Cataracts

Maria Vittoria Cicinelli, John C Buchan, Maneck Nicholson, Varshini Varadaraj, Rohit C Khanna

94 million people are blind or visually impaired globally, and cataract is the most common cause of blindness worldwide. However, most cases of blindness are avoidable. Cataract is associated with decreased quality of life and reduced life expectancy. Most cases of cataract occur after birth and share ageing and oxidative stress as primary causes, although several non-modifiable and modifiable risk factors can accelerate cataract formation. In most patients, phacoemulsification with intraocular lens implantation is the preferred treatment and is highly cost-effective. There has been an increase in the use of comprehensive cataract surgical services, including diagnoses, treatment referrals, and rehabilitation. However, global inequity in surgical service quality is still a limitation. Implementation of preoperative risk assessment, risk reduction strategies, and new surgical technologies have made cataract surgery possible at an earlier stage of cataract severity with the expectation of good refractive outcomes. The main challenge is making the service that is currently available to some patients accessible to all by use of universal health coverage.

Lancet 2023; 401: 377–89

Published **Online** December 21, 2022 https://doi.org/10.1016/S0140-6736(22)01839-6

School of Medicine, Vita-Salute San Raffaele University, Milan, Italy (M V Cicinelli MD); **Department of Ophthalmology, IRCCS San Raffaele Scientific Institute, Milan, Italy** (M V Cicinelli); **International Centre for Eye Health, London School of Hygiene & Tropical Medicine, London, UK** (J C Buchan MD); **Allen Foster Community Eye Health Research Centre, Gullapalli Pratibha Rao International Centre for Advancement of Rural Eye Care** (R C Khanna MD) **and Brien Holden Eye Research Centre, L V Prasad Eye Institute** (M Nicholson MD, R C Khanna), **Hyderabad, India; Wilmer Eye Institute, Johns Hopkins Medicine, White Marsh, MD, USA** (V Varadaraj MD); **School of Optometry and Vision Science, University of New South Wales, Sydney, NSW, Australia** (R C Khanna); **School of Medicine and Dentistry, University of Rochester, Rochester, NY, USA** (R C Khanna)

Correspondence to: Rohit Khanna, L V Prasad Eye Institute, Banjara Hills, Hyderabad 500034, India **rohit@lvpei.org**

Introduction

The crystalline lens is a small, transparent, ocular structure in the anterior part of the eye that focuses the light on the retina and allows the eye to see clear images at different distances. Lens opacification is known as cataract. Although most cataract cases are age-related, congenital and paediatric cases can occur.

Although they are asymptomatic in early phases, cataracts can become visually impairing with time and can considerably reduce the quality of life and productivity of an individual. As surgical removal of a cataract and implantation of an artificial intraocular lens can effectively restore vision, cataract-related blindness is avoidable in most cases. Some risk factors are modifiable, such as ultraviolet light exposure and smoking, but no approved intervention prevents cataract development.

This Seminar aims to summarise the current understanding of acquired cataracts, including epidemiology, pathophysiology, classification, grading, symptoms, management, complications, and the latest developments in surgical treatment. Controversies and new options about cataract surgery administration are also discussed. Congenital and paediatric cataracts are not reviewed in this Seminar as their causes, consequences, and clinical management substantially differ from acquired cataracts.

Epidemiology

Cataract is a main cause of loss of vision worldwide. In 2020, an estimated 15 million people older than 50 years were classified as blind (presenting visual acuity <3/60 or less than 10° visual field around the central fixation) and an estimated 79 million people older than 50 years were classified as having moderate to severe visual impairment (presenting visual acuity <6/18 to 3/60) due to cataract worldwide.[1] These estimates show a 30% increase in cataract blindness and 93% increase in moderate to severe visual impairment compared with the year 2000. However, the age-standardised prevalence of cataract blindness has decreased by 28% and moderate to severe visual impairment has increased by 7% since 2000.[2] The overall increase in cases of cataract despite a decrease in age-standardised rates is because of the ageing of populations, which results in an increasing number of individuals older than 60 years.[2]

Most cases of cataract occur in low-income and middle-income countries, and cataract-related visual impairment is still a cause and a consequence of material poverty in resource-poor settings.[3] South Asia has the highest prevalence of cataract blindness and moderate to severe visual impairment worldwide (figure 1). Nonetheless, based on the Global Burden of Disease Study regions, south Asia (–36·5%); southeast Asia, east Asia, and Oceania (–43·0%); and North Africa and the Middle East (–40·0%) had the largest decrease in cataract blindness rates between 2000 and 2020.[1]

Anatomy and function of the lens

The crystalline lens is an avascular, biconvex structure located behind the iris and anterior to the vitreous. The lens is surrounded by an elastic capsule and is suspended from the ciliary body by a network of zonular fibres.[5]

The lens originates from the surface ectoderm. At 33 days' gestation, the lens appears as a cavitary sphere with epithelial cells lining it anteriorly and primary lens fibres lining it posteriorly (eg, lens vesicle). As anterior epithelial cells replicate throughout the lifetime of an individual, daughter cells migrate towards the equator of the lens, elongate, and progressively lose their organelles. New lens fibres (adult nucleus) arrange

Search strategy and selection criteria

We did a PubMed engine search using the terms "crystalline lens", "cataract", "phacoemulsification", or "intraocular lens". From an initial 108 501 results, we reviewed all studies published in English before April, 2022. We included meta-analyses, systematic reviews, randomised controlled trials, population-based studies, and clinical studies, and prioritised papers published in the past 3 years. We also included information from WHO and the Vision Loss Expert Group, an international group of experts in ophthalmic epidemiology assisting the Global Burden of Disease Study.

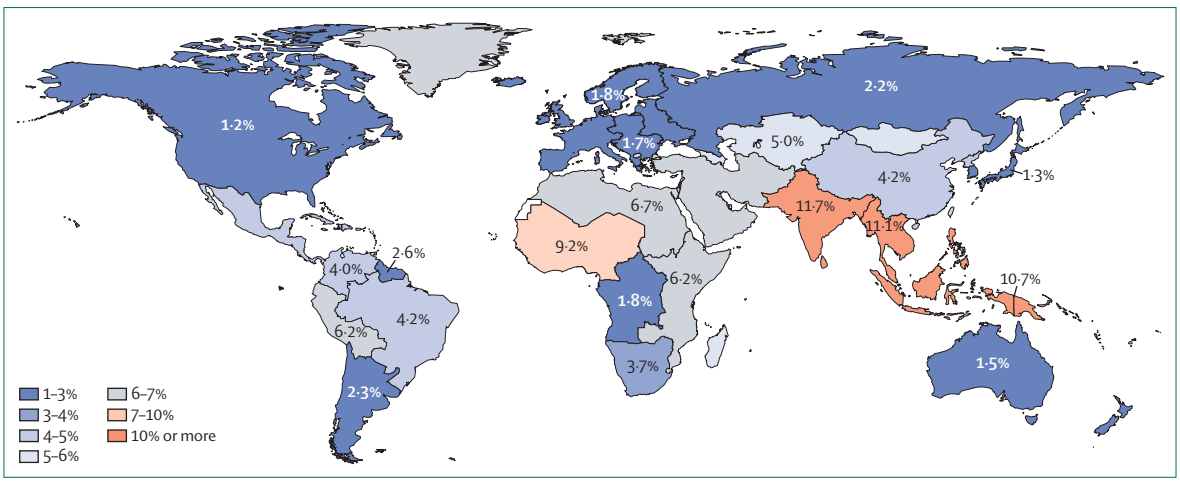

Figure 1: **Age-standardised prevalence of blindness, moderate vision impairment, and severe vision impairment because of cataract in 2020**
Reproduced with permission from the Global Burden of Disease Blindness and Vision Impairment Collaborators and Vision Loss Expert Group.[4]

concentrically around the primary fibres (embryonic and fetal nucleus), and the lens volume progressively increases. Cells dividing after sexual maturation constitute the lens cortex. Absence of blood vessels, paucity of cytosolic organelles, orderly arrangement of lens fibres and cytoskeletal proteins, minimal extracellular space, and balance of intracellular water ensure lens transparency.[6]

By changing its shape, the lens can see clear images at various distances. The refractive power of an unaccommodated lens is about 20 dioptres, a third of the total power of the eye;[7] the accommodative amplitude of the lens peaks at age 12 years and progressively decreases. Fibrotic changes in the ciliary muscle fibres, capsule stiffening, fibres stiffening, and a forward movement of the lens centre have been hypothesised as causes of accommodation insufficiency with age (eg, presbyopia). Additional lens functions include filtering ultraviolet radiation and correcting corneal spherical aberrations.[8]

Pathophysiology and risk factors of acquired cataract

The causes of acquired cataract are multifactorial[9] and include ageing[9,10] and oxidative stress as the main causes. Active maintenance of lens transparency and refractive index requires high metabolic activity, sustained by nutrients and antioxidants from the aqueous humour. With age, aqueous and lens transport systems decrease in efficiency and redox enzymatic activity. The synthesis of water-soluble crystallins reduces, leading to water-insoluble protein aggregation. Peptide lysis and oxidation cause protein misfolding, dysfunction, and instability.[11] Finally, nuclear yellow-brown chromophore amounts increase, leading to lens brunescence.[12]

See Online for appendix

Genetics and sex might also play a role in cataract development. Studies of the eyes of twins have shown that heredity explains up to 48% (95% CI 42–54)[13] of the variation within populations for nuclear cataracts and 58% (95% CI 51–64)[14] of the variation within populations for cortical cataracts. In 2021, a genome-wide association study identified several genetic loci associated with age-related cataracts.[15] Nonetheless, the proportion of clinical variability these loci explain is still unclear, as is the contribution of these loci in populations of diverse ethnic and environmental backgrounds. Women are at a greater risk of cataracts than men, potentially because of differences in life expectancy, health-seeking behaviours, and hormones.[16] Incidence of cataracts in postmenopausal women has been proposed to be higher than in men because of the effects of declining oestrogen on cataract formation, but data on the role of sex hormones in cataractogenesis remain inconclusive.[17]

Concurrent ocular diseases, such as myopia, uveitis, and anterior or posterior segment abnormalities, might induce or accelerate cataract formation. Local inflammation encourages both oxidative stress and lens epithelial cell proliferation time dependently and dose dependently.[18] Pseudoexfoliation syndrome causes cataracts via blood–aqueous barrier dysfunction.[19] Increased oxygen concentration around the lens is responsible for secondary cataracts after vitrectomy[20] or in hereditary vitreopathies.[21]

Systemic diseases, such as diabetes,[22] hypertension,[23] and obesity,[23] have been associated with an increased risk of cataracts. Other causes of acquired cataracts include trauma (penetrating or non-penetrating), metabolic diseases (eg, gout, galactosaemia, Fabry disease, and Wilson disease), and ocular (eg, retinitis pigmentosa or late-onset retinal dystrophy) or systemic inherited dystrophies (eg, Marfan syndrome, Down syndrome, myotonic dystrophy, Alport syndrome, or neurofibromatosis type 2; appendix p 1).

Regarding modifiable risk factors, substantial evidence exists that links cataracts to smoking,[24] electric and chemical burns, and non-ionising and ionising radiation (including ultraviolet radiation from sunlight exposure).[25,26] Chronic substantial alcohol consumption

might be associated with an increased risk of cataracts,[27] whereas low to moderate alcohol consumption might be protective.[28] Data from 2021 show that unclean cooking fuel use in low-income and middle-income countries might be a risk factor for cataracts, but results vary across age, sex, and geographical location.[29] Finally, chronic drug use, such as corticosteroids, phenothiazines, antidepressants, and miotics, is also associated with an increased risk of cataract formation. Data regarding statins are contradictory.[30]

Using ultraviolet-filtering glasses and hats, quitting smoking, and abstaining from substantial alcohol consumption are practical preventive strategies. Although oral antioxidant supplementation has been assessed for cataract prevention, its protective effects are inconclusive.[31] Dietary plant natural products and a Mediterranean diet have shown some protective effects against cataracts,[32] but robust evidence is needed.

Clinical classification, signs, and symptoms of cataracts

Cataracts are named according to the anatomical location in the lens or the characteristics of the opacities. Different cataracts vary in clinical presentation, symptoms, and risk factors (table).[33] The most common types of cataracts are nuclear (an opacification of the fetal and adult nucleus) and cortical (a spoke-like opacification of the lens cortex fibres). Although asymptomatic if lens opacity is mild, cataracts can become progressively visually impairing, affecting the ability of an individual to do daily activities, decreasing social functioning, increasing the risk of depression, and reducing life expectancy.[34]

Cataract grading systems have been developed for clinical practice and research, allowing the standardisation of cataract type, severity, and rate of progression assessment. There are several grading systems, of which the Lens Opacities Classification System III is most widely used.[35] However, all grading systems have issues with subjective evaluation, have few functional correlates, and do not provide clear surgical indications.[36]

Objective, automated classification systems that rely on anterior segment photography, Pentacam Scheimpflug or optical quality analysis systems, retinal photography, and optical coherence tomography might have more advantages than subjective grading systems of lens opacity severity but have not been routinely established in clinical practice.[37,38] Artificial intelligence systems can assist in diagnosis, grading, and referral of adult cataracts,[39] yet their value and cost-effectiveness need to be validated in real-world settings (eg, community screening and primary care venues, tertiary eye hospitals, or telemedicine [diagnosing patients virtually]).

Indication for surgical extraction

From a patient perspective, cataract surgery should be done when cataract-related visual symptoms interfere with quality of life or daily activities to the extent that the expected benefits of surgery outweigh the potential risks. As the risks of cataract surgery have reduced substantially in the past two decades, the clinical thresholds (eg, symptoms or lens opacification) for seeking surgery have consequently reduced also.[40]

Third-party systems (eg, health insurance) are attempting to restrict the number of people who qualify for cataract surgery by visual acuity thresholds or visual symptom scores.[41] However, the economic arguments for rationing are not strong because of the cost-effectiveness of cataract surgery.

Other than visual indications, lens extraction in the absence of cataract (eg, clear lens extraction [CLE]) might be beneficial for patients with, or at risk of, angle-closure glaucoma.[42] CLE can be electively done for high refractive errors[43] or presbyopia correction[37,44] in patients who do not want to wear spectacles.

Preoperative management

The preoperative clinical assessment of patients scheduled for cataract surgery aims to confirm surgical indications, feasibility, risks, and benefits (panel).[45] A complete dilated examination of the eyes allows screening

	Clinical characteristics	Associations	Main symptoms
Nuclear	Yellow-brown opacification of the fetal and adult nucleus	Age; diabetes	Blurry vision; loss of colour sensitivity; myopic shift
Cortical	Spoke-like cortex opacities with the same shape of lens fibres	Age; diabetes; ultraviolet radiation	Astigmatism; monocular diplopia; glare and halos around lights
Posterior subcapsular	Plaque-like opacification in the back portion of the lens	Diabetes; radiation; drug toxicity; inherited dystrophies; uveitis	Blurry vision; reduced light sensitivity; reduced near vision
Anterior subcapsular	Lens opacity underneath the anterior capsule	Diabetes; trauma (also phakic lenses); drugs; inflammation; irradiation; electrical burns	NS
Snowflake	White subcapsular opacities that look like snowflakes	Uncontrolled diabetes; hereditary associations	NS
Rosette	Flower-shaped opacification of nuclear lens fibres	Trauma; electrocution; chemical burns; exposure to radiation	NS
Christmas tree	Small, needle-like, multicoloured crystals in the lens cortex	Myotonic dystrophy	NS
Sutural	Congenital Y-shaped lens opacities that affect the fetal lens nucleus	Anomalous embryonic development of the lens	Usually asymptomatic
Cerulean	Blue and white opacifications in lens nucleus or cortex	Crystallin gene mutations	Usually asymptomatic
Anterior polar	Dot-like opacity in lens anterior capsule	Phenothiazines; aniridia or microphthalmia; intraocular tumours	NS
Posterior polar	Dot-like opacity in lens posterior capsule	Developmental	NS

NS=not specific.

Table: **Anatomical classification of types of cataracts and main clinical associations**

Panel: **Preoperative assessments of patients undergoing cataract extraction, their purposes, and examples**

Ocular evaluation

Screening for risk factors for intraoperative complications:

- Previous eye surgeries
- Shallow anterior chamber
- Pseudoexfoliation syndrome
- Zonular laxity
- Dense cataract

Identification of concomitant comorbidities:

- Corneal degeneration
- Corneal dystrophies
- Glaucoma
- Diabetic retinopathy
- Age-related macular degeneration

Biometry and lens power calculation

Measurement of the anatomical and refractive metrics of the globe:

- Corneal refractive power
- Globe axial length
- Anterior chamber depth
- Corneal spherical aberrations

Choice of the appropriate formula to calculate intraocular lens power:

- Regression formulas, such as SRK I or SRK II
- Vergence formulas, such as 2-variable formulas (Holladay 1, SRK-T, and Hoffer Q), 3-variable formulas (Haigis and Ladas super formula), 5-variable formulas (Barrett universal II), and 7-variable formulas (Holladay 2)
- Artificial intelligence-based formulas, such as Hill-Radial-Basis-Function calculator
- Ray tracing, such as Olsen or PhacoOptics

Systemic assessment

Screening for concomitant systemic conditions:

- Hypertension
- Diabetes
- Respiratory diseases

Record of medications list:

- α-blocking medications (doxazosin or tamsulosin) are associated with intraoperative iris billowing, iris prolapse, and poor mydriasis (floppy iris syndrome)
- Antithrombotic or antiplatelet agents

Need for general anaesthesia:

- Cognitive impairment
- Severe head tremor
- Claustrophobia
- Dyspnoea in supine position
- Inability to lie down on the back

for ocular risk factors for potential intraoperative or postoperative complications.[46] Risk stratification, sometimes expressed as composite risk scoring systems, allows for improved informed consent, case allocation, and planning for adjunctive devices or procedures (eg, capsular tension rings or iris hooks),[47] and could be further improved by including artificial intelligence in risk analysis.[48] Preoperative examination also allows for the identification of concomitant ocular comorbidities that affect the visual expectations of cataract extraction that both patients and doctors have.

The next part of preoperative management is measuring the corneal refractive power and the globe anatomical metrics to allow exact intraocular lens power estimation to focus light on the retina.[49] Although cataract surgery is not routinely done for refractive management only, a good refractive outcome is essential for patient satisfaction and is an established outcome indicator.[50,51] 85% of patients having postoperative refraction within 1 dioptre of predicted is regularly seen in well-resourced services.[52] To date, no single formula can provide an accurate intraocular lens power calculation. Nonetheless, new formulas have improved prediction of the most accurate intraocular lens power in patients with very large or very small eyes and mitigate the risk of inaccurate estimates in eyes that have had previous refractive surgery.[49]

The assessment of a preoperative patient includes screening for systemic illnesses and medications. Systematic reviews have found no benefit from any general work-up before cataract surgery.[53] One exception is checking blood pressure before surgery, as there is weak evidence that high blood pressure might increase the risk of intraoperative suprachoroidal haemorrhage.[54] Knowledge of diabetic status is also desirable preoperatively as this knowledge would encourage the use of additional agents, such as subconjunctival steroids, to reduce the risk of postoperative macular oedema.[55,56] Some systemic medications are essential to know about preoperatively. Some α-blocking medications (eg, tamsulosin or silodosin) are associated with a high risk of intraoperative iris billowing, prolapse, and poor mydriasis (intraoperative floppy iris syndrome [IFIS]; odds ratio 206·5, 95% CI 50·9–836·5), which might require adjustments to surgical technique.[57] Non-selective α-blocking medications (eg, alfuzosin, doxazosin, prazosin, and terazosin) are less associated with IFIS than tamsulosin, and are considered a safer choice than tamsulosin in cases of expected IFIS during cataract surgery.[58,59] Current guidelines suggest not to stop any drug preoperatively if cataract surgery with topical anaesthesia is planned.[60]

Anaesthesia and sedation

Cataract surgery can be safely carried out with local or topical anaesthetic in most patients. Topical anaesthesia is done by instilling anaesthetic eye drops on the cornea and in the conjunctival sac, with or without intracameral anaesthetic injected during surgery. Local anaesthesia is commonly done by injecting anaesthetic agents into the tissues around the globe (eg, Sub-Tenon's block). Retro-ocular analgesia is not used often, as it can have potential serious complications, such as retrobulbar haemorrhage,

brainstem anaesthesia, globe perforation, or local myotoxicity. General anaesthesia is indicated for patients with poor expected cooperation during surgery (panel).

Preoperative and perioperative anxiety can induce unintentional patient movement, reduced pain threshold, and extended operation times. Oral or intravenous sedation might improve the cooperation and satisfaction of a patient, but side-effects, such as respiratory depression and airway obstruction, excessive or paradoxical responses, long postoperative sedation, and cognitive dysfunction, might increase the overall risk of surgical complications.[61] Improved preoperative counselling has been shown to reduce perioperative anxiety.[62]

Types of cataract surgery

Phacoemulsification

Phacoemulsification is the reference standard of care for cataract surgery in most settings. It uses ultrasound energy to disintegrate the nucleus, which is then aspirated out of the eye (figure 2).

A clear corneal tunnel and one or two accessory incisions are constructed at the start of surgery. The anterior chamber is filled with a viscoelastic substance. A circular opening in the anterior capsule (the capsulorhexis) is made to access the nucleus and the cortical matter of the lens. The integrity of the corneal incisions and the size and shape of the capsular opening are determinants of the final refractive correction of the patient.[63] Phacoemulsification of the nucleus is done either by making grooves and disassembling the nuclear matter into quadrants or using instruments to break it into smaller pieces. The residual cortex is aspirated, a folded intraocular lens is placed through the tunnel into the capsular bag, and the corneal incisions are sealed with water. Stitches are rarely required.

Small incision cataract surgery

Small incision cataract surgery (SICS) requires the construction of a larger scleral tunnel than in phacoemulsification to allow entry into the anterior chamber of the eye and manual removal of the nucleus in toto. The rest of the process, including cortical aspiration and intraocular lens insertion, is similar to the phacoemulsification technique (figure 3). SICS is being used increasingly in low-income and middle-income countries as it is faster, less technology-dependent, and less expensive than phacoemulsification. A prospective randomised study of phacoemulsification and SICS showed no difference between the two techniques in achieving 20/60 functional acuity in a population who would not otherwise be able to afford phacoemulsification and advanced intraocular lenses.[64]

Femtosecond laser-assisted cataract surgery

Femtosecond laser-assisted cataract surgery (FLACS) was first introduced for clinical use in 2009[65] and relies on a femtosecond laser for the construction of clear corneal incision, the creation of a consistently sized anterior capsulotomy, and the fragmentation or softening of the nucleus. FLACS can increase precision and repeatability of the surgical process compared with manual surgery, but it is not a cost-effective procedure. Systematic reviews published in 2016 could not establish the equivalence or superiority of FLACS compared with standard phacoemulsification in terms of visual and refractive outcomes or overall complications.[66,67] Although FLACS might offer small benefits in particular complex cases of cataract, its substantial costs restrict widespread use in the near future.

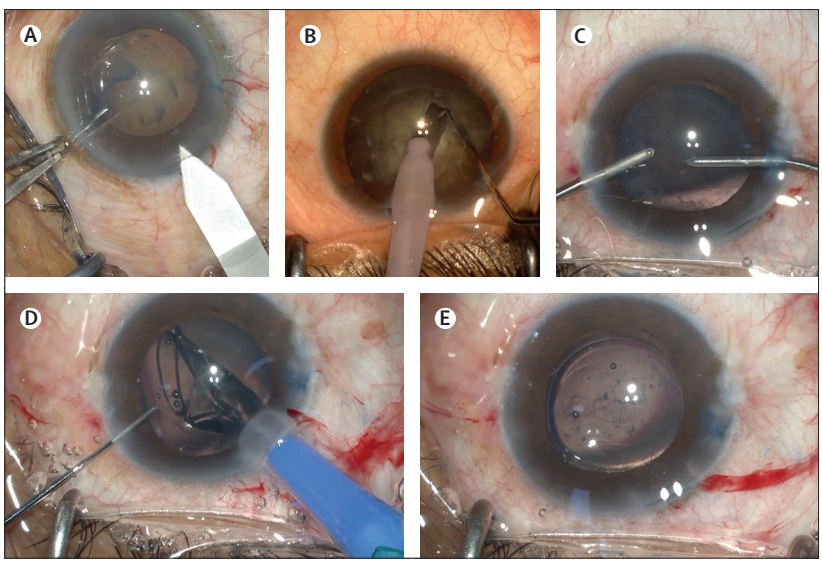

Figure 2: **The process of phacoemulsification**
After instilling anaesthetic drops and dilating drops in the eye preoperatively, the periocular skin is cleaned with povidone iodine, the surgical area is covered with a sterile drape, and a lid speculum is placed in the eye to keep the eyelids open. One or two paracenteses are created, and preservative-free lidocaine is injected into the anterior chamber, which is filled with a thick, dispersive OVD. (A) A clear corneal incision site, typically a triplanar wound to encourage sealing without stitches, is created temporally or superiorly. (B) After an anterior capsulorhexis and hydrodissection of the cortical matter from the nucleus matter, the nucleus is fragmented into smaller pieces, which are aspirated with a phacoemulsification probe. (C) The cortex is aspirated with an irrigation or aspiration probe. (D) After filling the capsular bag with a cohesive OVD, an intraocular lens is placed in the capsular bag. (E) The OVD is removed from the capsular bag and the anterior chamber, intracameral antibiotics are injected into the eye, and the corneal incisions are closed with stromal hydration. OVD=ophthalmic viscoelastic device.

Intraocular lenses

An intraocular lens is implanted into the eye in place of the crystalline lens at the end of the surgery. Intraocular lenses are classified according to their location of placement, design, material, and shape. The intraocular lens is placed within the bag if the capsular bag is intact. Other intraocular lens designs are preferred in the absence of adequate capsular support (appendix p 2). In rare cases of cataract surgery, the eye might be left without an intraocular lens (known as aphakia) because of intraoperative complications, or in advanced cases of cataract (eg, cataract nigra) in low-income and middle-income populations. However, leaving an eye aphakic is an unattractive option as the eye will require very thick glasses (more than +10·0 dioptres) to focus images.

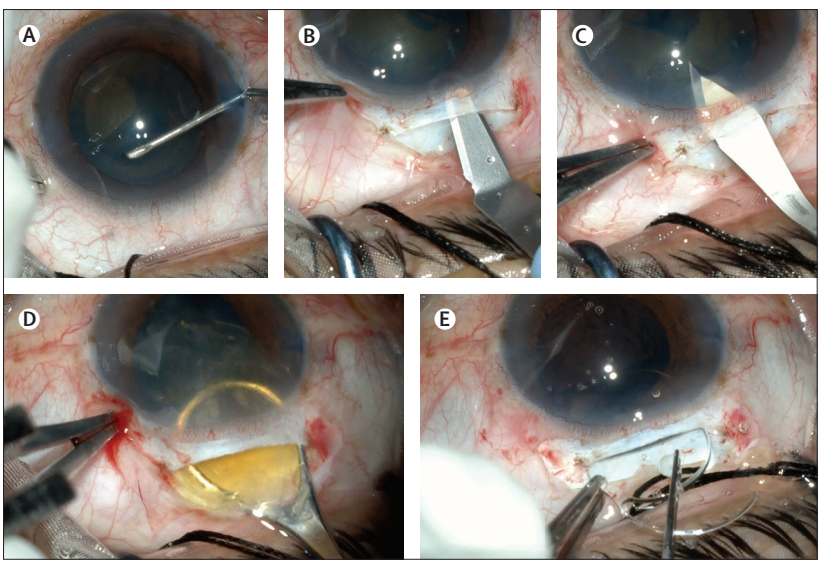

Figure 3: **The process of small-incision cataract surgery**
(A) A paracentesis is created and a dispersive OVD is injected to increase the size of the anterior chamber. (B) A trapezoidal sclerocorneal tunnel is made parallel to the ocular surface. (C) An internal corneal incision is made at the end of the sclerocorneal tunnel. A continuous curvilinear capsulorhexis is made using a cystotome or a rhexis forceps, then the cortical material from the lens capsule is hydrodissected. (D) The nucleus is prolapsed into the anterior chamber and is then expressed out. (E) The epinucleus and the cortical material are aspirated with a cannula through the sclerocorneal incision; an intraocular lens is placed into the capsular bag with a cohesive OVD. The scleral wound seals without stitches and the conjunctiva is closed by bipolar diathermy cautery. Subconjunctival injection of antibiotics and steroids is administered above the cut edge of the conjunctiva. OVD=ophthalmic viscoelastic device.

Standard intraocular lenses have monofocal power; they only focus the light at one predetermined distance, making it necessary to wear additional refractive correction for clear vision at different distances. Simultaneous correction for distance and near vision can be achieved by implanting high-quality lenses (eg, multifocal, also known as premium).[68] With multifocal intraocular lenses, more than 90% of patients do not need spectacles for distance or intermediate vision, and 70% do not need spectacles for near vision.[69] The negative aspect of multifocal intraocular lens is the substantially higher risk of glare (ie, discomfort when leaving a dark room and moving into bright sunlight; risk ratio [RR] 1·36, 95% CI 1·15–1·61) and halos (ie, halos of light around a source of bright light; RR 3·14, 95% CI 1·63–6·08) compared with monofocal intraocular lenses.[70] Extended depth of focus lenses circumvent multifocal intraocular lens disadvantages, but have worse near vision than other presbyopia-correcting intraocular lenses.[71]

Besides presbyopia, premium intraocular lenses can also correct astigmatism. Toric intraocular lenses provide better postoperative uncorrected distance visual acuity (mean difference –0·07 LogMAR, 95% CI –0·10 to –0·04), more spectacle independence (RR 0·51, 95% CI 0·36 to 0·71), and a lower degree of residual astigmatism (mean difference –0·37 dioptre, 95% CI –0·55 to –0·19) than non-toric intraocular lenses, with similar perioperative safety to monofocal intraocular lenses.[72]

Premium intraocular lenses are not recommended for patients with coexisting ocular pathologies, individuals with high expectations for visual results, or individuals with high visual demands (eg, professional drivers or pilots) because of the risk of glare and halos. Moreover, premium intraocular lenses are not reimbursed by insurance companies or national health-care services and are paid for by patients. As available studies have not shown more benefits of premium intraocular lenses than monofocal intraocular lenses, other than decreasing the need for corrective eyewear, premium intraocular lenses are not considered medically necessary.

A thorough preoperative evaluation, including patient selection and appropriate counselling about expectations and cost management, is essential for ensuring success with implanting lenses.

Postoperative management

Visual recovery after uncomplicated cataract surgery happens in 1–5 days after surgery. Patients are prescribed topical corticosteroids and topical antibiotics for 4–6 weeks and topical non-steroidal anti-inflammatory drugs (NSAIDs) typically for 4 weeks, depending on preoperative and postoperative risk factors. A combination of topical steroids and topical NSAIDs seems more effective in preventing postoperative macular oedema than a single-drug regimen.[73]

Suboptimal compliance with postoperative medications might compromise surgical outcomes.[74] To overcome this issue and reduce the cost of postoperative management, a so-called dropless cataract surgery has been conceptualised through topical compounded formulations, intraoperative intracameral injections of antibiotics or NSAIDs, and sustained-release drug implants.

Clinical follow-up visits assess the refraction, visual outcomes, and complications of a patient. A postoperative follow-up visit 1 day after uneventful phacoemulsification surgery provides little benefit.[75] The intraocular pressure might be transiently elevated, but it returns to normal amounts in 95% of non-glaucomatous patients with or without treatment.[76] Intraocular pressure increase cannot be tolerated in patients with glaucoma as it can result in further visual field damage.[77]

Most patients achieve refractive stability in 2 weeks, and refractive correction can be prescribed after this timeframe.[78]

Complications

Posterior capsule rupture

Posterior capsule rupture (PCR) and vitreous loss often occur together and are the most common intraoperative complications; they typically happen in about 1% of operations.[79,80] The rates of PCR are higher among doctors-in-training than in experienced surgeons, who can have occurrence rates as low as 0·1%.[81] Preoperative

risk factors for PCR include anxiety, poor anterior chamber visibility, an exaggerated Bell's phenomenon, and previous vitrectomy. Some factors, such as subluxated lenses and polar cataracts,[82] pseudoexfoliation syndrome, mature cataracts, small pupils, and low preoperative visual acuity also increase the risk of PCR.[83] PCR is a risk factor for endophthalmitis, cystoid macular oedema (CMO), retinal detachment, and pseudophakic bullous keratopathy. Precise management of vitreous loss is imperative to provide good visual outcomes.[84]

Nucleus drop

Part of the cataract can drop into the vitreous cavity, but this happens rarely (incidence 0·3%).[85] White cataracts, previous vitrectomy, poor preoperative visual acuity, small pupil, pseudoexfoliation syndrome, diabetic retinopathy, and male sex are risk factors for nucleus drop.[86] Pars plana vitrectomy (PPV), done the same day as cataract surgery, is the recommended treatment and is associated with reduced risks of subsequent retinal detachment.[87] A complication-free clinical course after PPV is the most important predictor of good vision.[88]

Postoperative complications within days of cataract surgery

Endophthalmitis

Endophthalmitis is the most severe ocular complication after cataract surgery. Incidence is 0·09–0·17% within 30 days of surgery,[89] but varies based on surgical and demographic factors.[90] Combining cataract surgery with other procedures, such as glaucoma surgery or anterior vitrectomy, increases the likelihood of endophthalmitis.[91] Baseline visual acuity is the main predictor of final visual outcome; diabetes, increased age, open posterior capsule, and presence of corneal infiltrates are poor prognostic factors. Although there is high-certainty evidence that preoperative topical povidone-iodine and intracameral antibiotics effectively prevent endophthalmitis,[92] there is no evidence assessing whether preoperative antibiotics are of any benefit.

Toxic anterior segment syndrome

Toxic anterior segment syndrome (TASS) is a sterile inflammation of the anterior segment; its incidence is 0·22%.[93] It can occur hours to months after cataract extraction. The clinical signs and symptoms of TASS resemble endophthalmitis. However, it responds to topical or oral steroids and does not respond to antibiotics.[94] Causes of TASS include improper cleaning of surgical instruments, use of enzymatic detergents or ultrasound baths,[95] inadvertent dilutions of intracameral drugs, preservatives, and abnormal pH or osmolarity of intraocular agents. If a TASS outbreak occurs, established protocols and online registries[96] can help establish possible causes. Visual outcomes are generally good but depend on the causes[97] and the extent of corneal damage.[98]

Postoperative complications within weeks of cataract surgery

Posterior capsular opacification

Posterior capsular opacification (PCO), also known as secondary cataract, is the most common postoperative complication of cataract surgery with an incidence of 7·1–22·6% (95% CI 6·4–24·1) after 5 years.[99] PCO is caused by the migration and proliferation of lens epithelial cells onto the posterior capsule. PCO can be visually impairing if it involves the central visual axis of the eye. Risk factors include young age, myopia, uveitic and traumatic cataracts, diabetes, and underlying retinal diseases. Treatment requires Nd:YAG laser capsulotomy, a laser procedure that can be done in the office of the doctor during the visit, to create an opening in the posterior capsule. Although non-invasive, quick, and effective, Nd:YAG capsulotomy might not be available in low-income and middle-income countries, and PCO causes up to 25% of postoperative visual impairment in existing studies.[100] Square-edge intraocular lenses have reduced PCO rates, even in the acrylic rigid intraocular lenses used in low-income and middle-income countries,[101] but do not always prevent PCO.

Pseudophakic cystoid macular oedema

Pseudophakic CMO results from fluid accumulation within or under the retina after surgery. Frank CMO is relatively uncommon after uncomplicated phacoemulsification (incidence is 0·1–3·8%),[102] but subclinical oedema has a higher prevalence.[103] Risk factors for pseudophakic CMO include previous vein occlusion, use of prostaglandin analogues, uveitis, diabetes, intraoperative complications (eg, PCR), extended surgery, and history of pseudophakic CMO in the other eye.[104] CMO can be prevented with topical NSAIDs before and after cataract extraction.[105] Topical NSAIDs, with or without topical corticosteroids, are the preferred treatment.[106] In non-responsive cases of CMO, intravitreal or periocular steroids are administered.

Residual refractive error

Residual refractive errors are one of the main reasons for patient dissatisfaction after cataract surgery. Inaccurate preoperative measurements and, rarely, intraocular lens mislabelling and patient misidentification, are potential causes.[107] Preoperative biometry in eyes with dry eye, previous refractive surgery, contact lens use, corneal dystrophy, corneal degeneration, and previous applanation tonometry should be checked for accuracy before intraocular lens calculations. Intraoperative complications, such as PCR and vitreous loss might also contribute to imprecise refractive correction.[108]

Surgical options for correcting residual refractive error include corneal-based (eg, laser in situ keratomileusis, photorefractive keratectomy, and limbal relaxing incisions) and lens-based enhancements; the choice of corrective intervention depends on the corneal thickness,

the degree of error, patient comorbidities, and the type of intraocular lens implanted.[109,110] A second intraocular lens above the first intraocular lens as a secondary posterior chamber intraocular lens can correct large residual refractive errors, especially in eyes with contraindications to keratorefractive surgery, fibrotic capsular bag, or posterior capsulotomy. Intraocular lens exchange is reserved to correct large residual refractive error in cases of intraocular lens dislocation and for patients dissatisfied with a multifocal intraocular lens placement.[111]

Pseudophakic bullous keratopathy

Loss of more endothelial cells because of surgery-related corneal trauma than a crucial amount (>700 cells per mm²) results in corneal oedema and bullae formation.[112] Pseudophakic bullous keratopathy (PBK) can occur after any intraocular surgery, but is more common after anterior chamber intraocular lens implantation, use of high phacoemulsification energy, and corneal endothelial dystrophy. Medical management of PBK includes the use of hyperosmotic agents to dehydrate the cornea. Steroids can also be used to control intraocular inflammation. Amniotic membrane grafting, corneal collagen crosslinking, and corneal transplantation could be attempted if the medical treatment is inadequate.[113]

Intraocular lens opacification

Intraocular lens opacification is uncommon but can cause substantial visual deterioration after uneventful cataract surgery. There are various opacification patterns, including calcification and glistening.[114] Surgical intraocular lens exchange is the only available option for opacified intraocular lenses.

Cataract surgery service provision

With more than 20 million surgeries performed annually worldwide,[115] cataract surgery is one of the most cost-effective health-care procedures.[116]

The cataract surgical rate (CSR)[117] quantifies the number of cataract surgeries performed annually per million population. In contrast, cataract surgical coverage (CSC) is the proportion of individuals with vision-impairing cataracts who have received cataract surgery. CSC is an indicator of how effectively services meet needs. Effective cataract surgical coverage (eCSC) combines CSC with a measure of the quality of care (eg, postoperative visual outcomes).[118] eCSC is more informative for integrated, people-centred eye care, and WHO has proposed including it in the interventions needed to achieve universal health coverage and the Sustainable Development Goals established by the UN member states.[119]

There can be discrepancies between CSC and eCSC. A survey of 67 337 people reported a median eCSC of 36·7% (IQR 30·2–50·6%) globally, approximately a third lower than the median CSC (53·7%, 46·1–66·6%). The biggest differences between CSC and eCSC are in Yemen (eCSC to CSC ratio 44%), Malawi (eCSC to CSC ratio 47%), and Eritrea (eCSC to CSC ratio 51%), reinforcing the fact that inequities in surgical quality exist between high-income countries and low-income and middle-income countries.[100] This geographical variability in visual outcomes after cataract surgery can be largely attributed to the quality of cataract surgical services and postoperative care.[120]

Immediate sequential bilateral cataract surgery (ISBCS) in routine cataract patients is controversial. ISBCS is recommended for patients requiring general anaesthesia,[121] as the risk of repeated general anaesthesia is higher than the perceived risks of ISBCS. However, ISBCS is not recommended for patients with an increased risk of infection, corneal decompensation, or other complications. Clusters of adverse events have been reported, making ISBCS seem excessively risky for routine cases to some surgeons. With adequate preventive procedures, the absolute risk of bilateral infection is extremely low nowadays (estimated at one in several million worldwide);[122] routine ISBCS is increasingly being used in low-population density contexts (eg, Scandinavia or Canada)[123] and in locations where many elective surgeries have yet to be done due to COVID-19-related lockdowns.[124]

Risks and benefits of cataract surgery

Cataract surgery has substantial benefits regarding vision and health-related quality of life[125] and protects against unplanned emergency admissions to hospital due to falls or hip fractures.[126] Furthermore, second-eye surgery is a cost-effective intervention.[127] Evidence from a longitudinal study suggested a 30% reduced risk of developing dementia in patients who had cataract extraction,[128] which might support cataract surgery as a preventive measure against dementia. Similarly, cataract surgery might have a positive effect on depression.[129] Cataract surgery can enhance light entrance into the eye and increase melatonin secretion, normalising circadian rhythms and improving sleep regulation.[130]

Risks of cataract surgery are related to the progression of underlying ocular diseases, such as age-related macular degeneration (AMD) and diabetic retinopathy. Population-based studies have found an increased risk of late AMD after cataract surgery,[131] probably due to the relationship between inflammation after surgery and neurodegeneration. However, data from 2022 have not confirmed these results.[132] Some studies advocate that blue light (not screened by the crystalline lens) might induce phototoxic retinal damage, but a 2022 systematic review did not find any advantage of blue-light filtering intraocular lenses in delaying AMD onset.[133] Data on diabetic retinopathy progression after cataract surgery in people with diabetes are controversial.[134] After cataract surgery, patients with diabetes might be at higher risk of macular oedema than patients without diabetes,[102] and appropriate measures should be planned before surgery.

Conflicting associations have been published between cataract surgery and mortality. In a population-based study in the USA, self-reported cataract surgery (an indicator of previous cataract that was visually impairing and required cataract extraction) predicted a 13% higher risk of all-cause mortality during 10 years and a 36% higher risk of vascular-related mortality than in people with no history of cataract surgery.[135] However, in a previous US national cohort with cataracts, cataract surgery was associated with a 27% decreased hazard of all-cause mortality compared with those who did not undergo cataract surgery.[136] Similarly, in a prospective cohort study of 74 044 participants in the Women's Health Initiative with cataracts, cataract surgery was associated with decreased risk for all-cause mortality and mortality attributed to vascular, cancer-related, accidental, neurological, pulmonary, and infectious causes.[137] Although improvements in quality of life and overall functioning after cataract surgery support the hypothesis that cataract surgery can protect against mortality, further studies are needed to examine the mechanisms of this association.

Sustainability

More than 90% of ophthalmic theatre staff in the USA believe operating waste (ie, hospital waste attributed to operating rooms) to be excessive.[138] Regulations preventing the reuse of surgical consumables and medications for multiple patients in high-income countries enforce practices that are unsustainable.

Cataract surgery substantially contributes to greenhouse gas emissions due to health care. A 2022 scoping review assessing the environmental costs of eye-care services reported different greenhouse gas emissions produced by cataract services in different regulatory settings.[139] In one example, a phacoemulsification cataract extraction in a UK hospital produced more than 20 times the greenhouse gas emission of the same procedure in an Indian hospital.[140] If the aspiration of universal health coverage is achieved with a global cataract surgical rate of around 8000 operations per million population per year, the use of current operating practices of high-income countries would mean global cataract surgery alone will generate 14·5 metric tonnes of CO_2 annually, a total larger than the output of many countries (eg, Kenya outputs 14·3 Mt).[141]

An evidence-based approach to surgical sustainability is advocated, promoting a change in surgical culture and regulations to encourage reusing items and reducing environmental costs and the associated risks of climate change.

Training

The ideal number of cataract surgeries needed to reduce surgical complications is debatable and ranges between 70 and 300.[142] Surgeons in their first year of independent practice are nine times more likely to have complications than experienced surgeons; each additional year of practice is associated with 10% decrease in the risk of adverse events.[143]

Training in cataract surgery is more challenging than training in macroscopic surgical procedures. Trainees are in total control of the operation regardless of their previous experience. Moreover, cataract patients are usually awake and hear any instructions given by the supervising surgeon or comments made by the trainee. Simulation of cataract surgery is increasingly being used in high-income countries, either in virtual reality, high-fidelity synthetic eyes, or in a wet laboratory (ie, a laboratory in which dead animal tissues are the basis of the simulation-based training method). Virtual reality training has been shown to reduce operating times, reduce intraoperative complications, and increase supervising doctor ratings of the quality of surgery in the operating room.[144]

Conclusions and future research

Despite the increase in cataract surgery coverage in the past two decades, cataract is still the leading cause of blindness worldwide. Treatment solely for cataract is being used less in favour of comprehensive eye care that includes preventive measures, prompt identification of cataract cases and referral for surgery, and rehabilitation after cataract extraction, but global inequity exists.

The improvement of guidelines and risk stratification systems, the widespread use of phacoemulsification, and progress in preoperative planning have improved surgical safety, refractive outcomes, and patient satisfaction. These improvements mean operating at an early stage of cataract development is possible.

Challenges remain regarding surgical management of refractive errors and presbyopia, and for patients with ocular comorbidities. Emerging research has indicated that cataract surgery might decrease the risk of dementia, depression, and overall mortality, but large-scale studies are needed.

As the increasing number of cases of blindness due to cataracts is reduced, expected increases in surgical volumes will increase both the environmental and financial burden of the procedure, and the search for sustainable approaches is still an issue. Moreover, cataract prevention is an area that has not had many developments and will probably continue to be a research topic in future.

Contributors

MVC, JCB, MN, and VV did the literature search and data collection for this Seminar. MVC wrote the original draft. JCB, MN, and VV wrote this Seminar. MN created the figures. RCK supervised this Seminar, did reviewing and editing, and did project administration.

Declaration of interests

We declare no competing interests.

References

1 Pesudovs K, Lansingh VC, Kempen JH, et al. Cataract-related blindness and vision impairment in 2020 and trends over time in relation to VISION 2020: the Right to Sight: an analysis for the Global Burden of Disease Study. *Invest Ophthalmol Vis Sci* 2021; **62:** 3523.

2 Global Burden of Disease 2019 Blindness and Vision Impairment Collaborators. Causes of blindness and vision impairment in 2020 and trends over 30 years, and prevalence of avoidable blindness in relation to VISION 2020: the Right to Sight: an analysis for the Global Burden of Disease Study. *Lancet Glob Health* 2021; **9:** e144–60.

3 Polack S, Eusebio C, Mathenge W, et al. The impact of cataract surgery on activities and time-use: results from a longitudinal study in Kenya, Bangladesh and the Philippines. *PLoS One* 2010; **5:** e10913.

4 Global Burden of Disease 2019 Blindness and Vision Impairment Collaborators. Trends in prevalence of blindness and distance and near vision impairment over 30 years: an analysis for the Global Burden of Disease Study. *Lancet Glob Health* 2021; **9:** e130–43.

5 Kuszak JR, Brown HG. Embryology and anatomy of the lens. In: Albert D, Jakobiec F, eds. Principles and practice of ophthalmology. Philadelphia, PA: Saunders, 1994: 82.

6 Delaye M, Tardieu A. Short-range order of crystallin proteins accounts for eye lens transparency. *Nature* 1983; **302:** 415–17.

7 Donaldson PJ, Grey AC, Maceo Heilman B, Lim JC, Vaghefi E. The physiological optics of the lens. *Prog Retin Eye Res* 2017; **56:** e1–24.

8 Artal P, Berrio E, Guirao A, Piers P. Contribution of the cornea and internal surfaces to the change of ocular aberrations with age. *J Opt Soc Am A Opt Image Sci Vis* 2002; **19:** 137–43.

9 West SK, Valmadrid CT. Epidemiology of risk factors for age-related cataract. *Surv Ophthalmol* 1995; **39:** 323–34.

10 Hodge WG, Whitcher JP, Satariano W. Risk factors for age-related cataracts. *Epidemiol Rev* 1995; **17:** 336–46.

11 Michael R, Bron AJ. The ageing lens and cataract: a model of normal and pathological ageing. *Philos Trans R Soc Lond B Biol Sci* 2011; **366:** 1278–92.

12 Bron AJ, Vrensen GF, Koretz J, Maraini G, Harding JJ. The ageing lens. *Ophthalmologica* 2000; **214:** 86–104.

13 Hammond CJ, Snieder H, Spector TD, Gilbert CE. Genetic and environmental factors in age-related nuclear cataracts in monozygotic and dizygotic twins. *N Engl J Med* 2000; **342:** 1786–90.

14 Hammond CJ, Duncan DD, Snieder H, et al. The heritability of age-related cortical cataract: the twin eye study. *Invest Ophthalmol Vis Sci* 2001; **42:** 601–05.

15 Choquet H, Melles RB, Anand D, et al. A large multiethnic GWAS meta-analysis of cataract identifies new risk loci and sex-specific effects. *Nat Commun* 2021; **12:** 3595.

16 Hiller R, Sperduto RD, Ederer F. Epidemiologic associations with nuclear, cortical, and posterior subcapsular cataracts. *Am J Epidemiol* 1986; **124:** 916–25.

17 Costanian C, Aubin MJ, Buhrmann R, Freeman EE. Interaction between postmenopausal hormone therapy and diabetes on cataract. *Menopause* 2020; **27:** 263–68.

18 Minkus CL, Pistilli M, Dreger KA, et al. Risk of cataract in intermediate uveitis. *Am J Ophthalmol* 2021; **229:** 200–09.

19 Küchle M, Amberg A, Martus P, Nguyen NX, Naumann GO. Pseudoexfoliation syndrome and secondary cataract. *Br J Ophthalmol* 1997; **81:** 862–66.

20 Holekamp NM, Shui YB, Beebe DC. Vitrectomy surgery increases oxygen exposure to the lens: a possible mechanism for nuclear cataract formation. *Am J Ophthalmol* 2005; **139:** 302–10.

21 Snead MP. Hereditary vitreopathy. *Eye (Lond)* 1996; **10:** 653–63.

22 Pizzol D, Veronese N, Quaglio G, et al. The association between diabetes and cataract among 42,469 community-dwelling adults in six low- and middle-income countries. *Diabetes Res Clin Pract* 2019; **147:** 102–10.

23 Yuan S, Wolk A, Larsson SC. Metabolic and lifestyle factors in relation to senile cataract: a mendelian randomization study. *Sci Rep* 2022; **12:** 409.

24 Ye J, He J, Wang C, et al. Smoking and risk of age-related cataract: a meta-analysis. *Invest Ophthalmol Vis Sci* 2012; **53:** 3885–95.

25 Lipman RM, Tripathi BJ, Tripathi RC. Cataracts induced by microwave and ionizing radiation. *Surv Ophthalmol* 1988; **33:** 200–10.

26 Neale RE, Purdie JL, Hirst LW, Green AC. Sun exposure as a risk factor for nuclear cataract. *Epidemiology* 2003; **14:** 707–12.

27 Wang W, Zhang X. Alcohol intake and the risk of age-related cataracts: a meta-analysis of prospective cohort studies. *PLoS One* 2014; **9:** e107820.

28 Chua SYL, Luben RN, Hayat S, et al. Alcohol consumption and incident cataract surgery in two large UK cohorts. *Ophthalmology* 2021; **128:** 837–47.

29 Li X, Guo Y, Liu T, et al. The association of cooking fuels with cataract among adults aged 50 years and older in low- and middle-income countries: results from the WHO Study on global AGEing and adult health (SAGE). *Sci Total Environ* 2021; **790:** 148093.

30 Alves C, Mendes D, Batel Marques F. Statins and risk of cataracts: a systematic review and meta-analysis of observational studies. *Cardiovasc Ther* 2018; **36:** e12480.

31 Chew EY, SanGiovanni JP, Ferris FL, et al. Lutein/zeaxanthin for the treatment of age-related cataract: AREDS2 randomized trial report number 4. *JAMA Ophthalmol* 2013; **131:** 843–50.

32 García-Layana A, Ciufo G, Toledo E, et al. The effect of a Mediterranean diet on the incidence of cataract surgery. *Nutrients* 2017; **9:** E453.

33 Litt M, Carrero-Valenzuela R, LaMorticella DM, et al. Autosomal dominant cerulean cataract is associated with a chain termination mutation in the human beta-crystallin gene *CRYBB2*. *Hum Mol Genet* 1997; **6:** 665–68.

34 Lamoureux EL, Fenwick E, Pesudovs K, Tan D. The impact of cataract surgery on quality of life. *Curr Opin Ophthalmol* 2011; **22:** 19–27.

35 Gali HE, Sella R, Afshari NA. Cataract grading systems: a review of past and present. *Curr Opin Ophthalmol* 2019; **30:** 13–18.

36 Chew M, Chiang PP, Zheng Y, et al. The impact of cataract, cataract types, and cataract grades on vision-specific functioning using Rasch analysis. *Am J Ophthalmol* 2012; **154:** 29–38.

37 Wang W, Zhang J, Gu X, et al. Objective quantification of lens nuclear opacities using swept-source anterior segment optical coherence tomography. *Br J Ophthalmol* 2022; **106:** 790–94.

38 Garcin T, Grivet D, Thuret G, Gain P. Using Optical Quality Analysis System for predicting surgical parameters in age-related cataract patients. *PLoS One* 2020; **15:** e0240350.

39 Wu X, Huang Y, Liu Z, et al. Universal artificial intelligence platform for collaborative management of cataracts. *Br J Ophthalmol* 2019; **103:** 1553–60.

40 Buchan JC, Amoaku W, Barnes B, et al. How to defuse a demographic time bomb: the way forward? *Eye (Lond)* 2017; **31:** 1519–22.

41 Déry J, Ruiz A, Routhier F, et al. A systematic review of patient prioritization tools in non-emergency healthcare services. *Syst Rev* 2020; **9:** 227.

42 Azuara-Blanco A, Burr J, Ramsay C, et al. Effectiveness of early lens extraction for the treatment of primary angle-closure glaucoma (EAGLE): a randomised controlled trial. *Lancet* 2016; **388:** 1389–97.

43 Lyle WA, Jin GJ. Clear lens extraction for the correction of high refractive error. *J Cataract Refract Surg* 1994; **20:** 273–76.

44 Viljanen A, Koskela K, Koskela H, Tuuminen R, Uusitalo H. One-year results of health-related and vision-related quality of life after clear lens extraction and multifocal intraocular lens implantation. *Am J Ophthalmol* 2021; **227:** 240–44.

45 Chandra S, Sivaprasad S, Ursell PG, et al. Recurring themes during cataract assessment and surgery. *Eye (Lond)* 2021; **35:** 2482–98.

46 Zetterberg M, Kugelberg M, Nilsson I, Lundström M, Behndig A, Montan P. A composite risk score for capsule complications based on data from the Swedish National Cataract Register: relation to surgery volumes. *Ophthalmology* 2021; **128:** 364–71.

47 Han JV, McGhee CNJ. New Zealand Cataract Risk Stratification system confirms reduction in intraoperative complication rates in phacoemulsification for all grades of surgeon. *Clin Exp Ophthalmol* 2021; **49:** 86–87.

48 Tognetto D, Giglio R, Vinciguerra AL, et al. Artificial intelligence applications and cataract management: a systematic review. *Surv Ophthalmol* 2021; **67:** 817–29.

49 Kane JX, Chang DF. Intraocular lens power formulas, biometry, and intraoperative aberrometry: a review. *Ophthalmology* 2021; **128:** e94–114.

50 Marmamula S, Barrenakala NR, Challa R, et al. Visual outcomes after cataract surgery among the elderly residents in the 'homes for the aged' in South India: the Hyderabad Ocular Morbidity in Elderly Study. *Br J Ophthalmol* 2021; **105:** 1087–93.

51 Mahmud I, Kelley T, Stowell C, et al. A proposed minimum standard set of outcome measures for cataract surgery. *JAMA Ophthalmol* 2015; **133:** 1247–52.

52 Brogan K, Diaper CJM, Rotchford AP. Cataract surgery refractive outcomes: representative standards in a National Health Service setting. *Br J Ophthalmol* 2019; **103:** 539–43.

53 Keay L, Lindsley K, Tielsch J, Katz J, Schein O. Routine preoperative medical testing for cataract surgery. *Cochrane Database Syst Rev* 2019; **1:** CD007293.

54 Obuchowska I, Mariak Z. Risk factors of massive suprachoroidal hemorrhage during extracapsular cataract extraction surgery. *Eur J Ophthalmol* 2005; **15:** 712–17.

55 Wielders LHP, Schouten JSAG, Winkens B, et al. Randomized controlled European multicenter trial on the prevention of cystoid macular edema after cataract surgery in diabetics: ESCRS PREMED Study Report 2. *J Cataract Refract Surg* 2018; **44:** 836–47.

56 Singh RP, Lehmann R, Martel J, et al. Nepafenac 0.3% after cataract surgery in patients with diabetic retinopathy: results of 2 randomized phase 3 studies. *Ophthalmology* 2017; **124:** 776–85.

57 Keklikci U, Isen K, Unlu K, Celik Y, Karahan M. Incidence, clinical findings and management of intraoperative floppy iris syndrome associated with tamsulosin. *Acta Ophthalmol* 2009; **87:** 306–09.

58 Chang DF, Campbell JR, Colin J, Schweitzer C. Prospective masked comparison of intraoperative floppy iris syndrome severity with tamsulosin versus alfuzosin. *Ophthalmology* 2014; **121:** 829–34.

59 Haridas A, Syrimi M, Al-Ahmar B, Hingorani M. Intraoperative floppy iris syndrome (IFIS) in patients receiving tamsulosin or doxazosin—a UK-based comparison of incidence and complication rates. *Graefes Arch Clin Exp Ophthalmol* 2013; **251:** 1541–45.

60 Grzybowski A, Ascaso FJ, Kupidura-Majewski K, Packer M. Continuation of anticoagulant and antiplatelet therapy during phacoemulsification cataract surgery. *Curr Opin Ophthalmol* 2015; **26:** 28–33.

61 Katz J, Feldman MA, Bass EB, et al. Adverse intraoperative medical events and their association with anesthesia management strategies in cataract surgery. *Ophthalmology* 2001; **108:** 1721–26.

62 Ahmed KJ, Pilling JD, Ahmed K, Buchan J. Effect of a patient-information video on the preoperative anxiety levels of cataract surgery patients. *J Cataract Refract Surg* 2019; **45:** 475–79.

63 Li S, Hu Y, Guo R, et al. The effects of different shapes of capsulorrhexis on postoperative refractive outcomes and the effective position of the intraocular lens in cataract surgery. *BMC Ophthalmol* 2019; **19:** 59.

64 Ruit S, Tabin G, Chang D, et al. A prospective randomized clinical trial of phacoemulsification vs manual sutureless small-incision extracapsular cataract surgery in Nepal. *Am J Ophthalmol* 2007; **143:** 32–38.

65 Nagy Z, Takacs A, Filkorn T, Sarayba M. Initial clinical evaluation of an intraocular femtosecond laser in cataract surgery. *J Refract Surg* 2009; **25:** 1053–60.

66 Day AC, Gore DM, Bunce C, Evans JR. Laser-assisted cataract surgery versus standard ultrasound phacoemulsification cataract surgery. *Cochrane Database Syst Rev* 2016; **7:** CD010735.

67 Popovic M, Campos-Möller X, Schlenker MB, Ahmed II. Efficacy and safety of femtosecond laser-assisted cataract surgery compared with manual cataract surgery: a meta-analysis of 14 567 eyes. *Ophthalmology* 2016; **123:** 2113–26.

68 Alio JL, Plaza-Puche AB, Férnandez-Buenaga R, Pikkel J, Maldonado M. Multifocal intraocular lenses: an overview. *Surv Ophthalmol* 2017; **62:** 611–34.

69 Rosen E, Alió JL, Dick HB, Dell S, Slade S. Efficacy and safety of multifocal intraocular lenses following cataract and refractive lens exchange: metaanalysis of peer-reviewed publications. *J Cataract Refract Surg* 2016; **42:** 310–28.

70 Khandelwal SS, Jun JJ, Mak S, Booth MS, Shekelle PG. Effectiveness of multifocal and monofocal intraocular lenses for cataract surgery and lens replacement: a systematic review and meta-analysis. *Graefes Arch Clin Exp Ophthalmol* 2019; **257:** 863–75.

71 Böhm M, Petermann K, Hemkeppler E, Kohnen T. Defocus curves of 4 presbyopia-correcting IOL designs: diffractive panfocal, diffractive trifocal, segmental refractive, and extended-depth-of-focus. *J Cataract Refract Surg* 2019; **45:** 1625–36.

72 Kessel L, Andresen J, Tendal B, Erngaard D, Flesner P, Hjortdal J. Toric intraocular lenses in the correction of astigmatism during cataract surgery: a systematic review and meta-analysis. *Ophthalmology* 2016; **123:** 275–86.

73 Wielders LHP, Schouten JSAG, Winkens B, et al. European multicenter trial of the prevention of cystoid macular edema after cataract surgery in nondiabetics: ESCRS PREMED study report 1. *J Cataract Refract Surg* 2018; **44:** 429–39.

74 Shorstein NH, Myers WG. Drop-free approaches for cataract surgery. *Curr Opin Ophthalmol* 2020; **31:** 67–73.

75 Grzybowski A, Kanclerz P. Do we need day-1 postoperative follow-up after cataract surgery? *Graefes Arch Clin Exp Ophthalmol* 2019; **257:** 855–61.

76 Smith JA, Anderson DR. Effect of the intraocular lens on intraocular pressure. *Arch Ophthalmol* 1976; **94:** 1291–94.

77 Tranos P, Bhar G, Little B. Postoperative intraocular pressure spikes: the need to treat. *Eye (Lond)* 2004; **18:** 673–79.

78 McNamara P, Hutchinson I, Thornell E, Batterham M, Iloski V, Agarwal S. Refractive stability following uncomplicated cataract surgery. *Clin Exp Optom* 2019; **102:** 154–59.

79 Zaidi FH, Corbett MC, Burton BJ, Bloom PA. Raising the benchmark for the 21st century—the 1000 cataract operations audit and survey: outcomes, consultant-supervised training and sourcing NHS choice. *Br J Ophthalmol* 2007; **91:** 731–36.

80 Ng DT, Rowe NA, Francis IC, et al. Intraoperative complications of 1000 phacoemulsification procedures: a prospective study. *J Cataract Refract Surg* 1998; **24:** 1390–95.

81 Vajpayee RB, Sharma N, Dada T, Gupta V, Kumar A, Dada VK. Management of posterior capsule tears. *Surv Ophthalmol* 2001; **45:** 473–88.

82 Narendran N, Jaycock P, Johnston RL, et al. The Cataract National Dataset electronic multicentre audit of 55,567 operations: risk stratification for posterior capsule rupture and vitreous loss. *Eye (Lond)* 2009; **23:** 31–37.

83 Theodoropoulou S, Grzeda MT, Donachie PHJ, Johnston RL, Sparrow JM, Tole DM. The Royal College of Ophthalmologists' National Ophthalmology Database Study of cataract surgery. Report 5: clinical outcome and risk factors for posterior capsule rupture and visual acuity loss following cataract surgery in patients aged 90 years and older. *Eye (Lond)* 2019; **33:** 1161–70.

84 Norregaard JC, Bernth-Petersen P, Bellan L, et al. Intraoperative clinical practice and risk of early complications after cataract extraction in the United States, Canada, Denmark, and Spain. *Ophthalmology* 1999; **106:** 42–48.

85 Pande M, Dabbs TR. Incidence of lens matter dislocation during phacoemulsification. *J Cataract Refract Surg* 1996; **22:** 737–42.

86 Lundström M, Dickman M, Henry Y, et al. Risk factors for dropped nucleus in cataract surgery as reflected by the European Registry of Quality Outcomes for Cataract and Refractive Surgery. *J Cataract Refract Surg* 2020; **46:** 287–92.

87 Vanner EA, Stewart MW, Liesegang TJ, Bendel RE, Bolling JP, Hasan SA. A retrospective cohort study of clinical outcomes for intravitreal crystalline retained lens fragments after age-related cataract surgery: a comparison of same-day versus delayed vitrectomy. *Clin Ophthalmol* 2012; **6:** 1135–48.

88 Scott IU, Flynn HW Jr, Smiddy WE, et al. Clinical features and outcomes of pars plana vitrectomy in patients with retained lens fragments. *Ophthalmology* 2003; **110:** 1567–72.

89 Kresloff MS, Castellarin AA, Zarbin MA. Endophthalmitis. *Surv Ophthalmol* 1998; **43:** 193–224.

90 Creuzot-Garcher C, Benzenine E, Mariet AS, et al. Incidence of acute postoperative endophthalmitis after cataract surgery: a nationwide study in France from 2005 to 2014. *Ophthalmology* 2016; **123:** 1414–20.

91 Pershing S, Lum F, Hsu S, et al. Endophthalmitis after cataract surgery in the United States: a report from the Intelligent Research in Sight Registry, 2013-2017. *Ophthalmology* 2020; **127:** 151–58.

92 Friling E, Lundström M, Stenevi U, Montan P. Six-year incidence of endophthalmitis after cataract surgery: Swedish national study. *J Cataract Refract Surg* 2013; **39:** 15–21.

93 Sengupta S, Chang DF, Gandhi R, Kenia H, Venkatesh R. Incidence and long-term outcomes of toxic anterior segment syndrome at Aravind Eye Hospital. *J Cataract Refract Surg* 2011; **37:** 1673–78.

94 Matsou A, Tzamalis A, Chalvatzis N, Mataftsi A, Tsinopoulos I, Brazitikos P. Generic trypan blue as possible cause of a cluster of toxic anterior segment syndrome cases after uneventful cataract surgery. *J Cataract Refract Surg* 2017; **43:** 848–52.

95 Mamalis N. Toxic anterior segment syndrome: role of enzymatic detergents used in the cleaning of intraocular surgical instruments. *J Cataract Refract Surg* 2016; **42:** 1249–50.

96 American Society of Cataract and Refractive Surgery. TASS Registry. 2022. www.ascrs.org/tass-registry (accessed March 20, 2022).

97 Oshika T, Eguchi S, Goto H, Ohashi Y. Outbreak of subacute-onset toxic anterior segment syndrome associated with single-piece acrylic intraocular lenses. *Ophthalmology* 2017; **124:** 519–23.

98 Pineda R 2nd, Jain V, Gupta P, Jakobiec FA. Descemet's stripping endothelial keratoplasty: an effective treatment for toxic anterior segment syndrome with histopathologic findings. *Cornea* 2010; **29:** 694–97.

99 Ursell PG, Dhariwal M, O'Boyle D, Khan J, Venerus A. 5 year incidence of YAG capsulotomy and PCO after cataract surgery with single-piece monofocal intraocular lenses: a real-world evidence study of 20,763 eyes. *Eye (Lond)* 2020; **34:** 960–68.

100 Han X, Zhang J, Liu Z, et al. Real-world visual outcomes of cataract surgery based on population-based studies: a systematic review. *Br J Ophthalmol* 2022; published online April 11. https://bjo.bmj.com/content/early/2022/04/10/bjophthalmol-2021-320997.

101 Haripriya A, Chang DF, Vijayakumar B, et al. Long-term posterior capsule opacification reduction with square-edge polymethylmethacrylate intraocular lens: randomized controlled study. *Ophthalmology* 2017; **124:** 295–302.

102 Chu CJ, Johnston RL, Buscombe C, Sallam AB, Mohamed Q, Yang YC. Risk factors and incidence of macular edema after cataract surgery: a database study of 81984 eyes. *Ophthalmology* 2016; **123:** 316–23.

103 Wright PL, Wilkinson CP, Balyeat HD, Popham J, Reinke M. Angiographic cystoid macular edema after posterior chamber lens implantation. *Arch Ophthalmol* 1988; **106:** 740–44.

104 Henderson BA, Kim JY, Ament CS, Ferrufino-Ponce ZK, Grabowska A, Cremers SL. Clinical pseudophakic cystoid macular edema. Risk factors for development and duration after treatment. *J Cataract Refract Surg* 2007; **33:** 1550–58.

105 Kim SJ, Schoenberger SD, Thorne JE, Ehlers JP, Yeh S, Bakri SJ. Topical nonsteroidal anti-inflammatory drugs and cataract surgery: a report by the American Academy of Ophthalmology. *Ophthalmology* 2015; **122:** 2159–68.

106 Sivaprasad S, Bunce C, Crosby-Nwaobi R. Non-steroidal anti-inflammatory agents for treating cystoid macular oedema following cataract surgery. *Cochrane Database Syst Rev* 2012; **2:** CD004239.

107 Gibbons A, Ali TK, Waren DP, Donaldson KE. Causes and correction of dissatisfaction after implantation of presbyopia-correcting intraocular lenses. *Clin Ophthalmol* 2016; **10:** 1965–70.

108 Lundström M, Dickman M, Henry Y, et al. Risk factors for refractive error after cataract surgery: analysis of 282 811 cataract extractions reported to the European Registry of Quality Outcomes for cataract and refractive surgery. *J Cataract Refract Surg* 2018; **44:** 447–52.

109 Agarwal S, Thornell E, Hodge C, Sutton G, Hughes P. Visual outcomes and higher order aberrations following LASIK on eyes with low myopia and astigmatism. *Open Ophthalmol J* 2018; **12:** 84–93.

110 Kieval JZ, Al-Hashimi S, Davidson RS, et al. Prevention and management of refractive prediction errors following cataract surgery. *J Cataract Refract Surg* 2020; **46:** 1189–97.

111 Abdalla Elsayed MEA, Ahmad K, Al-Abdullah AA, et al. Incidence of intraocular lens exchange after cataract surgery. *Sci Rep* 2019; **9:** 12877.

112 Narayanan R, Gaster RN, Kenney MC. Pseudophakic corneal edema: a review of mechanisms and treatments. *Cornea* 2006; **25:** 993–1004.

113 Cohen EJ, Brady SE, Leavitt K, et al. Pseudophakic bullous keratopathy. *Am J Ophthalmol* 1988; **106:** 264–69.

114 Trivedi RH, Werner L, Apple DJ, Pandey SK, Izak AM. Post cataract-intraocular lens (IOL) surgery opacification. *Eye (Lond)* 2002; **16:** 217–41.

115 Wang W, Yan W, Müller A, He M. A global view on output and outcomes of cataract surgery with national indices of socioeconomic development. *Invest Ophthalmol Vis Sci* 2017; **58:** 3669–76.

116 Lansingh VC, Carter MJ, Martens M. Global cost-effectiveness of cataract surgery. *Ophthalmology* 2007; **114:** 1670–78.

117 Foster A. Cataract and "Vision 2020—the Right to Sight" initiative. *Br J Ophthalmol* 2001; **85:** 635–37.

118 Ramke J, Gilbert CE, Lee AC, Ackland P, Limburg H, Foster A. Effective cataract surgical coverage: an indicator for measuring quality-of-care in the context of universal health coverage. *PLoS One* 2017; **12:** e0172342.

119 Zhang JH, Ramke J, Jan C, et al. Advancing the Sustainable Development Goals through improving eye health: a scoping review. *Lancet Planet Health* 2022; **6:** e270–80.

120 McCormick I, Butcher R, Evans JR, et al. Effective cataract surgical coverage in adults aged 50 years and older: estimates from population-based surveys in 55 countries. *Lancet Glob Health* 2022; **10:** e1744–53.

121 Buchan JC, Donachie PHJ, Cassels-Brown A, et al. The Royal College of Ophthalmologists' National Ophthalmology Database study of cataract surgery: report 7, immediate sequential bilateral cataract surgery in the UK: current practice and patient selection. *Eye (Lond)* 2020; **34:** 1866–74.

122 Lacy M, Kung TH, Owen JP, et al. Endophthalmitis rate in immediately sequential versus delayed sequential bilateral cataract surgery within the Intelligent Research in Sight (IRIS) Registry data. *Ophthalmology* 2022; **129:** 129–38.

123 Friling E, Johansson B, Lundström M, Montan P. Postoperative endophthalmitis in immediate sequential bilateral cataract surgery: a nationwide registry study. *Ophthalmology* 2022; **129:** 26–34.

124 Bhalla JS, Zakai MU, Mehtani A. Immediate sequential bilateral cataract surgery and its relevance in COVID-19 era. *Indian J Ophthalmol* 2021; **69:** 1587–91.

125 Finger RP, Kupitz DG, Fenwick E, et al. The impact of successful cataract surgery on quality of life, household income and social status in south India. *PLoS One* 2012; **7:** e44268.

126 Gillespie LD, Robertson MC, Gillespie WJ, et al. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev* 2012; **9:** CD007146.

127 Frampton G, Harris P, Cooper K, Lotery A, Shepherd J. The clinical effectiveness and cost-effectiveness of second-eye cataract surgery: a systematic review and economic evaluation. *Health Technol Assess* 2014; **18:** 1–205.

128 Lee CS, Gibbons LE, Lee AY, et al. Association between cataract extraction and development of dementia. *JAMA Intern Med* 2022; **182:** 134–41.

129 Gutiérrez-Robledo LM, Villasís-Keever MA, Avila-Avila A, Medina-Campos RH, Castrejón-Pérez RC, García-Peña C. Effect of cataract surgery on frequency of falls among older persons: a systematic review and meta-analysis. *J Ophthalmol* 2021; **2021:** 2169571.

130 Nishi T, Saeki K, Miyata K, et al. Effects of cataract surgery on melatonin secretion in adults 60 years and older: a randomized clinical trial. *JAMA Ophthalmol* 2020; **138:** 405–11.

131 Klein BE, Howard KP, Lee KE, Iyengar SK, Sivakumaran TA, Klein R. The relationship of cataract and cataract extraction to age-related macular degeneration: the Beaver Dam Eye Study. *Ophthalmology* 2012; **119:** 1628–33.

132 Bhandari S, Vitale S, Agrón E, Clemons TE, Chew EY, Age-Related Eye Disease Study 2 Research Group. Cataract surgery and the risk of developing late age-related macular degeneration: the Age-Related Eye Disease Study 2 report number 27. *Ophthalmology* 2022; **129:** 414–20.

133 Lee JS, Li PR, Hou CH, Lin KK, Kuo CF, See LC. Effect of blue light-filtering intraocular lenses on age-related macular degeneration: a nationwide cohort study with 10-year follow-up. *Am J Ophthalmol* 2022; **234:** 138–46.

134 Romero-Aroca P, Fernández-Ballart J, Almena-Garcia M, Méndez-Marín I, Salvat-Serra M, Buil-Calvo JA. Nonproliferative diabetic retinopathy and macular edema progression after phacoemulsification: prospective study. *J Cataract Refract Surg* 2006; **32:** 1438–44.

135 Chen Y, Wang W, Liao H, et al. Self-reported cataract surgery and 10-year all-cause and cause-specific mortality: findings from the National Health and Nutrition Examination Survey. *Br J Ophthalmol* 2021; published online Oct 25. http://dx.doi.org/10.1136/bjophthalmol-2021-319678

136 Tseng VL, Yu F, Lum F, Coleman AL. Cataract surgery and mortality in the United States Medicare population. *Ophthalmology* 2016; **123:** 1019–26.

137 Tseng VL, Chlebowski RT, Yu F, et al. Association of cataract surgery with mortality in older women: findings from the Women's Health Initiative. *JAMA Ophthalmol* 2018; **136:** 3–10.

138 Chang DF, Thiel CL, Ophthalmic Instrument Cleaning and Sterilization Task Force. Survey of cataract surgeons' and nurses' attitudes toward operating room waste. *J Cataract Refract Surg* 2020; **46:** 933–40.

139 Buchan JC, Thiel CL, Steyn A, et al. Addressing the environmental sustainability of eye health-care delivery: a scoping review. *Lancet Planet Health* 2022; **6:** e524–34.

140 Thiel CL, Schehlein E, Ravilla T, et al. Cataract surgery and environmental sustainability: waste and lifecycle assessment of phacoemulsification at a private healthcare facility. *J Cataract Refract Surg* 2017; **43:** 1391–98.

141 The World Bank. CO2 emissions (kt). 2020. https://data.worldbank.org/indicator/EN.ATM.CO2E.KT (accessed March 1, 2022).

142 Kaplowitz K, Yazdanie M, Abazari A. A review of teaching methods and outcomes of resident phacoemulsification. *Surv Ophthalmol* 2018; **63:** 257–67.

143 Campbell RJ, El-Defrawy SR, Gill SS, et al. New surgeon outcomes and the effectiveness of surgical training: a population-based cohort study. *Ophthalmology* 2017; **124:** 532–38.

144 Lin JC, Yu Z, Scott IU, Greenberg PB. Virtual reality training for cataract surgery operating performance in ophthalmology trainees. *Cochrane Database Syst Rev* 2021; **12:** CD014953.