use but also helps to minimise plastic and drug waste, which contribute to human and planetary harm. A New Zealand study compared the carbon emissions of SLT laser with topical medications. The authors concluded that 'travel' is the largest source of emissions for glaucoma clinics. However, they also note that SLT reduces the eventual need for surgical interventions such as trabeculectomy, thereby reducing subsequent post-operative clinic visits and their associated travel-related emissions [61]. Furthermore, reducing reliance on glaucoma drops not only decreases the need for pharmacy visits to refill medication but also minimises visits to eye clinics due to side effects such as allergies and ocular surface disease. When considering potential waste-related carbon emissions associated with glaucoma medication, there is primary packaging (dispenser bottles) and secondary packaging (cardboard boxes). For patients with ocular surface disease, preservative-free eye drops are often dispensed in single-dose vials to maintain sterility [62]. Although these plastics theoretically can be recycled, only 8.7% are actually recycled, with the rest ending up in landfills or incinerators. Each 10 mL capacity bottle weighs 6.5g, representing a yearly impact of 7 kg CO_2 per person, whereas if a unit-dose preservative-free vial is used, up to 120 g of waste per month can be generated [63] To exacerbate the issue, many patients adhere to self-imposed cessation of use, often within 14–28 days of opening a multi-dose ophthalmic drop, which then leads to wastage of up to 71% of the total volume of medication remaining in each bottle when discarded [64]. For those requiring topical drop preparations, future practice may see greater use of punctal, intracanalicular, or even intracameral drug delivery systems; ophthalmic inserts; multi-use or multi-dose medications; microdosing spray dispensers; as well as biodegradable plastics [62, 65].

INTRAVITREAL INJECTIONS

The carbon footprint of a single intravitreal injection in a hospital-based service is estimated to be 13.68 kg CO_2e, with the majority attributed to travel (77%), followed by procurement (19%) and energy (4%) [66]. Anti-VEGF treatment, a sight-saving intervention particularly for neovascular age-related macular degeneration, demands substantial resources and often requires lifelong repeated injections, typically initially administered every 4 weeks [67]. While published data indicate that anti-VEGF treatment helps preserve vision in 90% of patients, real-world data suggest the rate is closer to 50%, primarily because patients do not receive treatment as regularly as needed. This is often due to elderly patients facing transportation challenges or depending on relatives to bring them in for treatment [68]. As a result, there is an increased risk of disease reactivation, leading to a greater risk of fibrosis, macular atrophy, and subsequent vision loss [69]. The role of longer-acting anti-VEGF treatments, such as Vabysmo and Eylea HD, presents an opportunity for patients to reduce the number of appointments by half (three to four visits instead of 6–12) [70, 71].

To improve convenience as well as reduce travel-related carbon emissions, administering injections closer to where patients live is a viable option. A New Zealand study shows that establishing local injection hubs or intravitreal clinics closer to patients can help reduce the carbon footprint by eliminating the need for travel to a tertiary centre for their injections [72]. While their condition stabilises, some patients remain under the care of retinal clinics for regular monitoring. In such cases, patient education and self-monitoring using the home optical coherence tomography (OCT), preferential hyperacuity perimetry technology, and app-based visual function tests represent an evolution in the management of retinal conditions. However, real-world data are needed regarding patient compliance, logistics, and equity [73]. Nonetheless, if successful, this approach could lead to better personalisation of care, improved understanding of disease progression, earlier detection of disease reactivation, and ultimately enhanced patient outcomes, as well as reduction in transportation and healthcare utilisation [74].

Reducing waste from intravitreal packs is a practical and achievable goal for all injectors. The American Society of Retina Specialists Sustainability Committee has proposed three key strategies: adopting reusable or biodegradable coolers for transporting injections, optimising packaging by transitioning to multidose formats and streamlining container designs to cut waste and costs, and eliminating unnecessary or rarely used items while ensuring patient safety and high-quality care [75]. While rethinking packaging, Ong et al. debated the use of intravitreal packs and lid speculums, stating that there is currently no theoretical evidence suggesting that the use of a sterile intravitreal pack influences the risk of endophthalmitis. Furthermore, they argued that the ’lid splinting’ technique and ’bimanual lid retraction’ do not pose a higher risk of endophthalmitis compared to speculum use [73].

Regarding the use of topical antibiotic prophylaxis after intravitreal injection, a large systematic review and meta-analysis demonstrate no benefit of its use, while asepsis and strict adherence to protocol remain the only evidence-based practices to reduce the risk of endophthalmitis [76]. The inappropriate and unnecessary use of antibiotics compromises patient safety by contributing to antimicrobial resistance, one of the top global public health threats, which claimed the lives of 1.27 million individuals worldwide in 2019 [77]. The American Academy of

Ophthalmology [78], the Royal College of Ophthalmologists [79], and the Royal Australian and New Zealand College of Ophthalmologists [80], EURETINA Expert Consensus [81] no longer recommend the use of topical antibiotic prophylaxis following intravitreal injection due to limited evidence of benefit. Interestingly, a newly published systematic review analysing 1,235,051 cataract operations found no additional benefit in the use of topical antibiotics post-operatively and concluded that intracameral antibiotics alone are sufficient [82]. These findings have led, and will continue to lead, to significant deviations in clinical practice, offering potential cost and carbon savings while ensuring patients are not exposed to the risks associated with antimicrobial resistance.

INTRAOCULAR TAMPONADES

Intraocular gases used as tamponades, such as sulphur hexafluoride (SF_6), hexafluoroethane (C_2F_6), and perfluoropropane (C_3F_8), are classified as 'greenhouse gases' by the United Nations Framework Convention on Climate Change (Kyoto Protocol, 1997). These gases contribute to Scope 1 emissions, with SF_6 having an exceptionally high global warming potential—23,900 times that of CO_2 [83]. A 1-year outcome study shows that use of 20% SF_6 in Descemet membrane endothelial keratoplasty (DMEK) procedure significantly reduces the rate of graft detachments hence rebubbling rates as opposed to 100% air tamponade [84]. A subsequent Liverpool study acknowledges the environmental impact of fluorinated gas use in corneal transplants [85]. Having analysed 357 procedures, they found that SF_6 30 mL canisters resulted in 1.5 tonnes of CO_2e over 3 years and that using smaller (15 mL) canisters could halve carbon emissions. They also recommended using air as an alternative tamponade in cases that have a low risk of graft detachment, where suitable [85].

In vitreoretinal surgeries, SF_6 (short-acting), C_2F_6 and C_3F_8 (long-acting) are commonly used. Unsurprisingly, a large multicentre study involving 4877 retinal procedures indicated that these procedures generated a total of 284.2 tonnes of CO_2e, the majority of which involved rhegmatogenous retinal detachment repair (67.3%) [86]. Studies have shown comparable rates of successful retinal re-attachment [87] and macular hole repair in terms of visual outcomes [88]. Although clinicians may favour short-acting SF_6 for its quicker recovery rate, it is also crucial to consider that SF_6, in particular, has a global warming potential 23,900 times that of carbon dioxide (CO_2) over a 100-year period and remains in the atmosphere for 3200 years [89]. On a positive note, efforts to replicate the effects of 20% SF_6 by using a diluted 8% C_2F_6 as an alternative tamponade have yielded positive outcomes while reducing environmental impact [90].

REFRACTIVE ERROR CORRECTION

The 2023 Carbon Footprint Report by Eco Eyewear found an average of 1482 kg of carbon dioxide equivalent emissions (kg CO_2e) per spectacle frame, taking into account the production of raw materials, transportation, packaging, distribution, and end-of-life management. Emissions vary depending on the material: 1703 kg CO_2e for bio-based frames, 1447 kg CO_2e for recycled metals, and 1296 kg CO_2e for materials made from ocean plastics [91]. The use of daily wear contact lenses is no more environmentally friendly than wearing glasses. As the majority of soft contact lenses are neither biodegradable or compostable, most are discarded as waste and end up in landfill. One in five consumers reportedly flush them down the drain, introducing micro- and nanoplastics into our waterways, which eventually enter the bloodstream and organ systems of mammals, including humans [92]. Interestingly, new evidence has shown microplastics in human vitreous humour leading to increase in intraocular pressure and retinopathy [93]. Recycling strategies, such as the ONE by ONE Recycling Programme in partnership with TerraCycle®, successfully recycled nearly 2.5 million used contact lenses, blister packs, and top foils in less than 2 years, diverting over 14,000 pounds of waste from landfill [94]. The program provides free shipping labels and designated bins for recyclable materials to the practitioner offering the service. However, many users remain unaware of recycling options, with only 7% reportedly recycling their lenses. Another notable recycling programme, EyeRecycle, is a scheme for all recyclable eye care waste products, including contact lenses, across ophthalmology clinics at academic institutions in the USA. This initiative is worth replicating in other eye centres globally to promote sustainable practices [92].

Preventive measures, such as myopia control in childhood, could potentially reduce the carbon burden associated with wearing glasses and contact lenses, in addition to lowering the risk of pathological myopia and retinal detachments requiring surgery. The Atropine for the Treatment of Myopia (ATOM) 2 study, conducted by Singaporean researchers, demonstrated that atropine 0.01% effectively slows myopia progression in children aged 6–12 years old with minimal side effects. Unlike higher concentrations of 0.1% and 0.5%, it had a negligible impact on accommodation and did not affect near vision [95]. While both genetic and environmental factors contribute to myopia development and progression, it is important to identify at-risk populations and implement early treatment to reduce the long-term burden of refractive error [96]. The American Academy of Ophthalmology highlights the use of public health strategies in promoting outdoor activities, orthokeratology lenses, and low-concentration atropine to slow myopia progression [97, 98]. Taiwan has incorporated a requirement of two hours of outdoor activity per day into its school-based myopia prevention strategy, yielding positive outcomes [99]. Similarly, Singapore has implemented a school-based program to address childhood myopia through education, encouragement of outdoor activities, screening, and early detection and management of myopia [100]. In countries where myopia is particularly prevalent, ophthalmologists and eye care professionals can advocate for myopia control policies to help reduce the disease burden and 'prescribe' outdoor time to their paediatric patients. While various studies [101–105] have demonstrated cost-effectiveness and increasing safety profile of refractive surgery in correcting refractive errors in the long-term, there is scarcity of data in regards to the life cycle assessments (LCA) and product carbon footprints (PCF) comparing refractive surgery as a "one-off" procedure versus long term use of glasses and contact lenses.

ADVANCES IN OCULAR IMAGING

Current applications, such as ultra-widefield optical coherence tomography angiography (OCTA), offer the potential to replace the more invasive fundus fluorescein angiography (FFA) exams in ophthalmology while maintaining high diagnostic accuracy [106]. Since it was discovered by Novotny and Alvis in 1959, FFA has been a widely used tool for assessing the anatomy, physiology, and health of the retinal and choroidal circulation, helping with the diagnosis and management of various eye conditions. It is commonly used for conditions such as diabetic retinopathy, retinal vein occlusions, and choroidal neovascularisation, as well as for evaluating cases of retinitis, choroiditis, retinal dystrophies, optic nerve pathologies, and ocular tumours. Nonetheless, it is invasive, and can lead to complications such as transient nausea, vasovagal syncope, or even extravasation of dye under the skin, which has the potential to cause skin necrosis. It is relatively contraindicated in pregnancy and absolutely contraindicated in cases of severe allergic reactions [107]. Furthermore, FFA being more time consuming requires an additional appointment and staffing, leading to an extra GHG emission (compared to OCTA) of 80.51 kgCO_2e per patient (building: 40.17 kgCO_2e, staff travel: 33.03 kgCO_2e, patient travel: 4.27 kgCO_2e, pharmaceuticals: 1.01 kgCO_2e, medical instrumentation: 1.41 kgCO_2e, and waste: 1.24 kgCO_2e). Reynolds and colleagues estimated that a 50% reduction in the number of FFA carried out would result in a saving of 34 tonnes of CO_2e per year in a single hospital [108]. Increasing evidence in the literature supports the successful use of widefield OCTA in detecting retinal vascularisation in proliferative diabetic retinopathy, with a sensitivity of 95% and a specificity of 88% [109]. The use of widefield or ultra-widefield OCTA could revolutionise diabetic retinopathy staging, offering a 'new way to see', as described by Russell and Han, by incorporating all structural and vascular aspects of the disease [110]. It has also proven effective in assessing choroidal vasculature changes associated with choroidal diseases, such as acute Vogt-Koyanagi-Harada disease [111]. While it provides detailed visualisation and quantification of non-perfused areas to aid clinicians in determining prognosis and planning treatment, it does have limitations—particularly those associated with high up-front costs, as well as additional expenses for maintenance, software updates, and operator training. Efforts to develop more affordable models will be essential for improving the accessibility and utility of the non-invasive and time-efficient widefield and ultra-widefield OCTA devices.

THE BURDEN OF SCREENING AND OUTPATIENT REVIEWS, AND THE ROLE OF VIRTUAL CONSULTATIONS, TELEOPHTHALMOLOGY, AND ARTIFICIAL INTELLIGENCE

In 1968, Wilson and Jungner published ten criteria and principles of screening, which remain the de facto starting point for screening decisions today [112]. However, we must also take into account the burden of ocular screening due to the large patient population, logistical challenges, staffing requirements, patient compliance, and the associated carbon emissions from attending outpatient appointments for eye screening. Glaucoma care constitutes approximately 20% of hospital outpatient service workload in the UK, with over one million hospital visits each year in England [113]. Around four million people participate in the NHS diabetic eye screening programme in England and Wales, with over 80% receiving routine retinal screening every 1–2 years [114]. Globally, the number of adults with diabetic retinopathy is expected to rise to 129.84 million by 2030 and 160.50 million by 2045 [115]. By 2040, an estimated 288 million people may be affected by some form of AMD [116].

A 2018 report commissioned by NHS Midlands and Lancashire estimated that the West Midlands could cut emissions by 533,535 kg CO_2e per year by transitioning 15% of all hospital follow-up appointments to telemedicine [117]. A systematic review shows carbon savings per consultation ranging from 0.70 to 372 kg CO_2e, primarily by decreasing transport-related emissions [118]. Similarly, the use of teleophthalmology in India has demonstrated a carbon saving of 2.89 kg CO_2e (80 km) per person in rural settings and 176.6 kg CO_2e (1666 km) per person in tertiary settings [119]. Thiel and colleagues conducted a LCA using Stanford Health Care data from 2019 to 2021. For all specialties combined, although there was 13% increase in clinic visits during the period studied, telemedicine reduced total greenhouse gas emissions by 36% [120].

Moorfields Eye Hospital in London has successfully introduced a video cloud-based platform that enables patients to receive urgent ocular advice without visiting the accident and emergency department. This initiative has resulted in a significant (78.6%) reduction in hospital visits through remote consultations and prescriptions [121]. In relation to the cataract care pathway, Lin described a sustainable telemedicine model to replace traditional face-to-face cataract assessment using imaging technology. Not only does it shorten the overall assessment time by half and reduce staffing requirements, but it has also proven to be safe with high satisfaction rates [122]. This is more feasible than a 'one-stop' cataract service (same-day assessment and cataract surgery), as the same number of staff is required to carry out assessment, listing, and pre-operative biometry regardless of the number of visits. Additionally, non-attendance rates and patients deemed 'unsuitable' for same-day cataract surgery due to blepharitis or asymptomatic cataracts may potentially compromise the efficient use of theatre time or capacity [123].

A large Finnish retrospective study reveals that a 1-month post-operative visit following an uneventful cataract surgery is unnecessary [124]. An exploratory study involving 181 patients reveals high level (80%) of satisfaction with telephone consultation shortly after cataract surgery to determine whether an in-house post-operative review is required [125]. To further consolidate these data, a multicentre, open-label, randomised controlled trial (CORE-RCT) is currently ongoing to provide scientific evidence on remote follow-up following cataract surgery in line with the digitisation of healthcare and to deliver insight into cost-effectiveness data [126].

As described by Ting and colleagues, Artificial Intelligence (AI) may have a potential role in the screening and management of the cataract care pathway via the detection and diagnosis of cataracts and telemedicine, subsequently minimising false positive referrals whilst reducing delays in referring patients who actually need cataract surgery [127]. A novel approach involving the use of an artificial intelligence conversational agent, Dora R1, for conducting follow-up assessments after cataract surgery has been demonstrated to be safe, acceptable, feasible, and cost-effective. The level of agreement with clinician was moderate-to-strong with an overall accuracy of 89% [128]. As the system undergoes trials in select trusts within the UK National Health System, it has been positively received by patients [129].

On the other hand, the optometrist-assisted and teleophthalmology-enabled referral pathway (OTRP) in the Danish healthcare system has been shown to lower healthcare costs and reduce waiting times. It also enhances patients' quality of life while minimising transportation expenses and productivity losses. Ultimately, this approach alleviates the workload of general ophthalmologists and contributes to reducing the carbon footprint [130]. Specialties like oculoplastics, where gross pathology is often evident to the naked eye, can take advantage of telemedicine. Video consultation clinics have proven useful regardless of age, and patients with conditions like lid malposition (entropion and ectropion), dermatochalasis, and post-operative reviews are more suitable candidates compared to those with epiphora or conjunctival or lid lesions [131]. Regarding eyelid lesions, a different approach, such as an 'image-based' eyelid lesion virtual service, has proven to be safe and reduces unnecessary clinic visits while helping to improve the utilisation of consultant-led clinic appointments [132].

While teleophthalmology helps reduce carbon emissions, data suggest that integrating autonomous AI into teleophthalmology could achieve an 80% reduction in carbon footprint [133]; however, the authors did not account for the high energy and water use of AI, nor emissions related to training of the eye care provider [134]. The utilisation of Deep Learning (DL) technology in AI applications has shown promising results in ocular screening [135–141]. A recent review highlights the role of AI in quantifying subclinical changes in AMD, assessing every possible voxel on the optical coherence tomography machine, and predicting disease progression—a task that is nearly impossible for clinicians [142]. Jan and colleagues emphasise a more standardised approach to diagnosing glaucoma by incorporating AI algorithms into primary care settings in Australia [143]. Similarly, a study in China has developed and validated a machine learning (ML) prediction model that detects diabetic retinopathy (DR), referable DR, and vision-threatening DR by utilising clinical data and OCTA parameters. This facilitates clinical decision-making regarding screening, referral, and monitoring of DR [144]. Additionally, home vision screening devices and applications have been developed to reduce the need for in-clinic visits [145, 146]. By combining DL, ML, AI applications, and self-directed screening programmes, the concept of small screening hubs could become a reality. Patients could attend these hubs, enter their details, and follow automated robotic instructions such as, "Put the goggles on, place your chin on the rest, head on the bar, and look at the green cross." While this may take years to fully develop, it presents a feasible solution to alleviating the ophthalmic screening burden in the future.

IMPACT ON UNDERSERVED POPULATIONS

Without careful consideration and execution, the use of AI-enabled technologies may exacerbate inequalities in underserved communities [147]. Developed countries are more advanced in integrating AI into healthcare compared to developing nations, largely due to differences in infrastructure, technological readiness, and economic resources [148, 149]. Additionally, ethical considerations vary significantly depending on cultural and socioeconomic diversity, leading to different approaches to AI implementation.

When revolutionising healthcare, (i) ethics, (ii) equity, (iii) inclusivity, and (iv) privacy are essential principles that must be considered to minimise healthcare disparities. While scholars should balance privacy and fairness, regulatory bodies must keep pace with the rapid advancements in health technology, such as AI [150]. Establishing firm governance structures that require global collaboration and prioritise equitable health outcomes is essential to ensuring that emerging technologies benefit all communities. The government's role in investing in robust digital connectivity, AI infrastructure, and policymaking can enhance access to resources, helping to bridge the digital divide. This investment would support network expansion, reduce disparities, and promote inclusivity for all [151].

The successful implementation of AI-enabled technologies presents an opportunity to improve healthcare access in rural settings through telemedicine, real-time remote monitoring, remote surgical supervision, educational tools, and advanced diagnostic modalities [152]. These technologies are also invaluable assets in predicting disease outbreaks in underserved communities by utilising predictive analytics, thereby improving health outcomes through early intervention [153]. For example, the Society for Family Health (SFH) partnered with Sand Technologies to equip medical staff with AI-powered diagnostic tools, addressing the shortage of healthcare professionals in underserved areas. This initiative enabled the digitisation of rural clinics, facilitating rapid, high-quality medical care and ultimately enhancing patient outcomes [151]. Two peer-reviewed Orbis studies highlight the benefits of AI in eye care for remote communities. Over 63% of patients preferred AI-led tests over human-led ones. Factors contributing to high satisfaction included the convenience of receiving eye exams during diabetes appointments, avoiding pupil dilation, and immediate access to printed reports on their condition [154].

CONCLUSIONS

Balancing the sustainability of ophthalmic practices, the burden of disease, and the impact of waste and climate change on human and planetary health presents both challenges and opportunities for the future of eye care. In 2022, The American Academy of Ophthalmology (AAO) established the Sustainability Task Force with the goal of engaging policymakers and members in carbon-reducing initiatives in clinical practice [155]. The AAO also joined forces with EyeSustain as a sponsoring society and participates in My Green Doctor as a professional society [156]. EyeSustain is a global alliance of over 50 ophthalmic organisations, societies, and members dedicated to advancing sustainable eye care and reducing waste [157]. My Green Doctor provides practice management resources for sustainable practices for medical clinics [158].

As research on the environmental impact of ophthalmic practices continues to grow, clinicians should rethink practical solutions such as viable strategies to enhance patient care while reducing carbon footprint and waste. Furthermore, advancements in technology hold promise in addressing access to ophthalmic care, particularly in underserved populations. With the integration of AI, ML and DL technology, ocular screening processes are evolving towards greater efficiency and accessibility. The development of self-directed screening hubs has the potential to revolutionise patient management, minimising the need for frequent in-clinic visits and reducing environmental impact. Future studies and LCAs should consider the environmental impact of AI, particularly its energy consumption and associated emissions. It is essential for clinicians to collaborate with developers and companies to ensure transparency regarding the energy consumption and environmental impact of supercomputer systems. This includes efforts to train AI using high-performance chips and graphics processing units, database storage requirements, and the energy needed for data processing and server cooling. Tools such as energy trackers or emission impact dashboards could be utilised to assess and quantify the resulting carbon emissions [159]. As we adopt newer practices such as ISBCS, clinical audits and good clinical governance play a crucial role in providing evidence-based data to support informed decisions about changes in practice, enhance confidence among clinicians and patients, and ensure transparency in guiding future practice for optimal patient care. Practitioners must rethink how to best care for their own patients and sustain their practices, while protecting public health. However, regulatory challenges, clinician attitudes, and patient acceptance must be carefully navigated to ensure successful implementation of high value care.

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Declarations

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