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11 | Lens and Cataract

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2024–2025
BCSC®
Basic and Clinical Science Course™

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11 | Lens and Cataract

Major Revision Edition

2024–2025
BCSC
Basic and Clinical Science Course™

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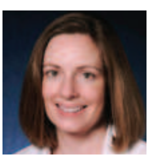

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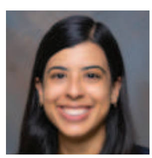

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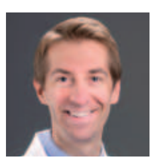

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Contents

Introduction to the BCSC

The Basic and Clinical Science Course (BCSC) is designed to meet the needs of residents and practitioners for a comprehensive yet concise curriculum of the field of ophthalmology. The BCSC has developed from its original brief outline format, which relied heavily on outside readings, to a more convenient and educationally useful self-contained text. The Academy updates and revises the course annually, with the goals of integrating the basic science and clinical practice of ophthalmology and of keeping ophthalmologists current with new developments in the various subspecialties.

The BCSC incorporates the effort and expertise of more than 100 ophthalmologists, organized into 13 Section faculties, working with Academy editorial staff. In addition, the course continues to benefit from many lasting contributions made by the faculties of previous editions. Members of the Academy Practicing Ophthalmologists Advisory Committee for Education, Committee on Aging, and Vision Rehabilitation Committee review every volume before major revisions, as does a group of select residents and fellows. Members of the European Board of Ophthalmology, organized into Section faculties, also review volumes before major revisions, focusing primarily on differences between American and European ophthalmology practice.

Organization of the Course

The Basic and Clinical Science Course comprises 13 volumes, incorporating fundamental ophthalmic knowledge, subspecialty areas, and special topics:

1 Update on General Medicine
2 Fundamentals and Principles of Ophthalmology
3 Clinical Optics and Vision Rehabilitation
4 Ophthalmic Pathology and Intraocular Tumors
5 Neuro-Ophthalmology
6 Pediatric Ophthalmology and Strabismus
7 Oculofacial Plastic and Orbital Surgery
8 External Disease and Cornea
9 Uveitis and Ocular Inflammation
10 Glaucoma
11 Lens and Cataract
12 Retina and Vitreous
13 Refractive Surgery

References

Readers who wish to explore specific topics in greater detail may consult the references cited within each chapter and listed in the Additional Materials and Resources section at the back of the book. These references are intended to be selective rather than exhaustive, chosen by the BCSC faculty as being important, current, and readily available to residents and practitioners.

Multimedia

This edition of Section 11, *Lens and Cataract,* includes multimedia—videos, interactive content (an "activity"), and online case studies—related to topics covered in the book. The multimedia content is available to readers of the print and electronic versions of Section 11 (aao.org/bcscvideo_section11, aao.org/bcscactivity_section11, and aao.org/bcsccasestudy_section11). Mobile-device users can scan the QR codes below (a QR-code reader may need to be installed on the device) to access this content.

Videos Activity Case Studies

Self-Assessment and CME Credit

Each volume of the BCSC is designed as an independent study activity for ophthalmology residents and practitioners. The learning objectives for this volume are given on page 1. The text, illustrations, and references provide the information necessary to achieve the objectives; the study questions allow readers to test their understanding of the material and their mastery of the objectives. Physicians who wish to claim CME credit for this educational activity may do so by following the instructions given at the end of the book.*

Conclusion

The Basic and Clinical Science Course has expanded greatly over the years, with the addition of much new text, numerous illustrations, and video content. Recent editions have sought to place greater emphasis on clinical applicability while maintaining a solid foundation in basic science. As with any educational program, it reflects the experience of its authors. As its faculties change and medicine progresses, new viewpoints emerge on controversial subjects and techniques. Not all alternate approaches can be included in this series; as with any educational endeavor, the learner should seek additional sources, including Academy Preferred Practice Pattern Guidelines.

The BCSC faculty and staff continually strive to improve the educational usefulness of the course; you, the reader, can contribute to this ongoing process. If you have any suggestions or questions about the series, please do not hesitate to contact the faculty or the editors.

The authors, editors, and reviewers hope that your study of the BCSC will be of lasting value and that each Section will serve as a practical resource for quality patient care.

*There is no formal American Board of Ophthalmology (ABO) approval process for self-assessment activities. Any CME activity that qualifies for ABO Continuing Certification credit may also be counted as "self-assessment" as long as it provides a mechanism for individual learners to review their own performance, knowledge base, or skill set in a defined area of practice. For instance, grand rounds, medical conferences, or journal activities for CME credit that involve a form of individualized self-assessment may count as a self-assessment activity.

Objectives

Upon completion of BCSC Section 11, *Lens and Cataract*, the reader should be able to

- describe the normal anatomy, embryologic development, physiology, and biochemistry of the crystalline lens
- identify congenital anomalies of the lens
- list types of congenital and acquired cataracts
- describe the association of cataracts with aging, trauma, medications, and systemic and ocular diseases
- describe the evaluation and management of patients with cataract and other lens abnormalities
- state the principles of cataract surgery techniques and associated surgical technology
- describe an appropriate differential diagnosis and management plan for intraoperative and postoperative complications of cataract surgery
- identify special circumstances in which cataract surgery techniques should be modified, and describe appropriate treatment plans

INTRODUCTION

The Lens and Cataract: A Brief Historical Perspective

Highlights

- Cataract surgery is not a modern invention; it has an ancient lineage and likely was first performed by a bold surgeon over 2500 years ago.
- Cataract surgery has undergone considerable evolution, and, in concert with other developments in engineering and medicine, has resulted in a more successful procedure with fewer complications.
- Phacoemulsification for cataract has become the dominant surgical technique in areas of high economic development; however, in less-developed areas, manual small-incision extracapsular cataract surgery (MSICS) is performed frequently and at a fraction of the cost, with comparable vision outcomes.

The ancient Greeks and Romans believed that the lens was the part of the eye responsible for sight. They theorized that the optic nerves were hollow channels through which "visual spirits" traveled from the brain to meet visual rays from the outside world at the lens, which they thought was located in the center of the globe; the visual information would then flow back to the brain. This concept is known as the *emanation theory of vision*. Celsus (25 BCE–50 CE) drew the lens in the center of the globe, with an empty space called the *locus vacuus* anterior to it, in CE 30 (Fig I-1).

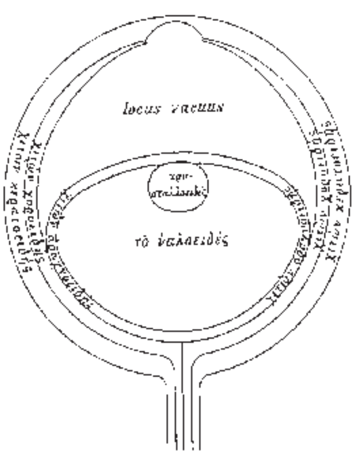


Figure I-1 The eye, after Celsus. *(From Gorin G.* History of Ophthalmology. *Publish or Perish, Inc; 1982.)*

These erroneous ideas about lens position and function persisted through the Middle Ages and into the Renaissance, as shown by the drawing of the Belgian anatomist Andreas Vesalius in 1543 (Fig I-2). The true position of the crystalline lens was illustrated by the Italian anatomist Fabricius ab Aquapendente in 1600 (Fig I-3). The Swiss physician Felix Plater (1536–1614) was the first to postulate that the retina, not the lens, was the part of the eye responsible for sight.

Today, many areas of lens physiology and biochemistry are subjects of active research. Lens regeneration has been studied since the 18th century. Regenerating the lens from epithelial cells in the lens, cornea, or iris has succeeded in several vertebrate species, notably newts and rabbits. In 2016, an experimental trial in children with congenital cataracts was able to regenerate working lenses from intact lens epithelial stem cells within 6–8 months. However, no medical treatment can yet prevent the formation or progression of cataract in the lens of the otherwise healthy adult eye, and theories about cataract formation and innovative forms of management continue to be developed. Although various risk factors for cataract formation have been identified (see Chapter 1), there is no clear evidence-based strategy to decrease cataract risk.

The high prevalence of lens disorders and continuing developments in their management make understanding this structure a vital component of ophthalmology training. The goal of Section 11 is to provide a curriculum for the study of the structure and function of the normal lens, the features of diseases involving the lens, and the surgical management of cataract in adults. For the ophthalmologist seeking to master cataract surgery, an appreciation of the development of the procedure, discussed herein, will help place modern techniques in perspective. Further discussion of pediatric lens disorders can be found in Section 6, *Pediatric Ophthalmology and Strabismus.*

Lin H, Ouyang H, Zhu J, et al. Lens regeneration using endogenous stem cells with gain of visual function. *Nature.* 2016;531(7594):323–328.

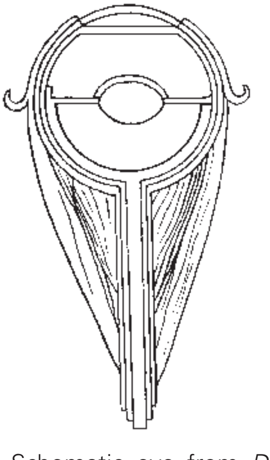


Figure I-2 Schematic eye from *De fabrica corporis humani*, by Andreas Vesalius (1514–1564). *(Reproduced with permission from the Ophthalmic Publishing Company. Feigenbaum A. Early history of cataract and the ancient operation for cataract.* Am J Ophthalmol. *1960;49:307.)*

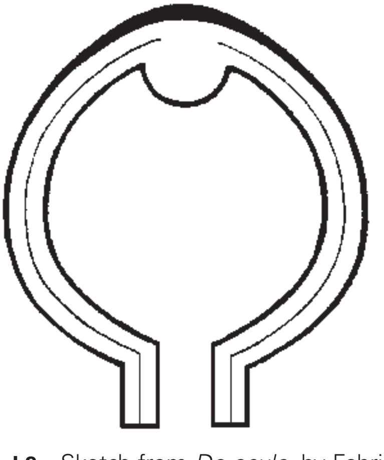


Figure I-3 Sketch from *De oculo,* by Fabricius ab Aquapendente (1537–1619), showing the correct position of the lens within the eye. *(Reproduced with permission from the Ophthalmic Publishing Company. Feigenbaum A. Early history of cataract and the ancient operation for cataract.* Am J Ophthalmol. *1960;49:307.)*

A Brief History of Cataract Surgery

Cataract, a clouding of the natural lens, can diminish visual acuity and has been an important impetus for surgical innovation. As you read this volume, consider the evolution of cataract surgery as the interplay between experimental science, technology advancements, and surgical technique.

Ancient and medieval therapy for cataract included couching, a technique whose history dates to approximately the fifth century BCE. Used throughout the Roman Empire, Europe, India, and sub-Saharan Africa, couching was performed on mature cataracts. With the patient in a seated position, the surgeon quickly inserted a needle posterior to the corneoscleral junction and pushed the lens inferiorly (Fig I-4) into the vitreous cavity. Although the lens remained in the eye, it no longer occluded the visual axis.

By 1600, anatomists had correctly identified the position of the crystalline lens (see Fig I-3) and understood cataract as opacification of the lens. A better understanding of the anatomy led to a fundamental improvement in the technique for treatment of cataract. Jacques Daviel (1696–1762) is credited with introducing an effective method to extract the opacified lens, rather than simply displace it from the visual axis. Daviel's method involved creating an incision through the inferior cornea, enlarging the wound with scissors, incising the lens capsule, expressing the nucleus, and removing the cortex by curettage, leaving the capsular bag in place (Fig I-5). This technique, called extracapsular cataract extraction (ECCE), became the new standard of care. Because of the large incision size used, early ECCE was complicated by problems with wound healing, vitreous and uveal prolapse, and infection. In addition, lens remnant–induced inflammation and capsular opacification were common, and secondary discission of pupillary membranes was often necessary.

Figure I-4 Couching. *(Reproduced from Duke-Elder S.* Diseases of the Lens and Vitreous; Glaucoma and Hypotony. *Mosby; 1969.* System of Ophthalmology; *vol II.)*

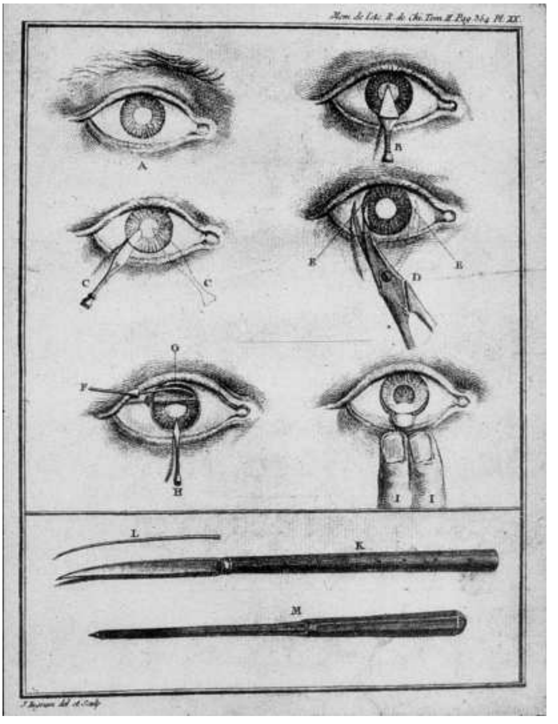


Figure I-5 A new method to cure cataract by extracting the crystalline lens. *(Reproduced from Louis M, et al.* Memoires de l'Académie Royale de Chirurgie. *Théophile Barrois Lejeune; 1787.)*

Subsequently, Albrecht von Graefe (1828–1870) advanced this technique by developing a corneal knife that created a cleaner incision and led to improved wound healing. The development of fine suture material, the invention of the binocular operating microscope, and the introduction of effective sterilization techniques reduced surgical complications. Variations on manual ECCE are widely used by surgeons in many countries today.

Removal of a cataract via intracapsular cataract extraction (ICCE) was first performed by Samuel Sharp in 1753. Today, this procedure is rarely performed, but its use may still be indicated, for example, in cases of traumatic cataract, when the zonule is disrupted. In ICCE, the lens, with its capsule intact, is removed through a limbal incision by disrupting the zonular fibers that attach the lens to the ciliary body. Various instruments were developed to grasp and extract the lens, including toothless forceps and suction cup–like devices called erysiphakes. Although ICCE avoids one likely complication of ECCE, in which the posterior capsule opacifies following surgery, it introduces a higher risk of vitreous prolapse and requires the placement of an anterior chamber intraocular lens (ACIOL) or an intraocular lens (IOL) attached to the iris or sclera because there is no possibility of capsular support. Twentieth-century advances in ICCE included chemical dissolution of zonular fibers with α-chymotrypsin, reported by José Barraquer in 1957, and use of the cryoprobe, introduced by Charles Kelman in 1962. ICCE remained the most widely used method for cataract surgery in the United States until the late 1970s, when ECCE, and later phacoemulsification, predominated. These cataract surgery techniques are presented in detail in Chapter 9.

Today, phacoemulsification is the preferred method of cataract extraction for most surgeons in areas of high economic development. However, not every cataract is a good candidate for removal by phacoemulsification, and the costly phacoemulsification unit may not be available to all surgeons in every locale. Therefore, it is useful for all surgeons to learn techniques that do not require phacoemulsification. Some of these techniques are older and typically used only in special circumstances or in complicated cases. Other techniques, for example, manual small-incision cataract surgery (MSICS), are now used widely by surgeons operating in areas without access to the latest technology or the logistical support phacoemulsification requires (eg, disposable tubing and electricity). Among skilled surgeons, vision outcomes with MSICS are demonstrably similar to those achieved with phacoemulsification, but less equipment is required and the financial costs associated with MSICS are lower.

Until 1949, cataract surgery always resulted in aphakia. To compensate for the loss of the refractive power of the natural lens, patients needed high-hyperopic spectacles, which were heavy and caused magnification and peripheral vision distortion. Once scleral contact lenses and corneal contact lenses were developed, patients could use them instead. Harold Ridley, an English ophthalmologist, observed that polymethyl methacrylate (PMMA) fragments from certain airplane cockpit windshields were well tolerated in the anterior segment of the eyes of injured World War II pilots. In 1949, after performing an ECCE on a 45-year-old woman, Ridley placed a disc-shaped PMMA lens into the posterior chamber of her eye (Fig I-6).

Ridley's lens corrected aphakic vision, but a high incidence of postoperative complications such as glaucoma, uveitis, and dislocation caused him to abandon his design. Ridley showed foresight in 3 important areas:

1. He constructed his original lens of PMMA, a biologically inert and optically clear material, in a biconvex design.
2. He used extracapsular surgery for cataract removal, preserving the capsule to support an IOL.
3. He placed the lens in the posterior chamber.

Although Ridley's work was highly controversial at the time, he ultimately received a knighthood and numerous professional accolades for his important contributions to cataract surgery.

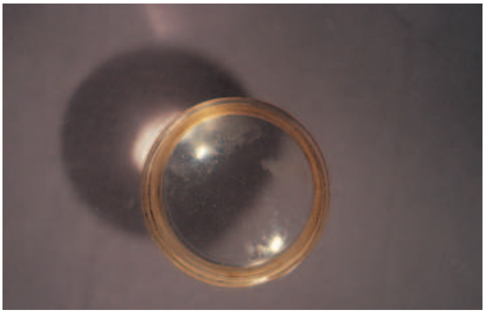


Figure I-6 Photograph of the original Ridley lens, which was first implanted by Harold Ridley in November 1949. *(Courtesy of Robert C. Drews, MD.)*

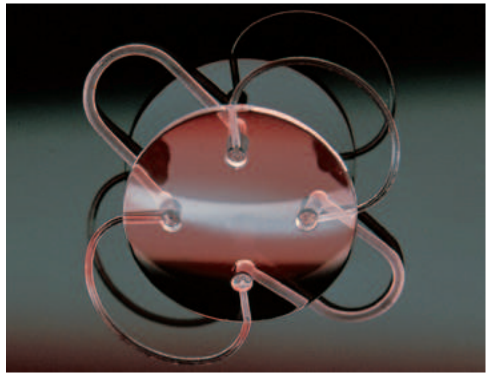


Figure I-7 Original iris-fixated lens designed by Svyatoslav Fyodorov, as made in the United States; 2 looped haptics were placed posterior to the iris, and the optic and 2 opposing loops were placed anterior to the iris. *(Courtesy of Robert C. Drews, MD.)*

The extracapsular cataract surgery of the 1950s was crude by modern standards and was generally associated with retained lens cortex, which caused fibrosis and adhesions between the iris and capsule. ICCE eliminated residual cortical material and became the preferred procedure. Because ICCE was more commonly performed in the early days of lens implantation, IOLs of that period featured optics with loops, struts, or holes for the sutures required for fixation to the iris for support (Fig I-7).

The anterior chamber angle was an alternate site for IOL support. The first ACIOLs, created by Joaquin Barraquer, Benedetto Strampelli, and others, ultimately required explantation because of severe inflammatory reactions. Oversized lenses and closed-loop IOLs caused pupillary distortion and contributed to development of uveitis-glaucoma-hyphema (UGH) syndrome. ACIOLs that were too short would spin, decenter, and come into contact with the corneal endothelium, leading to corneal edema.

Complications associated with rigid ACIOLs spurred the development of flexible, open-loop ACIOLs with 4-point fixation. These modifications dramatically improved clinical outcomes and allowed ACIOLs to remain an acceptable treatment option for cases with compromised capsular support or for secondary IOL insertion (see Chapter 8, Fig 8-12).

Sanduk Ruit, et al. A prospective randomized clinical trial of phacoemulsification vs manual sutureless small incision extracapsular cataract surgery in Nepal. *Am. J Ophthalmol.* 2007;143(1):32–38.

Posterior Chamber IOLs and Other Lens Modifications

With advances in cataract surgery technology, the desire to place the IOL within the lens capsule spurred research into posterior chamber lens implantation. In the 1970s, Steven Shearing modified a flexible version of a 3-piece IOL with closed loops by opening the loops and inserting the haptics into the capsular bag for posterior chamber placement. Subsequent, successful modifications of this lens by Shearing, Jerry Pierce, and Robert Sinskey allowed ECCE with posterior chamber IOL (PCIOL) implantation to become popular.

Thomas Mazzocco is credited with developing the foldable IOL. His plate-style lens design influenced the design of modern phakic refractive IOLs (see BCSC Section 13, *Refractive Surgery*). Foldable versions of the Shearing-style lens soon followed (see Chapter 8, Fig 8-11). The obvious advantage of the foldable-lens design is that it allows implantation of the IOL through a smaller incision, reducing the frequency of wound-related complications and postoperative astigmatism. The availability of a small-incision lens influenced many surgeons to adopt phacoemulsification as their primary technique. Monofocal IOL designs remain popular choices, but IOL modifications, such as toric, accommodating, and multifocal IOLS, have been developed to treat astigmatism and provide clearer vision at a range of working distances. See Chapters 8 and 9 in this volume, as well as BCSC Section 3, *Clinical Optics and Vision Rehabilitation*, for discussions of currently used IOL implants.

CHAPTER 1

Epidemiology of Cataract

Highlights

- Cataract is a world health problem and a leading cause of blindness and visual impairment.
- The risk of developing cataract is strongly correlated with older age, tobacco use, diabetes mellitus, and UV-B exposure. Other associated risk factors include hypertension, prolonged corticosteroid use, genetic predisposition, ocular trauma (including surgery such as vitrectomy), high myopia, and female gender.
- The role of various diets and nutritional supplements for preventing cataract development has not been consistently proven.
- The global rate of cataract surgery is increasing and can be correlated to the economic availability of health care. Cataract surgery is cost effective and associated with improved morbidity.

Introduction

Cataract is the leading cause of vision loss in the world. The World Health Organization (WHO) has estimated that more than 65.2 million people have moderate or severe distance-vision impairment or blindness due to cataract. The Global Burden of Disease, Injuries and Risk Factors study estimated that 12.6 million people were blind due to cataract in 2015 and that cataract was the leading cause of global blindness. The majority of cases of blindness due to cataract (up to 90%) are found in low-income countries (Fig 1-1).

Cataract may be congenital, metabolic, age-related, or traumatic in origin. The National Eye Institute estimates that the number of people in the United States who have or had cataract will approximately double from 24.4 million in 2010 to 50 million in 2050. Congenital cataract is responsible for 5%–20% of cases of blindness in children worldwide.

Flaxman SR, Bourne RRA, Resnikoff S, Vision Loss Expert Group of the Global Burden of Disease Study. Global causes of blindness and distance vision impairment 1990–2020: a systemic review and meta-analysis. *Lancet Glob Health*. 2017;5(12):e1221–1234.

Pascolini D, Mariotti SP. Global estimates of visual impairment: 2010. *Br J Ophthalmol.* 2012;96(5):614–618.

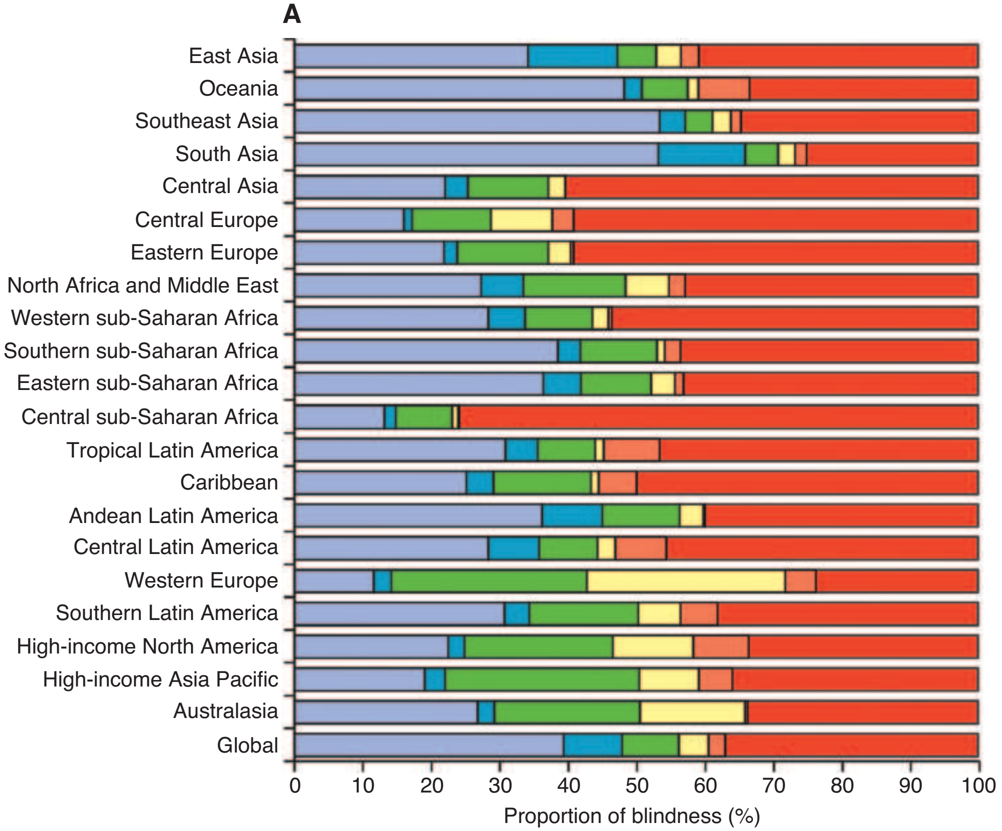


Figure 1-1 Causes of vision impairment by the Global Burden of Disease; both charts are age inclusive. **A,** Blindness. **B,** Moderate and severe vision impairment attributable to 5 leading causes of vision impairment and other conditions (combined). *(Burton MJ, Ramke J, Marques AP, et al. The Lancet Global Health Commission on global eye health: vision beyond 2020.* Lancet Glob Health. *2021;9(4):e489–551.)*

(Continued)

Cataract Prevalence and Distribution of Subtypes

While the adverse impact of cataract on vision worldwide is undeniable, the lack of a widely accepted, standardized classification for lens opacities makes it difficult to precisely determine the incidence and prevalence of cataract. Most estimates of the frequency of age-related cataract are based on data from select groups rather than from the general population. These population-based studies had differences in methodology, disease definition, and study participants.

According to data published by the National Institutes of Health in 2010, the risk of developing cataract in the United States increases starting around age 40. By age 75, half of White individuals in the United States have cataract. By age 80, 70% of White individuals have cataract, compared with 53% of Black individuals and 61% of Hispanic individuals.

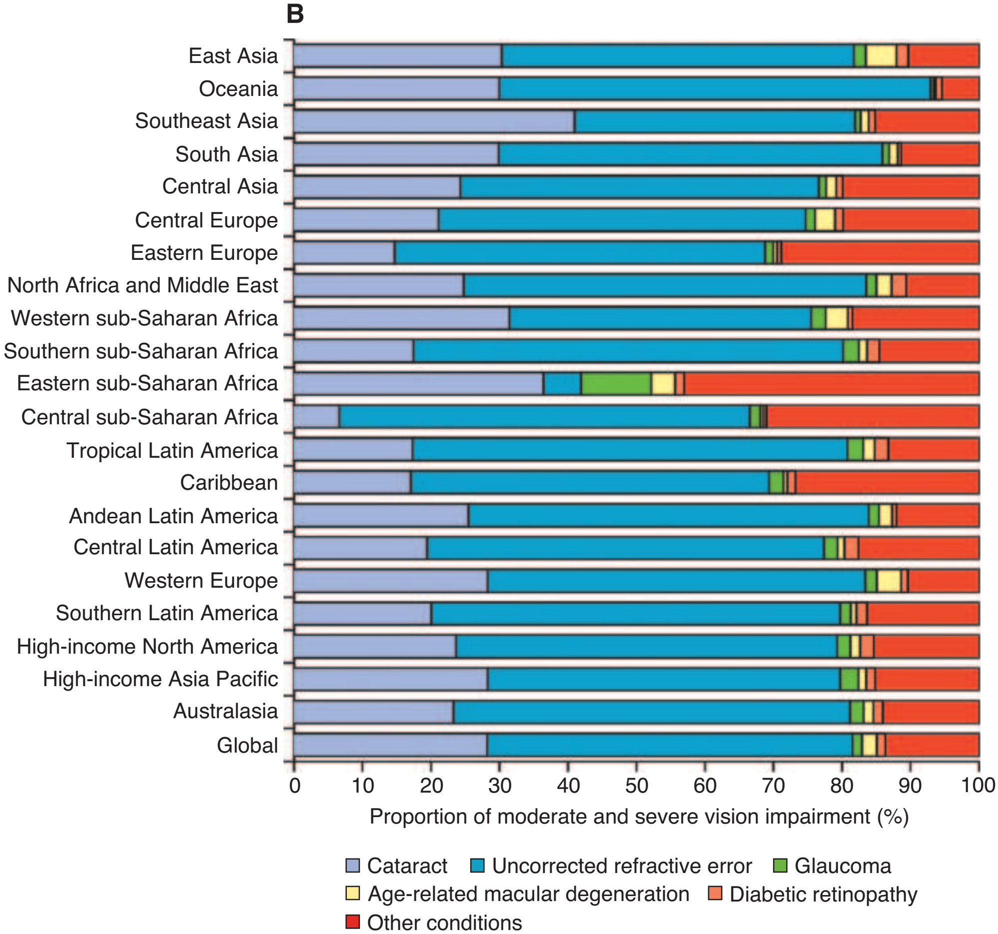


Figure 1-1 *(continued)*

Among all people with cataract in the United States, the vast majority (80%) were White, 8% were Black, and 7% were Hispanic; 61% were women and 39% were men.

The Beaver Dam Eye Study conducted in the late 1980s reported that 38.8% of men and 45.9% of women older than 74 years had visually significant cataract. For this study, "visual significance" was determined by photographic grading of lens opacities and a specified best-corrected visual acuity of 20/32 (logarithm of the minimum angle of resolution [logMAR] equivalent closest to the 20/30 Snellen fraction), excluding individuals with severe age-related maculopathy.

A follow-up to the Beaver Dam Eye Study in the early 1990s found that nuclear cataract occurred in 13.1%, cortical cataract in 8.0%, and posterior subcapsular cataract (PSC) in 3.4% of the study cohort. The incidence of all types of lens opacities rose with increasing age.

The 1998 Salisbury Eye Evaluation project was a prospective population-based cohort study designed to identify racial differences in the prevalence of cataracts in a group of Americans older than 65 years. Nuclear cataract was noted in 50.7% of White participants versus 33.5% of Black participants. Conversely, cortical cataract was more than 4 times more likely to be identified in Black individuals than in White individuals. PSC was found at roughly the same rate in both groups, between 5% and 10%.

The Barbados Eye Study provided prevalence data on lens opacities in a predominantly Black population. Cortical opacities were the most common type of cataract, and women had a higher frequency of opacification than did men.

Studies evaluating the incidence of different cataract subtypes among Asian populations include the Singapore Malay Eye Study and the Handan Eye Study. These studies suggest a higher rate of cortical cataract in Asian individuals than in White individuals. In 1994, the Italian-American Cataract Study Group conducted a study based in Parma, Italy. In this study's subgroup of participants aged 65–74 years, the cataract incidence was 18% cortical, 6% nuclear, and 6% PSC.

The prevalence of congenital cataract varies from country to country. Retrospective studies have shown a rate of 3 to 4 instances of visually significant cataract per 10,000 live births in the United States. Infantile cataract can be unilateral or bilateral and can vary in size, morphology, and opacification. Affected vision, as well as the course of treatment and prognosis, is widely variable and is described in more detail in BCSC Section 6, *Pediatric Ophthalmology and Strabismus.*

The Italian-American Cataract Study Group. Incidence and progression of cortical, nuclear, and posterior subcapsular cataracts. *Am J Ophthalmol.* 1994;118(5):623–631.

Klein BE, Klein R, Lee KE. Incidence of age-related cataract: the Beaver Dam Eye Study. *Arch Ophthalmol.* 1998;116(2):216–225.

Livingston PM, Carson CA, Stanislavsky YL, Lee SE, Guest CS, Taylor HR. Methods for a population-based study of eye disease: the Melbourne Visual Impairment Project. *Ophthalmic Epidemiol.* 1994;1(3):139–148.

Leske MC, Connell AM, Wu SY, Hyman L, Schachat A. Prevalence of lens opacities in the Barbados Eye Study. *Arch Ophthalmol.* 1997;115(1):105–111.

Varma R, Richter GM, Torres M, Foong AWP, Choudhury F, Azen SP, Los Angeles Latino Eye Study Group. Four-year incidence and progression of lens opacities: the Los Angeles Latino Eye Study. *Am J Ophthalmol*. 2010;149(5):728–734.

West SK, Duncan DD, Muñoz B, et al. Sunlight exposure and risk of lens opacities in a population-based study: the Salisbury Eye Evaluation project. *JAMA*. 1998;280(8):714–718.

Wu R, Wang JJ, Mitchell P, et al. Smoking, socioeconomic factors, and age-related cataract: the Singapore Malay Eye Study. *Arch Ophthalmol.* 2010;128(8):1029–1035.

Risk Factors for the Development of Cataract

Correlations for cataract development have been found, some stronger than others, within various populations and geographic locations. Increasing age was a consistent risk factor across all studies. Smoking increases the risk for nuclear sclerotic cataract and PSC. The Beaver Dam Eye Study and the Blue Mountains Eye Study, among others, concluded that there was a higher and dose-related risk of cataract development for study participants who smoked. Diabetes mellitus and exposure to UV-B light are also well established as consistent risk factors for cataract development.

Additional studies have suggested hypertension, prolonged corticosteroid use (systemic, inhaled, and topical), ocular trauma (including prior ocular surgery), genetic predisposition, female gender, and high myopia as risk factors for cataract development. Although high myopia was clearly associated with an increased incidence of nuclear cataract, all forms of myopia (low, moderate, and high) were associated with increased incidence of cataract surgery.

Studies have inconsistently associated certain other risk factors with cataract development. These factors include exogenous estrogen use, increased body mass index, and alcohol consumption. Heavy alcohol consumption may be neutral or increase the risk of cataract development, whereas moderate consumption may be protective. Studies looking at this question defined and collected data on moderate and heavy alcohol consumption differently, but the current recommended maximum alcohol intake in the United States (14 standard drinks per week for men and 7 standard drinks per week for women) falls within the range that may be protective against cataract formation.

The role of nutrition in cataract prevention, specifically the potential benefit of antioxidant supplementation, has long been a subject of interest and controversy. Although some initial studies suggested that increased intake of vitamins C and E could prevent cataract, in the Age-Related Eye Disease Study 1 (AREDS1), a formulation of vitamin C, vitamin E, beta carotene, zinc, and copper did not reduce the risk of progression to cataract surgery. In a large Italian trial, use of a multivitamin and mineral supplement benefited individuals with nuclear sclerotic cataract but increased the risk of PSC development. The Age-Related Eye Disease Study 2 (AREDS2) concluded that lutein/zeaxanthin supplements had no significant overall effect on rates of progression to cataract surgery, although patients in the lowest quintile of dietary lutein/zeaxanthin intake did have a reduced risk of cataract development following supplementation.

Age-Related Eye Disease Study Research Group. Risk factors associated with age-related nuclear and cortical cataract: a case-control study in the Age-Related Eye Disease Study, AREDS Report No. 5. *Ophthalmology.* 2001;108(8):1400–1408.

Age-Related Eye Disease Study Research Group 2 (AREDS2), Chew EY, SanGiovanni JP, Ferris FL, et al. Lutein/zeaxanthin for the treatment of age-related cataract: AREDS2 randomized trial report no. 4. *JAMA Ophthalmol.* 2013;131(7):843–850.

Chua SYL, Luben RN, Hayat S, UK Biobank Eye and Vision Consortium, et al. Alcohol consumption and incident cataract surgery in two large UK cohorts. *Ophthalmology.* 2021;128(6):837–847.

Mitchell P, Cumming RG, Attebo K, Panchapakesan J. Prevalence of cataract in Australia: the Blue Mountains Eye Study. *Ophthalmology*. 1997;104(4):581–588.

Cataract Surgery Rate and Outcomes

Globally, over 20 million cataract operations are performed each year. Cataract surgical rate and economic indicators have been shown to be closely associated to each other, indicating the strong influence of resource availability on health care delivery. According to the Lancet Global Health Commission on Global Eye Health: Vision Beyond 2020, the rate of cataract surgery can reach up to 10,000 operations per million population per year in high-income countries, while the surgery rate is less than 500 operations per million population per year in Sub-Saharan Africa. The WHO has determined that due to population growth and increasing longevity, the number of cataract operations performed worldwide must triple to keep pace with need, with a goal of 3000 operations per million population annually. The WHO also notes other factors that affect access to surgical care for cataracts. In general, women in low- and middle-income countries have higher rates of cataract but are less likely to undergo cataract surgery, while women in some high-income countries are more likely than men to utilize eye care services.

Cataract surgery is correlated with reduced morbidity. In 2012, a study of over 1.1 million US Medicare beneficiaries aged 65 and older determined that patients who had been diagnosed with cataract had a reduced risk of hip fracture within 1 year after surgery compared with patients who had not undergone cataract surgery. A 2022 study using data from the Adult Changes in Thought study showed that cataract extraction was associated with a lower dementia risk in people aged 65 years and older.

A 2013 follow-up study of the Blue Mountains Eye Study showed that cataract surgery was associated with significantly better long-term survival of older persons. However, in 2018, a large prospective cohort study conducted by the Women's Health Initiative showed that in women participants aged 65 and older, cataract surgery was associated with an increased risk for all-cause mortality and mortality attributed to vascular, cancer-related, accidental, pulmonary, and infectious causes. It is unclear whether the results were related to the surgical procedure itself or to the individual participants postponing the surgery until the hazard rates increased.

Cataract surgery is the most common surgery performed on an outpatient basis in the United States. Approximately 3.7 million cataract operations are performed each year. The rate of cataract surgery has increased steadily over the last 3 decades and so has the rate of second-eye operations within 3 months of the first. Although initial studies suggested second-eye cataract surgery had no effect on fall risk, a 2018 prospective study found that second-eye surgery provided additional benefits (73% fall reduction) compared with the number of falls before the first surgery, most likely due to increased binocular visual acuity and increased contrast sensitivity. Cataract surgery has been demonstrated to be an ever more cost-effective intervention for visual improvement in the United States, with an estimated cost per quality-adjusted life-year gain of $1001 for the first eye, $3101 for the second eye, and $1514 for bilateral surgery.

Brown GC, Brown MM, Busbee BG. Cost-utility analysis of cataract surgery in the United States for the year 2018. *J Cataract Refract Surg.* 2019;45(7):927–938.

Feng YR, Meuleners LB, Fraser ML, Brameld KJ, Agramunt S. The impact of first and second eye cataract surgeries on falls: a prospective cohort study. *Clin Interv Aging.* 2018;13: 1457–1464.

Fong CS, Mitchell P, Rochtchina E, Teber ET, Hong T, Wang JJ. Correction of visual impairment by cataract surgery and improved survival in older persons: the Blue Mountains Eye Study cohort. *Ophthalmology*. 2013;120(9):1720–1727.

Gollogly HE, Hodge DO, St Sauver JL, Erie JC. Increasing incidence of cataract surgery: population-based study. *J Cataract Refract Surg.* 2013;39(9):1383–1389.

Lee CS, Gibbons, LE, Lee AY, et al. Association between cataract extraction and development of dementia. *JAMA Intern Med.* 2022;182(2):134–141.

Lewallen S, Mousa A, Bassett K, Courtright P. Cataract surgical coverage remains lower in women. *Brit J Ophthalmol.* 2009;93(3):295–298.

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(1): 3–10.

Tseng VL, Yu F, Lum F, Coleman AL. Risk of fractures following cataract surgery in Medicare beneficiaries. *JAMA*. 2012;308(5):493–501.

CHAPTER 2

Anatomy

This chapter includes a related video. Go to aao.org/bcscvideo_section11 or scan the QR code in the text to access this content.

Highlights

- The lens contributes approximately 20.00 diopters (D) of the 60.00 D of power of an average eye.
- The anterior curvature of the lens increases with age, causing increased myopia. At the same time, the index of refraction decreases, which may make the eye more hyperopic.
- The central pole of the posterior lens capsule measures 2–4 µm thick.

See BCSC Section 2, *Fundamentals and Principles of Ophthalmology,* for additional discussion and illustrations of the topics covered in this chapter.

Normal Crystalline Lens

The crystalline lens is a transparent, biconvex structure located posterior to the iris and anterior to the vitreous body (Fig 2-1). The lens is suspended by numerous fibers that together are called the zonule. Collectively, this ring of fibers (the *zonule of Zinn*) attaches the lens to the ciliary body and can be considered a ligament. Components of the lens include the capsule, the epithelium, the cortex, and the nucleus (Fig 2-2).

An imaginary line called the *optic axis* joins the anterior and posterior poles of the lens, passing through them. Hypothetical lines on the lens surface that pass from one pole to the other are referred to as *meridians.* The *equator* of the lens is its greatest circumference.

The functions of the lens are

- to maintain its own clarity
- to refract light
- to provide accommodation, in conjunction with the zonule and the ciliary body

Lacking a blood supply and innervation after fetal development, the lens depends entirely on the aqueous humor to meet its metabolic requirements and also to remove its wastes.

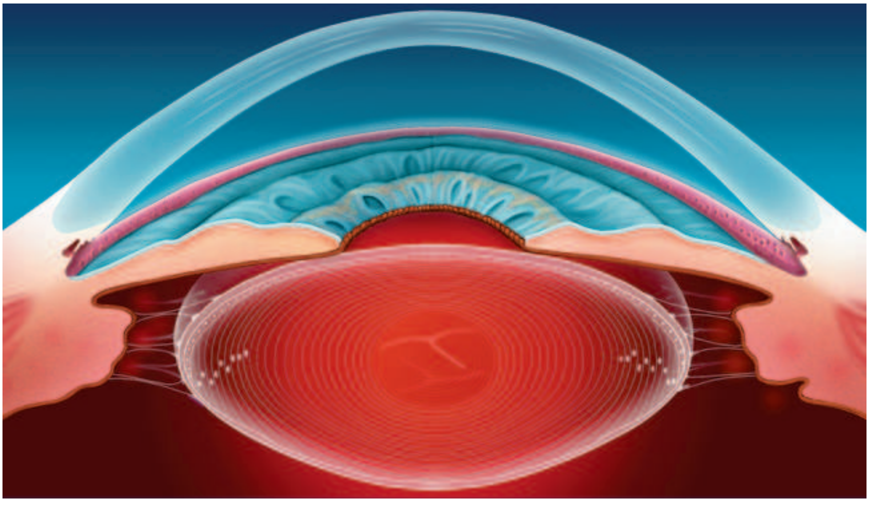


Figure 2-1 Cross section of the human crystalline lens, showing the relationship of the lens to the surrounding ocular structures. *(Illustration by Christine Gralapp.)*

The lens is able to refract light because its index of refraction—normally about 1.41 in the center and 1.39 in the periphery—is different from that of the aqueous and vitreous humors surrounding it. In its nonaccommodative state, the lens contributes approximately 20.00 D of the approximately 60.00 D of convergent refractive power of the average human eye; the air–cornea interface provides the rest, about 40.00–45.00 D.

The lens continues to grow throughout an individual's life. At birth, it measures about 6.4 mm equatorially and 3.5 mm anteroposteriorly and weighs approximately 90 mg. The lens of an adult typically measures 9–10 mm equatorially and about 5 mm anteroposteriorly and weighs approximately 255 mg. With increasing age, the relative thickness of the cortex increases; the lens also adopts an increasingly curved shape, so that older lenses have more refractive power. However, the index of refraction of the lens decreases with increasing age, probably as a result of the increasing presence of insoluble protein particles. Thus, with increasing age, the eye may become either more hyperopic or more myopic, depending on the balance of these opposing changes.

Capsule

The lens capsule is an elastic, transparent basement membrane that is composed of type IV collagen and other matrix proteins and laid down by the epithelial cells. The capsule contains the lens substance and is capable of molding it during accommodative changes. The outer layer of the lens capsule, the *zonular lamella,* serves as the point of attachment for the zonular fibers. The lens capsule is thickest in the anterior and posterior preequatorial zones and thinnest at the central posterior pole, where it may measure only 2–4 µm (Fig 2-3). At birth, the anterior lens capsule is considerably thicker than the posterior capsule, and its thickness increases throughout a person's life.

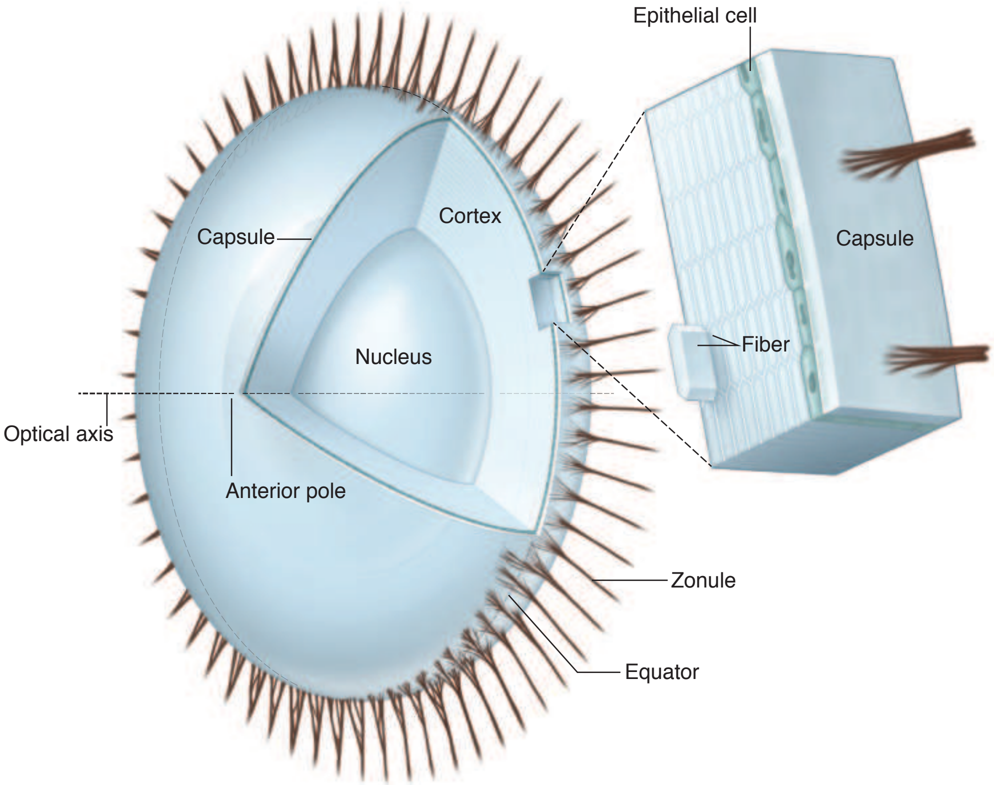


Figure 2-2 Structure of the normal human lens. *(Illustration by Mark Miller.)*

Zonular Fibers

As mentioned, the lens is supported by a system of fibers (the zonule) that originate from the basal lamina of the nonpigmented epithelium of the pars plana and pars plicata of the ciliary body. These zonular fibers, which are located in the valleys between the ciliary processes, consist of microfibrils composed of elastic tissue. They insert at discrete points on the lens capsule 1.5 mm anterior to the equator and 1.25 mm posterior to the equator (Fig 2-4). With increasing age, the equatorial zonular fibers regress, leaving separate anterior and posterior layers that appear in a triangular shape on cross section of the zonular ring. The fibers are 5–30 µm in diameter; on light microscopy, they are revealed as eosinophilic structures that have a positive periodic acid–Schiff (PAS) reaction. Ultrastructurally, the strands, or microfibrils, composing the fibers are 8–10 nm in diameter, with 12–14 nm of banding (Video 2-1).

VIDEO 2-1 Endoscopic view of ciliary body, zonular fibers, and lens capsule.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

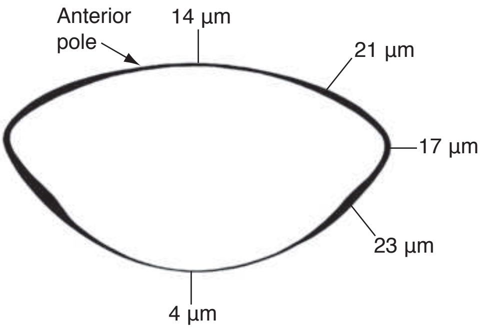


Figure 2-3 Schematic of the adult lens capsule showing the relative thickness of the capsule in different zones. *(Illustration by Christine Gralapp.)*

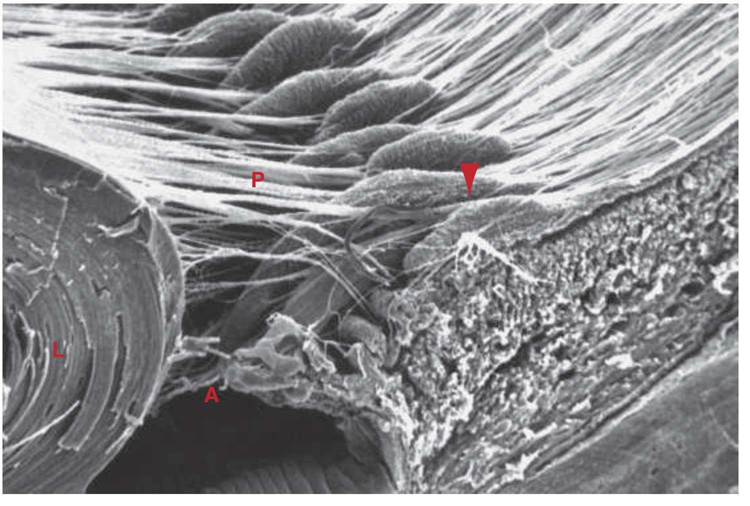


Figure 2-4 Scanning electron micrograph of a sagittally cut specimen of the ciliary body, zonular fibers, and lens *(L)* of the eye of a 4-year old rhesus monkey. The anterior *(A)* and posterior *(P)* zonular fibers are attached to the zonular plexus *(arrowhead)* posteriorly in the valleys between the ciliary processes. *(Courtesy of Johannes W. Rohen, MD, PhD, and Cassandra Flügel-Koch, MD, PhD.)*

Lens Epithelium

Immediately posterior to the anterior lens capsule is a single layer of epithelial cells. These cells are metabolically active and carry out all normal cell activities, including biosynthesis of DNA, RNA, protein, and lipid. They also generate adenosine triphosphate to meet the energy demands of the lens. The epithelial cells are mitotic; the greatest activity of premitotic (replicative, or S phase) DNA synthesis occurs in a ring around the anterior lens known as the *germinative zone*. The newly formed cells migrate toward the equator, where they differentiate into fibers. This area, called the bow region, is where the epithelial cells begin the process of terminal differentiation into lens fibers (Fig 2-5).

During this differentiation, perhaps the most dramatic morphologic change occurs when the epithelial cells elongate to form lens fiber cells. This elongation is associated with a tremendous increase in the mass of cellular proteins in the fiber cell membrane. At the same time, the cells lose organelles, including nuclei, mitochondria, and ribosomes. The

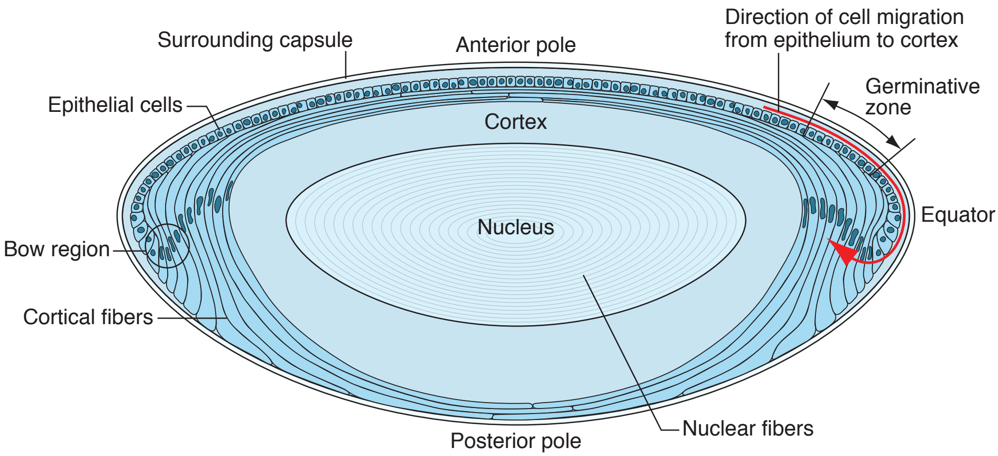


Figure 2-5 Schematic of the mammalian lens in cross section. *Arrow* indicates the direction of cell migration from the epithelium to the cortex. *(Illustration by Mark Miller.)*

loss of these organelles is optically advantageous, because light passing through the lens is no longer absorbed or scattered by these structures. However, because these new lens fiber cells lack the metabolic functions previously carried out by the organelles, they are now dependent on glycolysis for energy production (see Chapter 3 in this volume).

Nucleus and Cortex

As new fibers are laid down, no cells are lost from the lens. The new fibers crowd and compact the previously formed fibers; the older layers are located toward the center. The oldest layers, the *embryonic and fetal lens nuclei,* were produced during embryogenesis and persist in the center of the lens (see Chapter 4, Fig 4-1). The outermost fibers are the most recently formed and make up the cortex of the lens.

Lens sutures (see Chapter 4, Figs 4-1 and 4-2) are formed by the interdigitation of the anterior and posterior tips of the spindle-shaped fibers. Multiple optical zones, as well as Y-shaped sutures located within the lens nucleus, are visible on slit-lamp biomicroscopy. (See Chapter 4 in this volume for further discussion of the embryonic nucleus and lens sutures.)

Strata of epithelial cells with differing optical densities are laid down throughout life, creating the zones of demarcation between the cortex and the nucleus. However, there is no morphologic distinction between the cortex and the nucleus; rather, the transition between these regions is gradual. Although some surgical texts and this volume make distinctions between the nucleus, endonucleus, epinucleus, and cortex, these terms relate only to potential differences in the behavior and appearance of the material during surgical procedures.

Barraquer RI, Michael R, Abreu R, Lamarca J, Tresserra F. Human lens capsule thickness as a function of age and location along the sagittal lens perimeter. *Invest Ophthalmol Vis Sci.* 2006;47(5):2053–2060.

Clark JI. Biology of the transparent lens and changes with age. In: Albert DM, Miller JW, Azar DT, Young LH, eds. *Albert & Jakobiec's Principles and Practice of Ophthalmology.* 4th ed. Springer; 2022.

CHAPTER 3

Biochemistry and Physiology

This chapter includes a related video. Go to aao.org/bcscvideo_section11 or scan the QR code in the text to access this content.

Highlights

- The human lens is composed of 66% water and 33% protein.
- Water-soluble proteins make up 80% of a young lens; water-insoluble proteins increase with both increasing age and opacification and make up as much as 90% of a brunescent cataract.
- Anaerobic glycolysis produces most of the adenosine triphosphate (ATP) used in lens metabolism.
- High glucose levels in an individual result in elevated levels of sorbitol and fructose within the lens.
- Accommodation increases the curvature of the central anterior lens surface and the dioptric power of the eye.

See BCSC Section 2, *Fundamentals and Principles of Ophthalmology,* for additional discussion of several of the topics discussed in this chapter.

Molecular Biology

Crystallin Proteins

The human lens has a protein concentration of 33% of its wet weight, which is at least twice the concentration found in most tissues. Lens proteins are commonly divided into 2 groups, based on water solubility (Fig 3-1); the ratio of these 2 groups changes with increasing age. Water-soluble proteins account for approximately 80% of lens proteins in a young lens; with increasing age, the percentage of water-insoluble proteins increases. The water-soluble group consists mainly of a group of proteins called *crystallins.* The crystallins can be divided into 2 major groups, α-crystallins and β,γ-crystallins.

α-Crystallins are the largest of the crystallins. In their native state, their molecular mass ranges between 600 and 800 kilodaltons (kDa); they represent about one-third of the lens proteins by mass. They may also combine with other crystallins, forming much larger complexes. There are 2 α-crystallin subunits, αA and αB, each with a molecular mass of approximately 20 kDa, which form heteromeric complexes containing about 30 subunits.

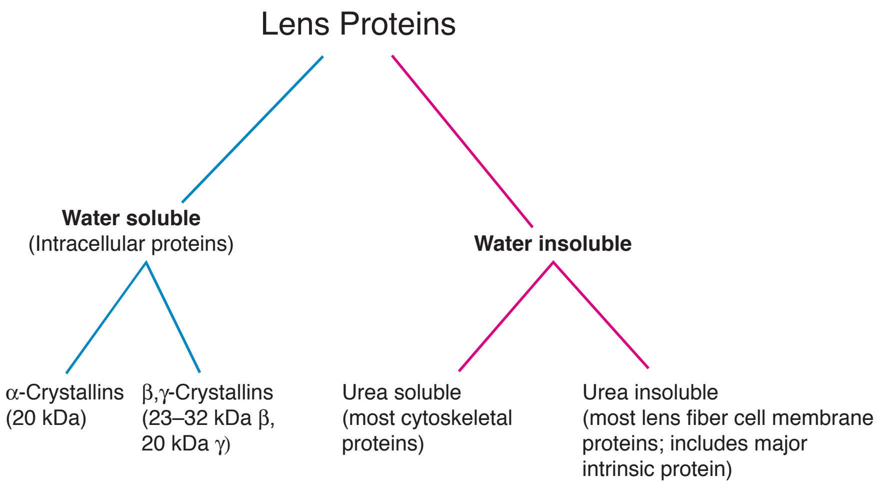


Figure 3-1 Overview of lens proteins.

The α-crystallins are members of the family of small heat-shock proteins; their complexes bind to partially denatured proteins and prevent them from aggregating. Their primary function in lens fiber cells appears to be to inhibit the complete denaturation and insolubilization of the other crystallins.

The basic structure of the β-crystallins and γ-crystallins has been maintained through hundreds of millions of years of vertebrate evolution. X-ray studies have demonstrated fourfold repetition of a core 3-dimentional structural motif, suggesting that the β,γ-crystallins might have arisen from double duplication and fusion of a gene for a 40-residue polypeptide. β,γ-crystallins are subdivided into 2 groups, based on molecular mass and isoelectric points.

The β-crystallins, a complex group of oligomers composed of polypeptides, are encoded by 7 genes. Their molecular masses range from 23 to 32 kDa. The individual polypeptides associate with each other, forming dimers and higher-order complexes in their native state. By gel chromatography, the β-crystallins can be separated into βH (β high-molecular-mass) and βL (β low-molecular-mass) fractions.

The γ-crystallins are the smallest of the crystallins, with a molecular mass in the range of 20 kDa or less. In humans, the gamma family is encoded by 4 genes. Because the native γ-crystallins do not associate with each other or with other proteins, they have the lowest molecular mass of the crystallin fractions.

Membrane Structural Proteins and Cytoskeletal Proteins

The water-insoluble fraction of lens proteins can be divided into 2 fractions based on solubility in an 8 molar (M) solution of urea:

- The *urea-soluble fraction* of the young lens contains cytoskeletal proteins that provide the structural framework of the lens cells.
- The *urea-insoluble fraction* of the young lens contains the plasma membranes of the lens fiber cells.

The microfilaments and microtubules found in the urea-soluble fraction of the lens are similar to those found in other cell types. However, the lens contains 2 classes of intermediate filaments that are unusual: one class is made from the protein *vimentin,* which is not usually found in epithelial cells; the other class, the *beaded filaments,* is composed of the proteins phakinin and filensin, which are specific to the lens. Genetic disruption of the structure of the beaded filaments leads to disruption of the structure of the lens fiber cells and ultimately to cataract formation.

In the urea-insoluble fraction of the lens, several proteins are associated with the fiber-cell plasma membranes. One of these makes up nearly 50% of the membrane proteins and is known as *major intrinsic protein* (*MIP;* also known as *aquaporin 0*), a member of a class of proteins called *aquaporins.* Other members of the aquaporin family are found throughout the body, where they serve predominantly as water channels. MIP first appears in the lens just as the fibers begin to elongate. With increasing age, this protein, which has a molecular mass of 28 kDa, undergoes proteolytic cleavage, forming a protein fragment with a molecular mass of 22 kDa. When an individual reaches 20–30 years of age, the relative proportions of these 2 proteins become about equal. Over time, the protein fragment with the molecular mass of 22 kDa predominates in the lens nucleus.

Hejtmancik JF, Piatigorsky J. Lens proteins and their molecular biology. In: Albert D, Miller J, Azar D, Blodi B, eds. *Albert & Jakobiec's Principles and Practice of Ophthalmology.* 3rd ed. Vol 1. Saunders; 2008:chap 105.

Increase of Water-Insoluble Proteins With Age

As the lens ages, its proteins aggregate, forming very large particles. These particles become water insoluble and scatter light, increasing the opacity of the lens. Even if the lens remains relatively transparent, the water-insoluble protein fraction increases with age. Although conversion of the water-soluble proteins into water-insoluble proteins appears to be a natural process in lens fiber maturation, it may occur more quickly in cataractous lenses.

In cataracts with significant browning of the lens nucleus *(brunescent cataracts),* the increase in the amount of water-insoluble protein is directly correlated to the degree of opacification. In markedly brunescent cataracts, up to 90% of the nuclear proteins may be insoluble. Associated oxidative changes, including protein-to-protein and protein-to-glutathione disulfide bond formation, result in decreased levels of the reduced form of glutathione and increased levels of glutathione disulfide (oxidized glutathione) in the cytoplasm of the nuclear fiber cells. Glutathione is essential to maintain a reducing environment in the lens cytoplasm. Depletion of the reduced form of glutathione accelerates protein crosslinking, protein aggregation, and light scattering.

In addition to undergoing increased formation of disulfide bonds, nuclear proteins are also highly crosslinked by nondisulfide bonds. This insoluble protein fraction contains yellow-brown pigments that are found in higher concentration in nuclear cataracts. Increased fluorescence is generated by nondisulfide crosslinks that form in brunescent nuclear cataracts.

Carbohydrate Metabolism

See Figure 3-2 for an overall diagram of glucose metabolism in the lens.

> **Clinical considerations** Lens metabolism maintains a clear lens and derives most of its energy from anaerobic glycolysis. In high-glucose conditions, hexokinase becomes inhibited by products of glycolysis, and aldose reductase becomes relatively increased, converting more glucose to sorbitol. Sorbitol is poorly permeable, and elevated levels of both sorbitol and fructose increase the osmotic pressure within the lens, resulting in myopic shift, disruption of normal cytoskeletal architecture, and opacification of the lens. In acute hyperglycemia, hyperopic shifts may occur, however.

Glycolysis and Hexose Monophosphate Shunt

The goal of lens metabolism is the maintenance of lens transparency. In the lens, energy production largely depends on glucose metabolism. Glucose enters the lens from the aqueous humor both by *simple diffusion* and by a mediated transfer process called *facilitated diffusion*. Most of the glucose transported into the lens is phosphorylated to glucose-6-phosphate (G6P) by the enzyme hexokinase. This reaction is 70–100 times slower than that of other enzymes involved in lens glycolysis and is, therefore, rate-limited. Once formed, G6P enters 1 of 2 metabolic pathways:

- *Anaerobic glycolysis.* The more active of the 2 pathways, anaerobic glycolysis provides most of the high-energy phosphate bonds required for lens metabolism. In anaerobic glycolysis, substrate-linked phosphorylation of adenosine diphosphate (ADP) to adenosine triphosphate (ATP) occurs at 2 steps along the pathway from glucose metabolism to lactate. The rate-limiting step in the glycolytic pathway itself occurs at the level of the enzyme phosphofructokinase, which is regulated via feedback control by metabolic products of the glycolytic pathway. This pathway is much less efficient than the aerobic citric acid cycle (also called the tricarboxylic acid cycle or the Krebs cycle), because only 2 net molecules of ATP are produced for each glucose molecule utilized, whereas the aerobic citric acid cycle produces an additional 36 molecules of ATP from each metabolized glucose molecule (oxidative metabolism). Because of the low oxygen tension in the lens, only about 3% of the lens glucose passes through the citric acid cycle to produce ATP; however, even this low level of aerobic metabolism produces approximately 25% of the ATP of the lens.
- *The hexose monophosphate (HMP) shunt.* Also known as the *pentose phosphate pathway*, the HMP shunt is the less active pathway for utilization of G6P in the lens—on average, less than 5% of lens glucose is metabolized by this route. This pathway, which is stimulated in the presence of elevated levels of glucose, is involved in the generation of nicotinamide adenine dinucleotide phosphate (NADPH), or reducing power.

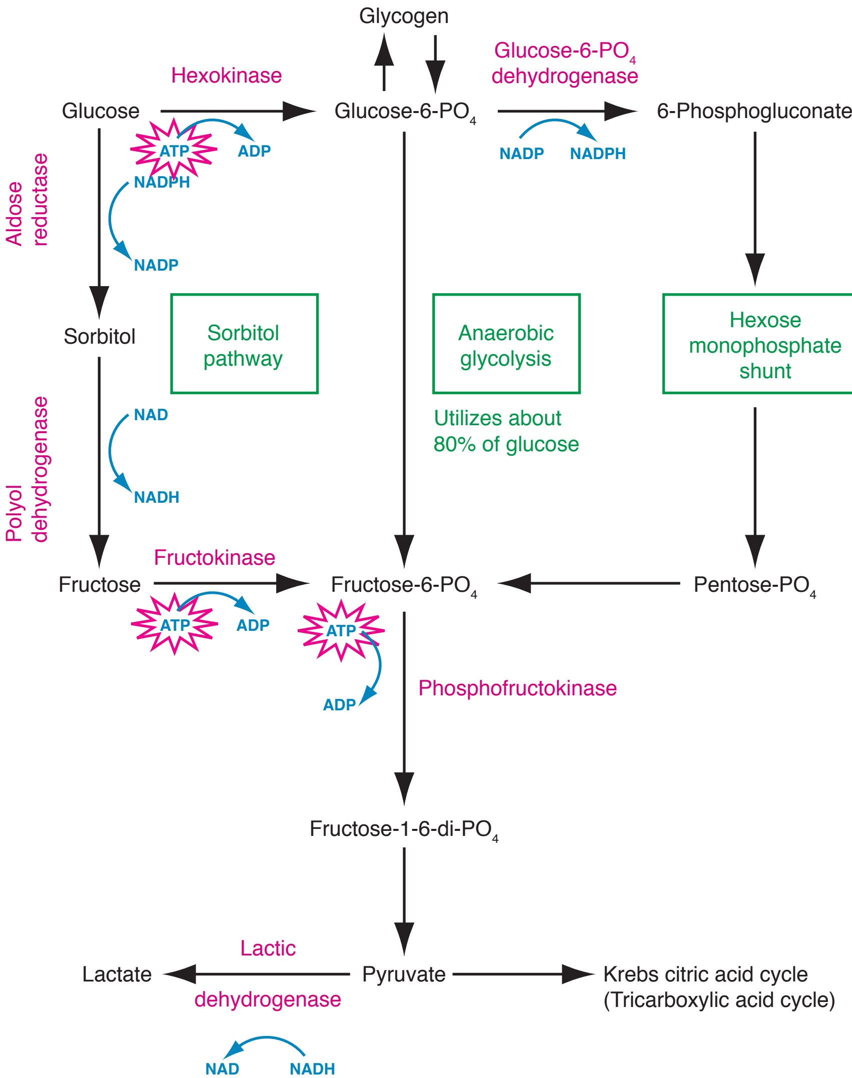


Figure 3-2 Simplified scheme of glucose metabolism in the lens. ADP, adenosine diphosphate; ATP, adenosine triphosphate; NAD, nicotinamide adenine dinucleotide; NADH, nicotinamide adenine dinucleotide hydrogen; NADP, nicotinamide adenine dinucleotide phosphate; NADPH, nicotinamide adenine dinucleotide phosphate (reduced form). *(Adapted with permission from Hart WM Jr, ed.* Adler's Physiology of the Eye: Clinical Application. *9th ed. Mosby; 1992:362.)*

Sorbitol Pathway

The glucose that is not phosphorylated to G6P enters the *sorbitol pathway,* which is yet another pathway for lens glucose metabolism, or it is converted into gluconic acid. The key enzyme in the sorbitol pathway is aldose reductase; this enzyme has been found to play a pivotal role in the development of "sugar" cataracts. In comparison with hexokinase, aldose reductase has a very low affinity for glucose. Less than 4% of lens glucose is normally converted to sorbitol.

As noted in the previous section, the hexokinase reaction is rate-limited in phosphorylating glucose in the lens and is inhibited by the feedback mechanisms of the products of glycolysis. When the amount of glucose increases in the lens (as occurs in individuals in hyperglycemic states), the sorbitol pathway is activated relatively more than the glycolytic pathway, and sorbitol accumulates (Fig 3-3).

Sorbitol is metabolized to fructose by the enzyme polyol dehydrogenase. Unfortunately, this enzyme has a relatively low affinity (high K_m [Michaelis constant; the apparent affinity constant]), meaning that considerable sorbitol will accumulate before being further metabolized. This characteristic, combined with the poor permeability of the lens to sorbitol, results in retention of sorbitol in the lens.

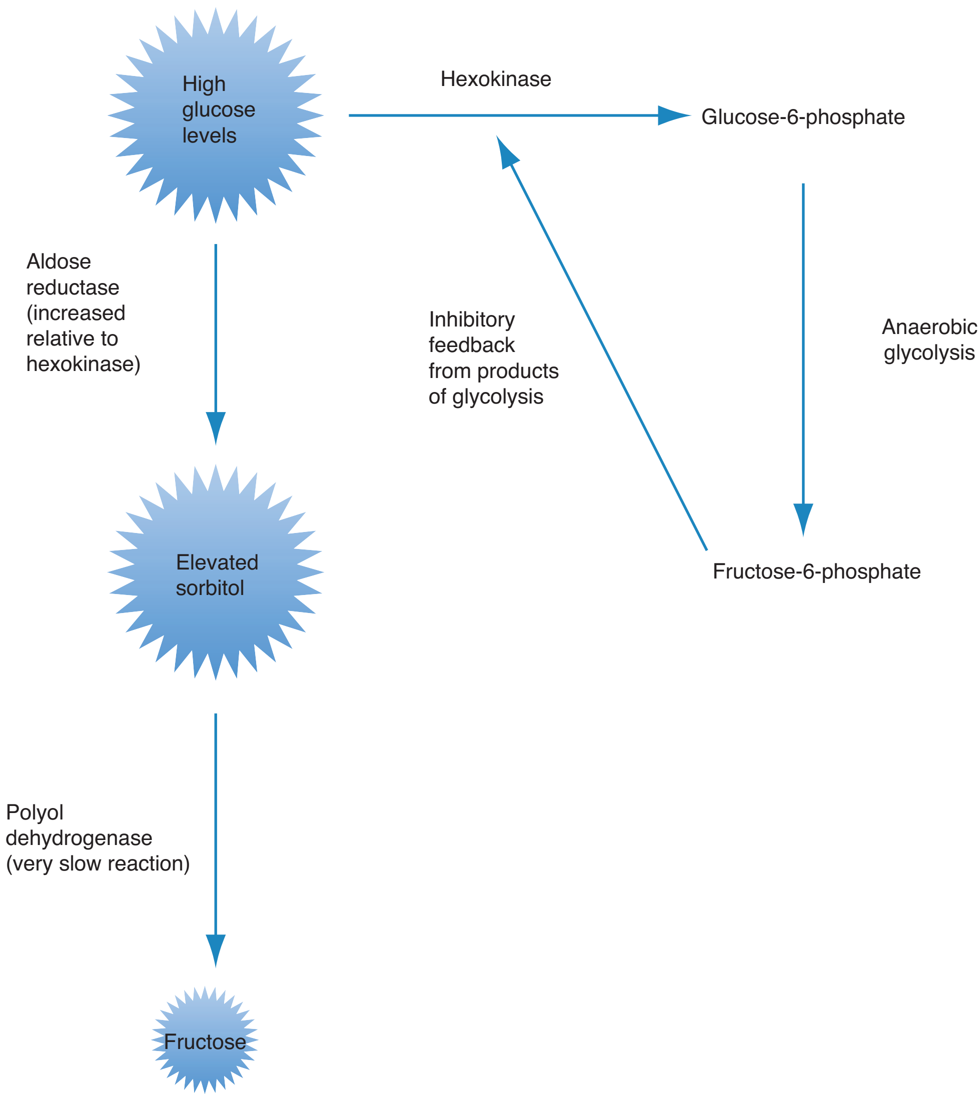


Figure 3-3 Sorbitol pathway in a hyperglycemic state. *(Courtesy of Charles Cole, MD.)*

A high ratio of NADPH (the reduced form of NADP) to nicotinamide adenine dinucleotide hydrogen (NADH) drives the reaction in the direction of sorbitol accumulation. The accumulation of NADP that occurs as a consequence of activation of the sorbitol pathway may cause the HMP shunt stimulation that is observed in the presence of an elevated lens glucose level. In addition to a rise in sorbitol levels, fructose levels also increase in a lens incubated in a high-glucose environment. Together, the 2 sugars increase the osmotic pressure within the lens, drawing in water. At first, the energy-dependent pumps of the lens are able to compensate, but ultimately, they are overwhelmed, resulting in swelling of the fibers, disruption of the normal cytoskeletal architecture, and opacification of the lens.

Studies of cataract development in various hyperglycemic animal species demonstrate the pivotal role of aldose reductase in cataractogenesis in animals. Those species that have high aldose reductase activities develop lens opacities, whereas those lacking aldose reductase do not. In addition, specific inhibitors of this enzymatic activity, applied either systemically or topically to 1 eye, decrease the rate of onset and the severity of glucose cataracts in experimental studies.

Galactosemia, a metabolic disorder that prevents the body from processing galactose, can also result in cataract formation. See BCSC Section 2, *Fundamentals and Principles of Ophthalmology.*

Clinical considerations The lens is able to sustain normal metabolism in a nitrogen environment. Provided with ample glucose, the anoxic in vitro lens remains completely transparent, has normal levels of ATP, and maintains its ion and amino acid pump activities. However, when deprived of glucose, the lens cannot maintain these functions and becomes hazy after several hours, even in the presence of oxygen. For this reason, dextrose is added to the irrigation fluid used in vitrectomy procedures.

Oxidative Damage and Protective Mechanisms

Free radicals, each of which has at least 1 unpaired electron, are generated in the course of normal cellular metabolic activities and may also be produced by external agents such as radiant energy; they are highly reactive and can damage lens fibers. Peroxidation of lens fiber plasma or plasma membrane lipids has been suggested as a factor contributing to lens opacification.

Because oxygen tension in and around the lens is normally low, free radical reactions may not involve molecular oxygen; instead, the free radicals may react directly with molecules. DNA is easily damaged by free radicals. Although some of the damage to the lens is reparable, some of it may be permanent. Free radicals can also attack the proteins or membrane lipids in the lens cortex; no repair mechanisms are known to ameliorate such damage. In lens fibers, where protein is no longer synthesized, free radical damage may lead to polymerization and crosslinking of lipids and proteins, resulting in an increase in the fibers' water-insoluble protein content.

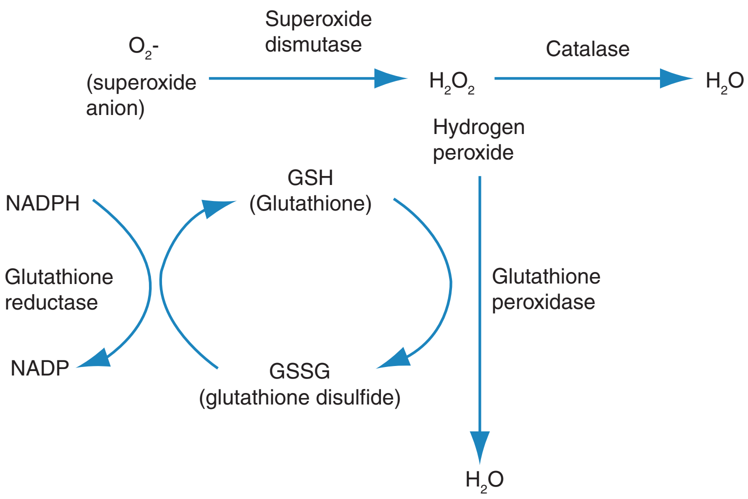


Figure 3-4 Free radical scavenger pathway in the lens. *(Courtesy of Charles Cole, MD.)*

The lens is equipped with several enzymes that work together to destroy the superoxide anion, O_2^-, thus protecting against free radical or oxidative damage (Fig 3-4):

- Superoxide dismutase catalyzes the destruction of the superoxide anion, O_2^-.
- Catalase breaks down the hydrogen peroxide produced by superoxide dismutase.
- Glutathione peroxidase catalyzes a reaction that results in the formation of glutathione disulfide (GSSG), which is then reconverted to glutathione (GSH) by glutathione reductase, using the pyridine nucleotide NADPH. The primary source of erythrocyte NADPH, the HMP shunt, provides NADPH as the reducing agent. Thus, glutathione acts indirectly as a major free radical scavenger in the lens.

In addition, both vitamin E and ascorbic acid are present in the lens. Each of these substances can act as a free radical scavenger and thus protect against oxidative damage. See BCSC Section 2, *Fundamentals and Principles of Ophthalmology,* for additional discussion.

Clinical considerations Increased oxygen levels in the eye may have a role in cataract formation. Long-term hyperbaric oxygen therapy leads to myopic shift, increased opacification of the lens nucleus, and often nuclear cataracts. The lens is exposed to increased oxygen acutely during retina procedures and chronically after vitrectomy. Because vitrectomy is associated with high rates of nuclear cataract formation, it has been suggested that the low oxygen level created by the gel structure of the vitreous body protects the lens from oxidative damage.

Beebe DC. The lens. In: Kaufman PL, Alm A, eds. *Adler's Physiology of the Eye: Clinical Application.* 11th ed. Mosby; 2011:131–163.

Kataria AS, Thompson JT. Cataract formation and progression in patients less than 50 years of age after vitrectomy. *Ophthalmology Retina.* 2017;1(2):149–153.

Lens Physiology

Throughout a person's life, lens epithelial cells at the equator divide and develop into lens fibers, resulting in continual growth of the lens (see Chapter 2, Figs 2-2 and 2-5, in this volume). The lens cells with the highest metabolic rate are found in the epithelium and outer cortex. These superficial cells utilize oxygen and glucose for the active transport of electrolytes, carbohydrates, and amino acids into the lens. Because the lens is avascular, the task of maintaining transparency poses several challenges. The older cells, found toward the center of the lens, must be able to communicate with the superficial cells and the environment outside the lens. This communication is accomplished through low-resistance gap junctions that facilitate the exchange of small molecules from cell to cell. Lens fiber cells also have abundant water channels in their membranes, made up of MIP. It is not yet certain whether MIP serves primarily in the lens as a water channel, as an adhesion molecule that minimizes the extracellular space between fiber cells, or as both. Minimizing the extracellular space between fiber cells is important in reducing the scattering of light as it passes through the lens.

Maintenance of Lens Water and Cation Balance

The normal human lens contains approximately 66% water and 33% protein; this proportion changes very little with aging. The lens cortex is more hydrated than the lens nucleus. About 5% of the lens volume is the water found between the lens fibers in the extracellular spaces. Within the lens, sodium and potassium concentrations are maintained at 20 millimolar (mM) and 120 mM, respectively.

Perhaps the most important aspect of lens physiology is the mechanism that controls water and electrolyte balance, which is critical to lens transparency. Because transparency is highly dependent on the structural and macromolecular components of the lens, perturbation of cellular hydration can readily lead to opacification. It is noteworthy that disruption of water and electrolyte balance is not a feature of nuclear cataracts. In cortical cataracts, however, the water content rises significantly.

Lens epithelium: site of active transport

The lens is less hydrated and has higher levels of potassium ions (K^+) and amino acids than the surrounding aqueous and vitreous humors. Conversely, the lens contains lower levels of sodium ions (Na^+), chloride ions (Cl^-), and water than its surrounding environment. The cation balance between the inside and outside of the lens is the result both of the permeability properties of the lens cell membranes and of the activity of the sodium-potassium pumps, which reside within the cell membranes of the lens epithelium and each lens fiber. The mechanism of the sodium-potassium pumps, namely pumping sodium ions out while taking potassium ions in, relies on the breakdown of ATP and is regulated by the enzyme Na^+,K^+-ATPase. Inhibition of Na^+,K^+-ATPase leads to loss of cation balance and elevated water content in the lens.

Pump-leak theory

The combination of active transport and membrane permeability is often referred to as the pump-leak system of the lens (Fig 3-5). According to the *pump-leak theory,* potassium and various other molecules, such as amino acids, are actively transported into the

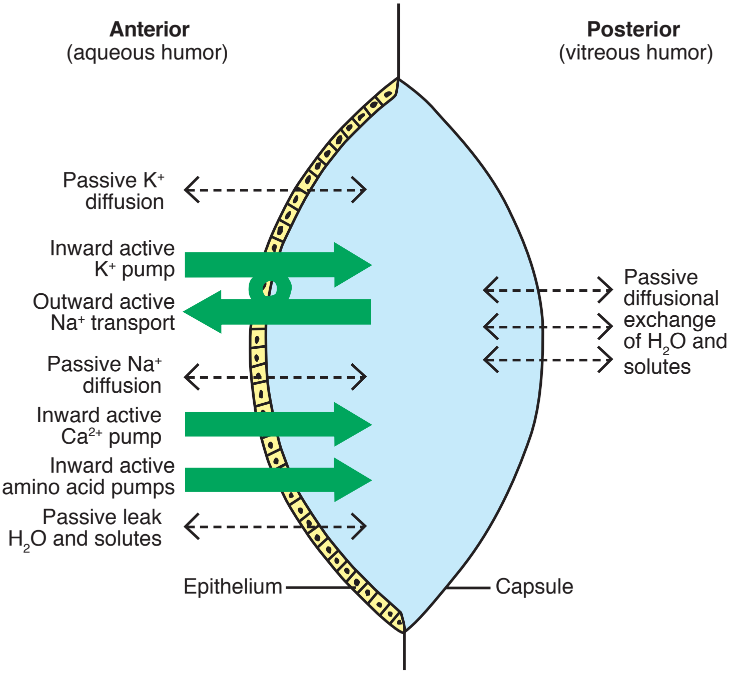


Figure 3-5 The pump-leak theory of pathways of solute movement in the lens. The major site of active-transport mechanisms is the anterior epithelium, whereas passive diffusion occurs over both surfaces of the lens. *(Modified with permission from Paterson CA, Delamere NA. The lens. In: Hart WM Jr, ed.* Adler's Physiology of the Eye. *9th ed. Mosby; 1992:365.)*

lens anteriorly via the epithelium. They then passively diffuse out with the concentration gradient through the back of the lens, where there are no active-transport mechanisms. Conversely, sodium flows in through the back of the lens with the concentration gradient and then is actively exchanged for potassium by the epithelium.

In support of the pump-leak theory, an anteroposterior gradient was found for both ions: potassium was concentrated in the anterior lens; sodium, in the posterior lens. Most of the Na^+,K^+-ATPase activity is found in the lens epithelium and the superficial cortical fiber cells. The active-transport mechanisms are lost if the capsule and attached epithelium are removed from the lens but not if the capsule alone is removed by enzymatic degradation with collagenase. These findings support the hypothesis that the epithelium is the primary site for active transport in the lens.

Accommodation and Presbyopia

Accommodation, the mechanism by which the eye changes focus from distant to near images, occurs when the action of the ciliary muscle on the zonular fibers changes the lens shape. The lens substance is most malleable during childhood and the young-adult years, progressively losing its ability to change shape with increasing age.

According to the Helmholtz theory of accommodation, most of the accommodative change in lens shape occurs at the central anterior lens surface. The central anterior capsule is thinner than the peripheral capsule (see Chapter 2, Fig 2-3), and the anterior zonular fibers insert slightly closer to the visual axis than do the posterior zonular fibers, resulting in a central anterior bulge during accommodation. The curvature of the posterior lens surface changes minimally with accommodation. The central posterior capsule, which is the thinnest area of the capsule, maintains the same curvature regardless of zonular tension.

The ciliary muscle is a ring-shaped muscle that, on contraction, has the opposite effect from what one intuitively expects of a sphincter. When a sphincter muscle contracts, it usually tightens its grip. However, when the ciliary muscle contracts, the diameter of the muscle ring is reduced, thereby relaxing the tension on the zonular fibers and allowing the lens to become more spherical while maintaining its position. Thus, when the ciliary muscle contracts, the axial thickness of the lens increases, the equatorial diameter of the lens decreases, and the dioptric power of the lens increases, resulting in accommodation. When the ciliary muscle relaxes, the zonular tension increases, the lens flattens, and the dioptric power of the eye decreases (Table 3-1; Video 3-1).

Table 3-1 Changes With Accommodation

	With Accommodation	Without Accommodation
Ciliary muscle action	Contraction	Relaxation
Ciliary ring diameter	Decreases	Increases
Zonular tension	Decreases	Increases
Lens shape	More spherical	Flatter
Lens equatorial diameter	Decreases	Increases
Axial lens thickness	Increases	Decreases
Central anterior lens capsule curvature	Steepens	Flattens
Central posterior lens capsule curvature	Minimal change	Minimal change
Lens dioptric power	Increases	Decreases

VIDEO 3-1 Changes with accommodation.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

The accommodative response may be stimulated by the known or apparent size and distance of an object or by blur, chromatic aberration, or a continual oscillation of ciliary tone. Accommodation is mediated by the parasympathetic fibers of cranial nerve III (the oculomotor nerve). Parasympathomimetic drugs (eg, pilocarpine) induce accommodation, whereas parasympatholytic medications (eg, atropine) block accommodation. Drugs that relax the ciliary muscle are called *cycloplegics.*

The *amplitude of accommodation* is the amount of change in the eye's refractive power that is produced by accommodation. It diminishes with age and may be affected by some medications and diseases.

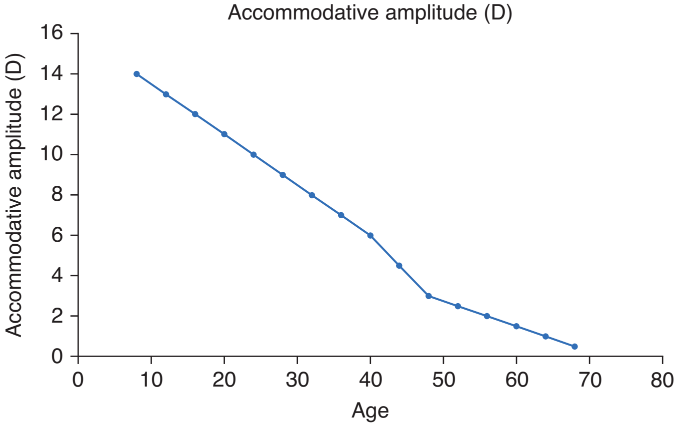


Figure 3-6 Loss of accommodation with age, shown in diopters (D). *(Courtesy of Charles Cole, MD.)*

Clinical Pearl In adolescents, the accommodative power is generally 12.00–16.00 diopters (D); in people aged 40 years, the power has decreased to 4.00–8.00 D. In people older than 50 years, the average accommodative power decreases to less than 2.00 D (Fig 3-6).

Presbyopia is the gradual loss of accommodative response, resulting from reduced elasticity of the crystalline lens. Once an individual is approximately 40 years of age or older, the rigidity of the lens nucleus reduces accommodation, as contraction of the ciliary muscle no longer results in increased convexity and dioptric power of the anterior surface of the lens. This decreased accommodation then becomes clinically significant. Studies have shown that, throughout a lifetime, the hardness or stiffness of the human lens increases more than 1000-fold. (See also BCSC Section 3, *Clinical Optics and Vision Rehabilitation.*)

Glasser A. Accommodation. In: Kaufman PL, Alm A, eds. *Adler's Physiology of the Eye: Clinical Application.* 11th ed. Mosby; 2011:40–69.

CHAPTER 4

Embryology and Developmental Anomalies

This chapter includes a related video. Go to aao.org/bcscvideo_section11 or scan the QR code in the text to access this content.

Highlights

- The lens is derived from surface ectoderm.
- Approximately one-third of congenital cataracts are a component of a syndrome, one-third are an isolated inherited trait, and one-third result from undetermined causes.
- Most hereditary cataracts are inherited in an autosomal dominant pattern, and they are almost always bilateral.
- Trauma is the most common cause of acquired lens displacement.
- A subluxated lens is partially displaced from the pupil but remains in the pupillary area; a luxated or dislocated lens is completely displaced from the pupil.

Normal Development of the Lens

The formation of the human crystalline lens begins very early in embryogenesis (Fig 4-1; Video 4-1). At approximately 25 days of gestation, 2 lateral evaginations, called the *optic vesicles,* form from the forebrain, or diencephalon. As the optic vesicles enlarge and extend laterally, they become closely apposed and adherent to the *surface ectoderm,* a single layer of cuboidal cells, in 2 patches on either side of the head. (See BCSC Section 2, *Fundamentals and Principles of Ophthalmology,* for additional discussion and illustrations of ocular development.)

Lens Placode

At approximately 27 days of gestation, the ectoderm cells that overlie the optic vesicles become columnar. This area of thickened cells is called the *lens placode.* Growth factors of the *bone morphogenetic protein (BMP)* family are required for formation of the lens placode and, subsequently, the lens.

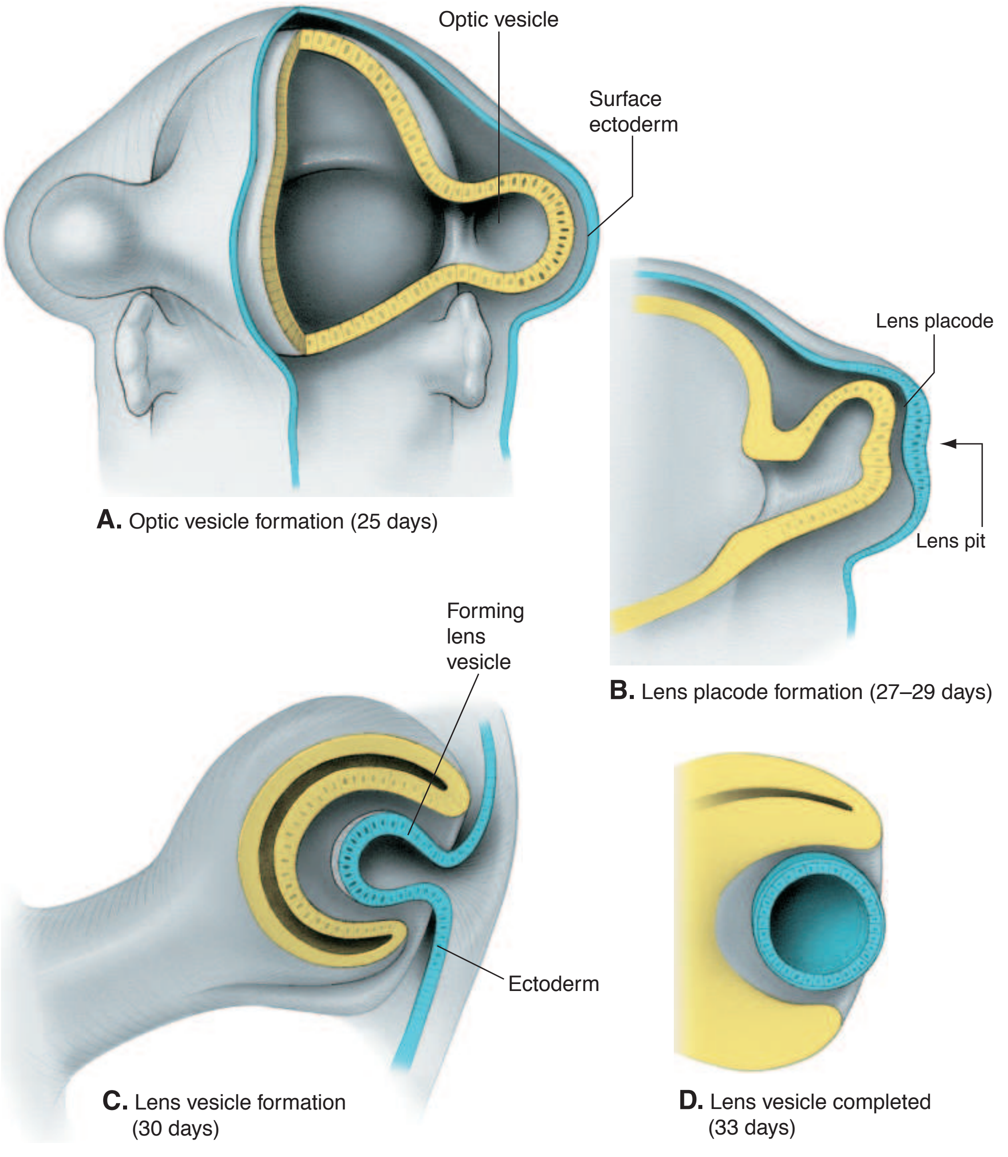


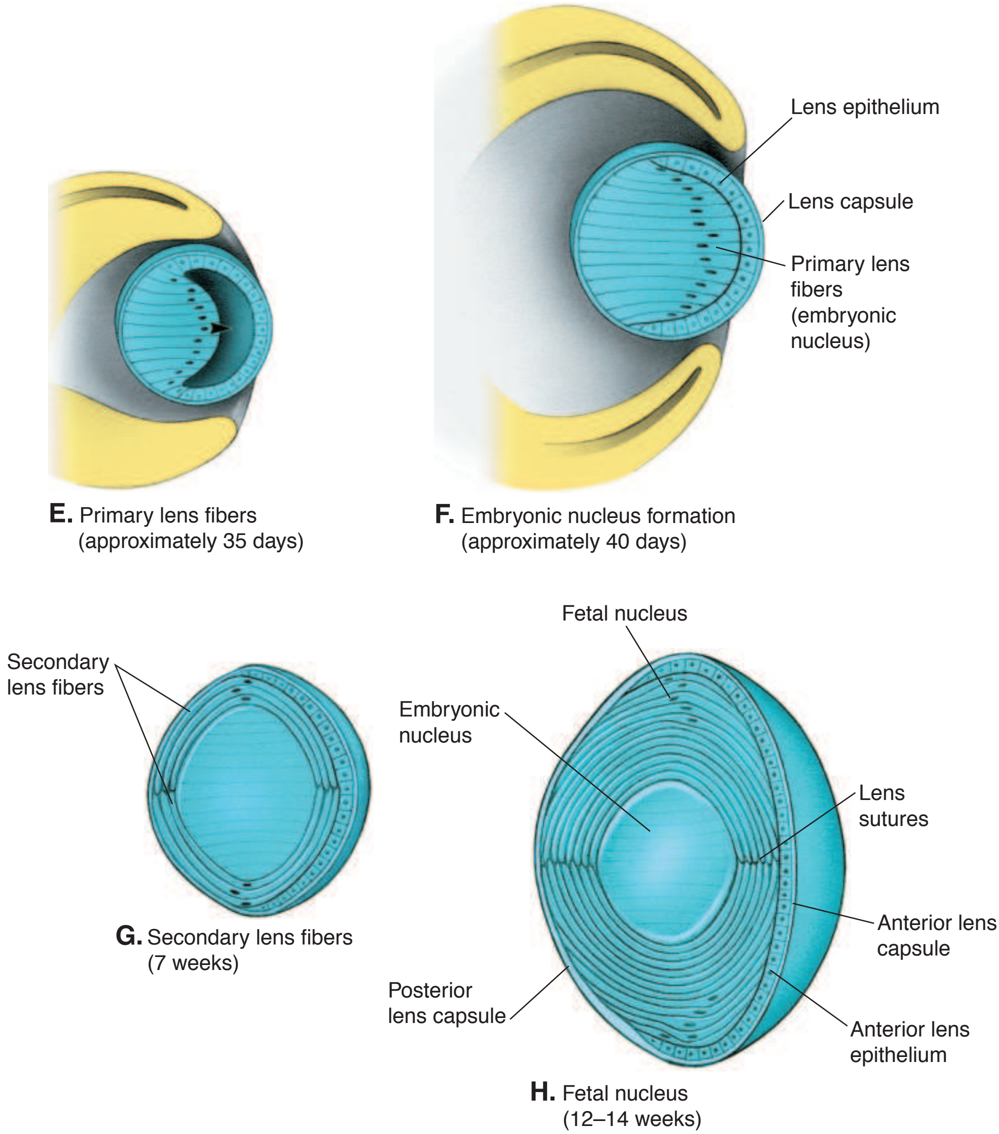
Figure 4-1 Embryologic development of the lens. *(Illustration by Christine Gralapp.)*

(Continued)

VIDEO 4-1 Lens development.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

Lens Pit

The lens pit appears at 29 days of gestation as an indentation (infolding) of the lens placode. The lens pit deepens and invaginates to form the lens vesicle.



E. Primary lens fibers (approximately 35 days)

F. Embryonic nucleus formation (approximately 40 days)

G. Secondary lens fibers (7 weeks)

H. Fetal nucleus (12–14 weeks)

Figure 4-1 *(continued)*

Lens Vesicle

As the lens pit continues to invaginate, the stalk of cells connecting it to the surface ectoderm degenerates by programmed cell death (apoptosis), separating the lens cells from the surface ectoderm. The resultant sphere, a single layer of cuboidal cells encased in a basement membrane (the *lens capsule*), is called the *lens vesicle*. At the time of its formation at 30 days of gestation, the lens vesicle is approximately 0.2 mm in diameter.

Because the lens vesicle was formed through a process of invagination of the surface ectoderm, the apices of the cuboidal cells are oriented toward the lumen of the lens vesicle, with the base of each cell attached to the capsule around the periphery of the vesicle. While the lens vesicle is forming, the optic vesicle is simultaneously invaginating to form the 2-layered *optic cup.*

Primary Lens Fibers and the Embryonic Nucleus

The cells in the posterior layer of the lens vesicle stop dividing and begin to elongate between 33 and 35 days of gestation. As they elongate, they begin to fill the lumen of the lens vesicle. At approximately 40 days of gestation, the lumen of the lens vesicle is obliterated. The elongated cells are called the *primary lens fibers.* As the fiber cells mature, their nuclei and other membrane-bound organelles undergo degradation, a process that reduces light scattering. The primary lens fibers make up the embryonic nucleus that will ultimately occupy the central area of the adult lens.

The cells of the anterior lens vesicle give rise to the *lens epithelium,* a monolayer of cuboidal cells. Proliferation within the epithelium causes subsequent growth of the lens. The *lens capsule* develops as a basement membrane elaborated by the lens epithelium anteriorly and by lens fibers posteriorly.

Secondary Lens Fibers

After they proliferate, the epithelial cells near the lens equator elongate to form secondary lens fibers. The anterior aspect of each developing lens fiber extends anteriorly beneath the lens epithelium, toward the anterior pole of the lens. The posterior aspect of each developing lens fiber extends posteriorly along the capsule, toward the posterior pole of the lens. In this manner, new lens fibers are continually formed, layer upon layer. As each secondary fiber cell detaches from the capsule, it loses its nucleus and membrane-bound organelles. The secondary lens fibers formed between 2 and 8 months of gestation make up the *fetal nucleus.*

Lens Sutures and the Fetal Nucleus

As lens fibers grow anteriorly and posteriorly, a pattern emerges where the ends of the fibers meet and interdigitate with the ends of fibers arising on the opposite side of the lens, near the anterior and posterior poles. These patterns of cell association are known as *sutures.* Y-shaped sutures are recognizable at approximately 8 weeks of gestation; an erect Y-suture appears anteriorly and an inverted Y-suture appears posteriorly (Fig 4-2). As the lens fibers continue to form and the lens continues to grow, the pattern of lens sutures becomes increasingly complex, resulting in 12 or more suture branches in the adult eye. The mechanisms responsible for the precise formation and changing organization of the suture pattern remain obscure.

The human lens weighs approximately 90 mg at birth; it is about 6 mm in diameter, 4 mm thick, and approximately the same size and weight as a baby aspirin or large lentil seed. It increases in mass by approximately 2 mg per year, throughout life, as new fibers form.

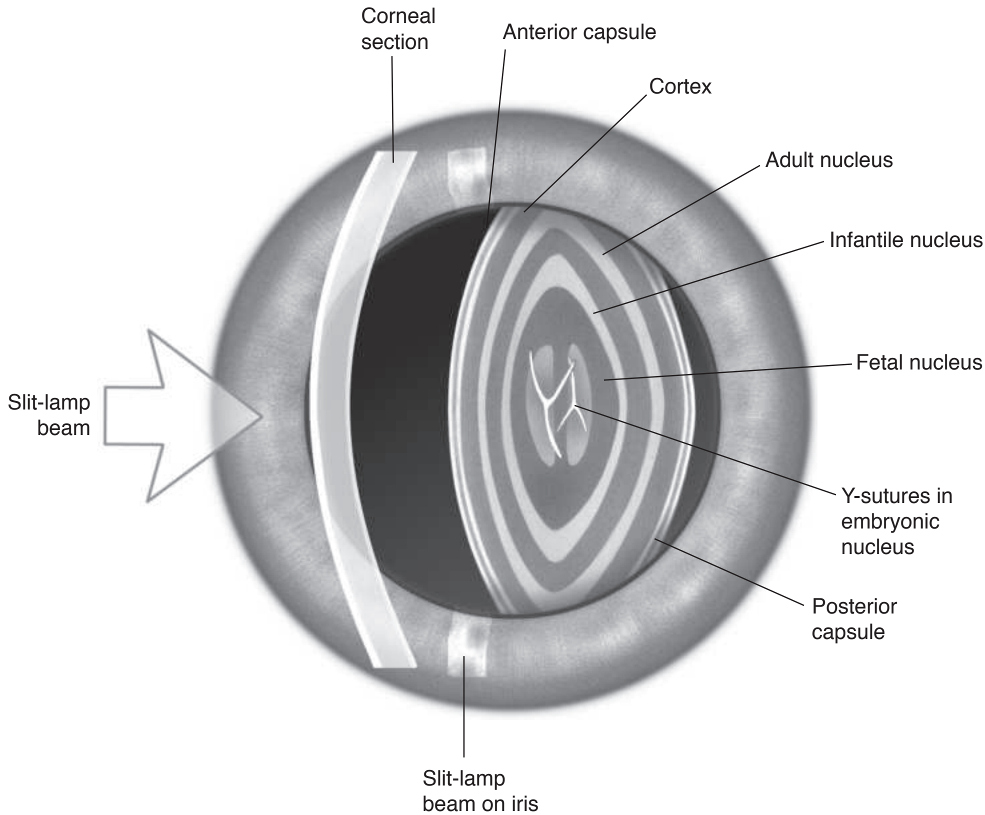


Figure 4-2 Y-shaped sutures, formed during embryogenesis, are visible within the adult lens with the use of the slit lamp. *(Illustration by Christine Gralapp.)*

Tunica Vasculosa Lentis

Around 1 month of gestation, the hyaloid artery, which enters the eye at the optic nerve head (also called the optic disc), branches to form a network of capillaries, the tunica vasculosa lentis, on the posterior surface of the lens capsule (Fig 4-3). These capillaries grow toward the equator of the lens, where they anastomose with a second network of capillaries, called the *anterior pupillary membrane,* which derives from the ciliary veins and covers the anterior surface of the lens. At approximately 9 weeks of gestation, the capillary network surrounding the lens is fully developed; it disappears by an orderly process of programmed cell death shortly before birth. Sometimes a remnant of the tunica vasculosa lentis persists as a small opacity or strand, called a *Mittendorf dot* (discussed later in this chapter), on the posterior aspect of the lens. In other eyes, remnants of the pupillary membrane are often visible as pupillary strands.

The Zonule of Zinn

Experimental evidence suggests that the zonular fibers are secreted by the ciliary epithelium, although how these fibers insert into the lens capsule is not known. The zonular fibers begin to develop at the end of the third month of gestation.

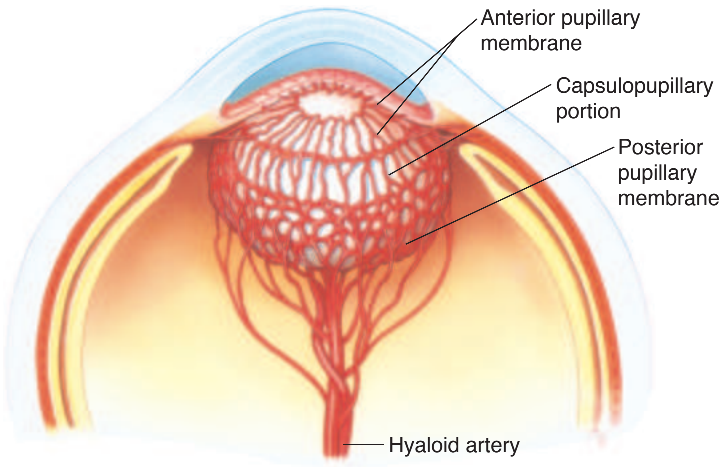


Figure 4-3 Components of the tunica vasculosa lentis. *(Illustration by Christine Gralapp.)*

Congenital Anomalies and Abnormalities

Most significant congenital anomalies of the eye and orbit are apparent on ultrasonography before birth. As a rule, the more profound the abnormality, the earlier in development it occurred. Disorders of the lens include abnormalities in lens shape, size, location, and development, as well as cataract (Table 4-1).

Congenital Aphakia

The lens is absent in congenital aphakia, a very rare anomaly. Congenital aphakia can be classified into 2 types:

- In *primary aphakia,* the lens placode fails to form (see Fig 4-1) from the surface ectoderm in the developing embryo.
- In *secondary aphakia,* the more common type, the developing lens is spontaneously absorbed.

Both forms of aphakia are usually associated with other malformations of the eye.

Lenticonus and Lentiglobus

Lenticonus is a localized, cone-shaped deformation of the anterior or posterior lens surface (Fig 4-4). Posterior lenticonus is more common than anterior lenticonus and is usually unilateral and axial in location. Anterior lenticonus is often bilateral and may be associated with Alport syndrome.

In lentiglobus, the localized deformation of the lens surface is spherical. Posterior lentiglobus is more common than anterior lentiglobus and is often associated with posterior polar opacities that vary in density.

Table 4-1 Lens Abnormalities

Abnormality	Disorder	Associated With
Shape	Microspherophakia	Weill-Marchesani syndrome (AR), Peters anomaly type 2, Marfan syndrome, Alport syndrome, Lowe syndrome, congenital rubella
	Lenticonus/lentiglobus	Alport syndrome, Lowe syndrome
	Anterior lenticonus	
	Coloboma	
Lens position	Ectopia lentis	Simple (AD), Ectopia lentis et pupillae (AR), trauma, Marfan syndrome, homocystinuria, aniridia, congenital glaucoma, Ehlers-Danlos syndrome, hyperlysinemia, Weill-Marchesani syndrome (AR), sulfite oxidase deficiency, Peters anomaly type 2
Extralenticular opacities	Persistent fetal vasculature	—
	Mittendorf dot	
	Epicapsular star	
Lenticular (cataract)	Capsulolenticular	Peters anomaly type 2
	Polar	Aniridia
	Capsular	Persistent fetal vasculature
	Sutural	
	Coronary	
	Cerulean	
	Nuclear	
	Complete	
	Membranous	
	Rubella	

AD = autosomal dominant; AR = autosomal recessive.

Clinical Pearl Retinoscopy through the center of the lens reveals a distorted and myopic reflex in both lenticonus and lentiglobus. These deformations can also be seen in the *red reflex,* where, by retroillumination, they appear as an "oil droplet." (This condition should not be confused with the "oil droplet" cataract of galactosemia, which is discussed in Chapter 5.) The posterior bulging may progress with initial worsening of the myopia, followed by opacification of the defect. Surrounding cortical lamellae may also opacify.

Lens Coloboma

A lens coloboma is an anomaly of lens shape (Fig 4-5). *Primary coloboma* is a wedge-shaped defect or indentation of the lens periphery that occurs as an isolated anomaly. *Secondary coloboma* is a flattening or indentation of the lens periphery caused by the lack

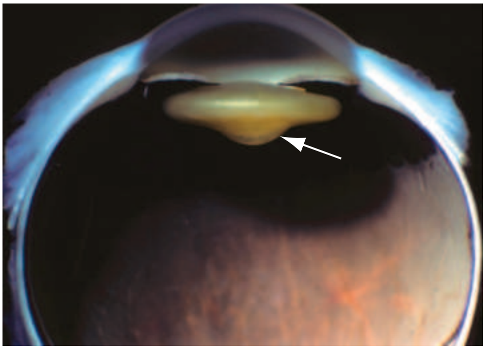


Figure 4-4 Posterior lenticonus *(arrow)*. *(Courtesy of Mission for Vision.)*

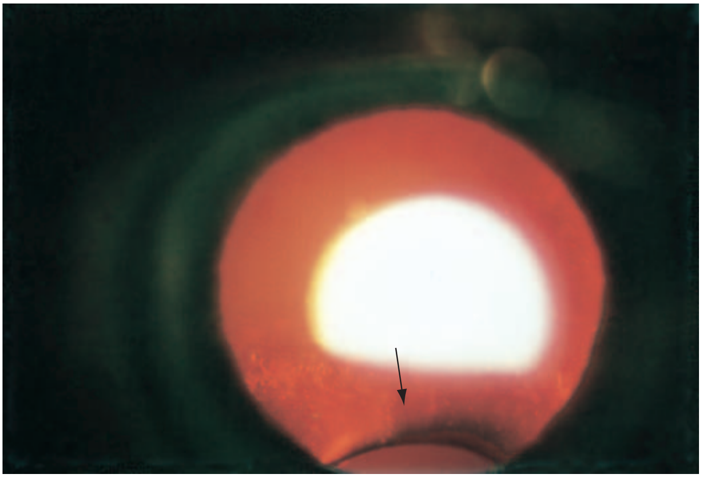


Figure 4-5 Coloboma of the lens *(arrow)* as viewed by retroillumination.

of ciliary body or zonular development. Lens colobomas are typically located inferonasally and may be associated with colobomas of the iris, optic nerve, or retina. Cortical lens opacification or thickening of the lens capsule may appear adjacent to the coloboma. The zonular attachments in the region of the coloboma are usually weakened or absent.

Mittendorf Dot

Mittendorf dot, mentioned earlier in this chapter, is a common anomaly observed in many healthy eyes. A small, dense white spot generally located inferonasal to the posterior pole of the lens, a Mittendorf dot is a remnant of the posterior pupillary membrane of the tunica vasculosa lentis (Fig 4-6). It marks the place where the hyaloid artery came into contact with the posterior surface of the lens in utero. Sometimes a Mittendorf dot is associated with a fibrous tail or remnant of the hyaloid artery that projects into the vitreous body; these remnants differ from persistent fetal vasculature (PFV), which is not seen in healthy eyes.

Epicapsular Star

Another very common remnant of the tunica vasculosa lentis is an epicapsular star (Fig 4-7). As its name suggests, this anomaly is a star-shaped distribution of tiny brown or golden flecks on the central anterior lens capsule. It may be unilateral or bilateral.

Peters Anomaly

Peters anomaly is part of a spectrum of disorders known as *anterior segment dysgenesis syndrome,* also referred to as *neurocristopathy* or *mesodermal dysgenesis.* (See also BCSC Section 6, *Pediatric Ophthalmology and Strabismus.*) Peters anomaly is characterized by a central or paracentral corneal opacity (leukoma) associated with thinning or absence of adjacent endothelium and Descemet membrane. In Peters anomaly type 1, iris strands adherent to the cornea are often present. In Peters anomaly type 2, the lens is adherent to the posterior cornea. In normal ocular development, the lens vesicle separates from the

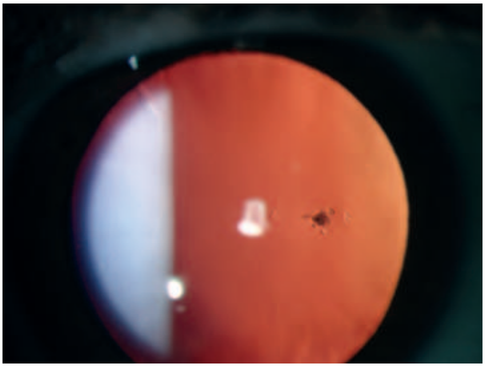


Figure 4-6 Mittendorf dot, as viewed by retroillumination. *(Courtesy of Matt Weed, MD. Photograph by D. Brice Critser, CRA. Used with permission from the University of Iowa and EyeRounds.org.)*

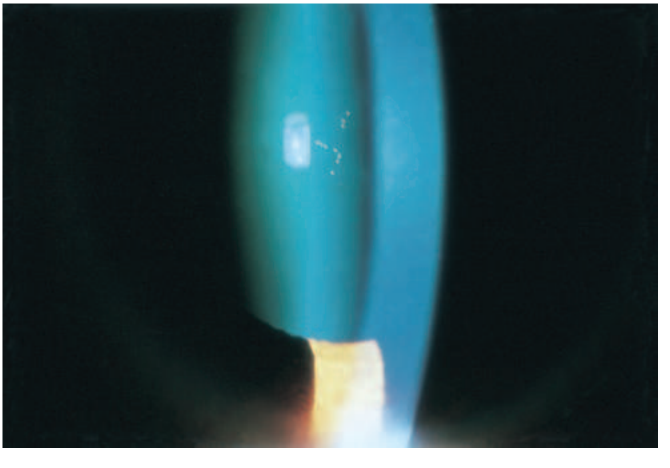


Figure 4-7 Epicapsular star.

surface ectoderm (the future corneal epithelium) at approximately 33 days of gestation. Peters anomaly is typically linked with the absence of this separation. It is often associated with alterations in or deletion of 1 allele of the genes normally involved in anterior segment development, including the transcription factors *PAX6, PITX2,* and *FOXC1*. Patients with Peters anomaly type 2 may also display the following lens anomalies:

- anterior cortical or polar cataract
- a misshapen lens displaced anteriorly into the pupillary space and the anterior chamber
- microspherophakia

Microspherophakia

Microspherophakia is a developmental abnormality in which the lens is small in diameter and spherical. The entire lens equator can be visualized at the slit lamp when the pupil is widely dilated (Fig 4-8). The spherical shape of the lens results in increased refractive power, which causes the eye to be highly myopic.

The cause of microspherophakia is believed to be faulty development of the secondary lens fibers during embryogenesis. Microspherophakia is most often seen as a part of Weill-Marchesani syndrome, but it may also occur as an isolated hereditary abnormality or, occasionally, in association with Peters anomaly, Marfan syndrome, Alport syndrome, Lowe syndrome, or congenital rubella. Individuals with Weill-Marchesani syndrome commonly have small stature, short and stubby fingers, and broad hands with reduced joint mobility. Weill-Marchesani syndrome is usually inherited as an autosomal recessive trait.

The spherical lens can block the pupil, causing secondary angle-closure glaucoma. Use of miotics aggravates this condition by increasing pupillary block and allowing additional forward lens displacement. Cycloplegics are the medical treatment of choice to break an attack of angle-closure glaucoma in patients with microspherophakia because these agents decrease pupillary block by tightening the zonular fibers, decreasing the anteroposterior lens diameter, and pulling the lens posteriorly. A laser iridotomy may also be useful in relieving angle closure in patients with microspherophakia. (See also BCSC Section 10, *Glaucoma.*)

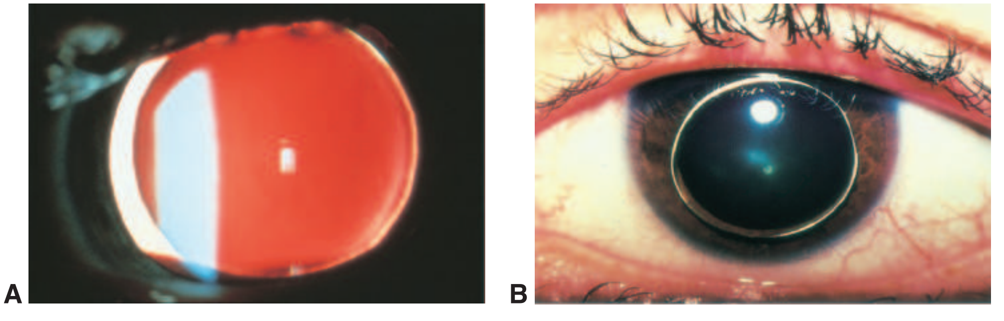


Figure 4-8 Microspherophakia. **A,** When the pupil is dilated, the entire lens equator can be seen at the slit lamp. **B,** Anterior dislocation of a microspherophakic lens. *(Part A courtesy of Karla J. Johns, MD.)*

Aniridia

Aniridia is an uncommon panocular syndrome in which the most dramatic manifestation is partial or nearly complete absence of the iris (Fig 4-9). Aniridia has been linked to the loss of 1 allele of the *PAX6* gene, a transcription factor that is important for the development and function of the cornea, lens, and retina. Associated findings include corneal pannus and epitheliopathy, glaucoma, foveal and optic nerve hypoplasia, and nystagmus. Aniridia is almost always bilateral. Two-thirds of cases are familial; one-third of cases are sporadic. Sporadic cases of aniridia are associated with a high incidence of Wilms tumor and the WAGR complex (*W*ilms tumor, *a*niridia, *g*enitourinary malformations, and *r*ange of developmental delays).

Anterior or posterior polar lens opacities may be present at birth in patients with aniridia. Cortical, subcapsular, or lamellar opacities develop in 50%–85% of these patients within the first 2 decades of life, and the lens opacities may progress, further impairing vision. Poor zonular integrity and ectopia lentis have also been reported in patients with aniridia.

Persistent Fetal Vasculature

Persistent fetal vasculature (PFV), also known as *persistent hyperplastic primary vitreous (PHPV),* is a congenital, nonhereditary ocular malformation that frequently involves the lens (Fig 4-10). In 90% of patients, it is unilateral. A white, fibrous, retrolental tissue is present, often in association with posterior cortical opacification. Progressive cataract formation often occurs, sometimes leading to a complete cataract. Other abnormalities associated with PFV include elongated ciliary processes, prominent radial iris vessels, persistent hyaloid artery, and intralenticular hemorrhage. (See BCSC Section 6, *Pediatric Ophthalmology and Strabismus,* and Section 12, *Retina and Vitreous,* for additional discussion.)

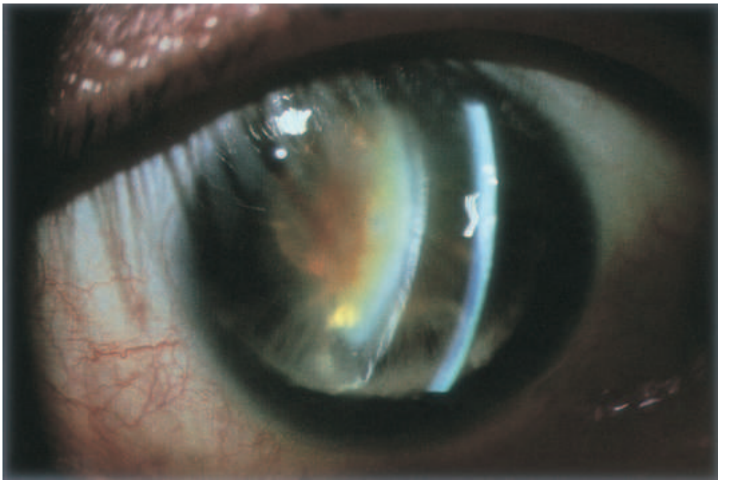


Figure 4-9 Cataract in a patient with aniridia.

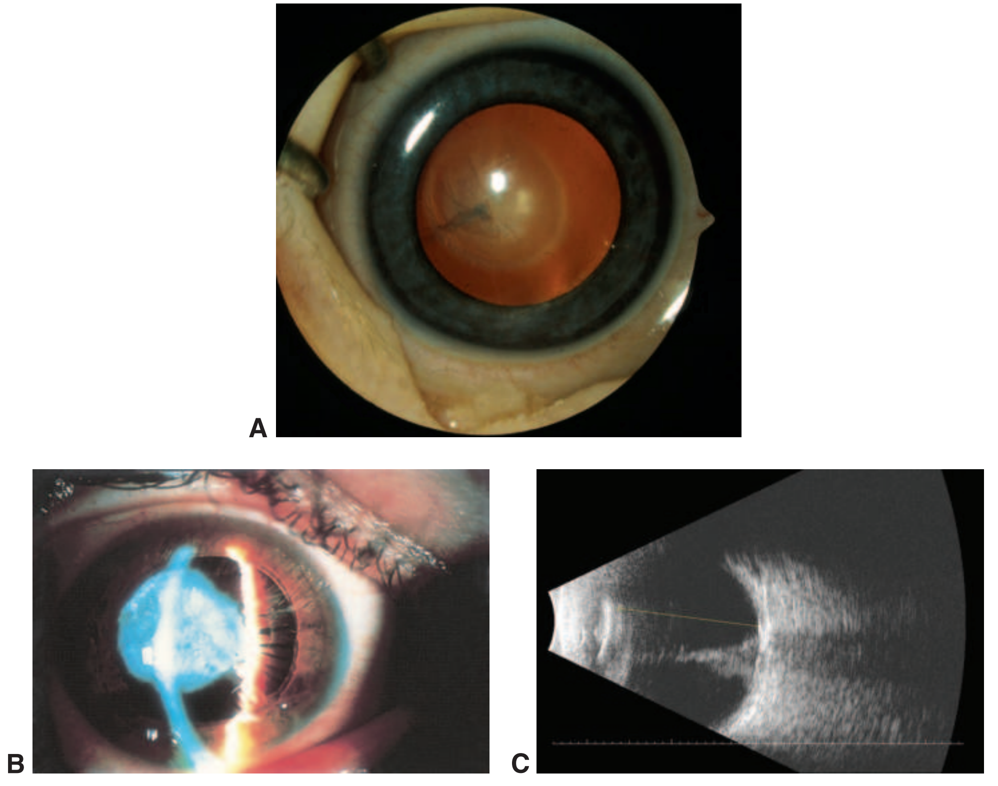


Figure 4-10 Persistent fetal vasculature (PFV). **A,** Mild variant with central retrolental membrane. **B,** Elongated ciliary processes are adherent to the lens. Note the dense fibrous plaque on the posterior lens capsule. **C,** Ultrasonogram of an eye with PFV. Note the dense stalk arising from the optic nerve and attaching to the posterior lens. *(Part A courtesy of David A. Plager, MD; part C courtesy of Edward L. Raab, MD.)*

Clinical Pearl Eyes with persistent fetal vasculature are usually smaller than normal. Although retinoblastoma is included in the differential diagnosis, retinoblastoma is found in microphthalmic eyes only on rare occasions, and cataract is unusual in eyes with retinoblastoma.

Congenital Cataract

Congenital cataracts are present at birth but may not be identified immediately. Infantile cataracts develop during the first year of life. Because some lens opacities escape detection at birth and are noted only on later examination, these terms are used interchangeably by many physicians. In this book, the term *congenital cataract* is used for both categories of lens opacities. These cataracts are fairly common, occurring in 1 of every 2000 live births, and cover a broad spectrum of severity. While some lens opacities do not progress and are visually insignificant, others can cause profound visual impairment.

Congenital cataracts may be unilateral or bilateral. They can be classified by morphology, presumed or defined genetic etiology, presence of specific metabolic disorders, or associated ocular anomalies or systemic findings (Table 4-2). In general, approximately one-third of congenital cataracts are a component of a more extensive syndrome or disease (eg, cataract resulting from congenital rubella syndrome), one-third occur as an isolated inherited trait, and one-third result from undetermined causes. Metabolic diseases tend to be more commonly associated with bilateral cataracts. (For a discussion of the evaluation of pediatric patients with congenital cataracts, see BCSC Section 6, *Pediatric Ophthalmology and Strabismus.*) Congenital cataracts occur in a variety of morphologic configurations, including lamellar, polar, sutural, coronary, cerulean, nuclear, capsular, complete, membranous, and rubella.

Lamellar

Of the congenital cataracts, lamellar, or *zonular,* cataracts are the most common type (Fig 4-11). They are characteristically bilateral and symmetric, and their effect on vision

Table 4-2 Etiology of Pediatric Cataracts

Type	
Unilateral	**Bilateral**
Idiopathic	Idiopathic
Ocular anomalies	Heredity[a]
Persistent fetal vasculature	Genetic and metabolic diseases
Anterior segment dysgenesis	Trisomy 21 (Down syndrome)
Posterior lenticonus	Hallermann-Streiff syndrome
Posterior lentiglobus	Lowe syndrome
Posterior pole tumors	Galactosemia
Retinal detachment (any cause)	Trisomy 13, 15, 18
Coloboma	Hypoglycemia/Hyperglycemia
Trauma (including child abuse)	Alport syndrome
Masked bilateral cataract	Myotonic dystrophy
Radiation (may be unilateral or bilateral)	Fabry disease
	Hypoparathyroidism
	Intrauterine infections
	Cytomegalovirus
	Rubella
	Syphilis
	Toxoplasmosis
	Varicella
	Ocular anomalies
	Aniridia
	Anterior segment dysgenesis syndrome
	Toxicity
	Corticosteroids
	Radiation (may be unilateral or bilateral)

[a]Autosomal dominant most common; also autosomal recessive or X-linked.

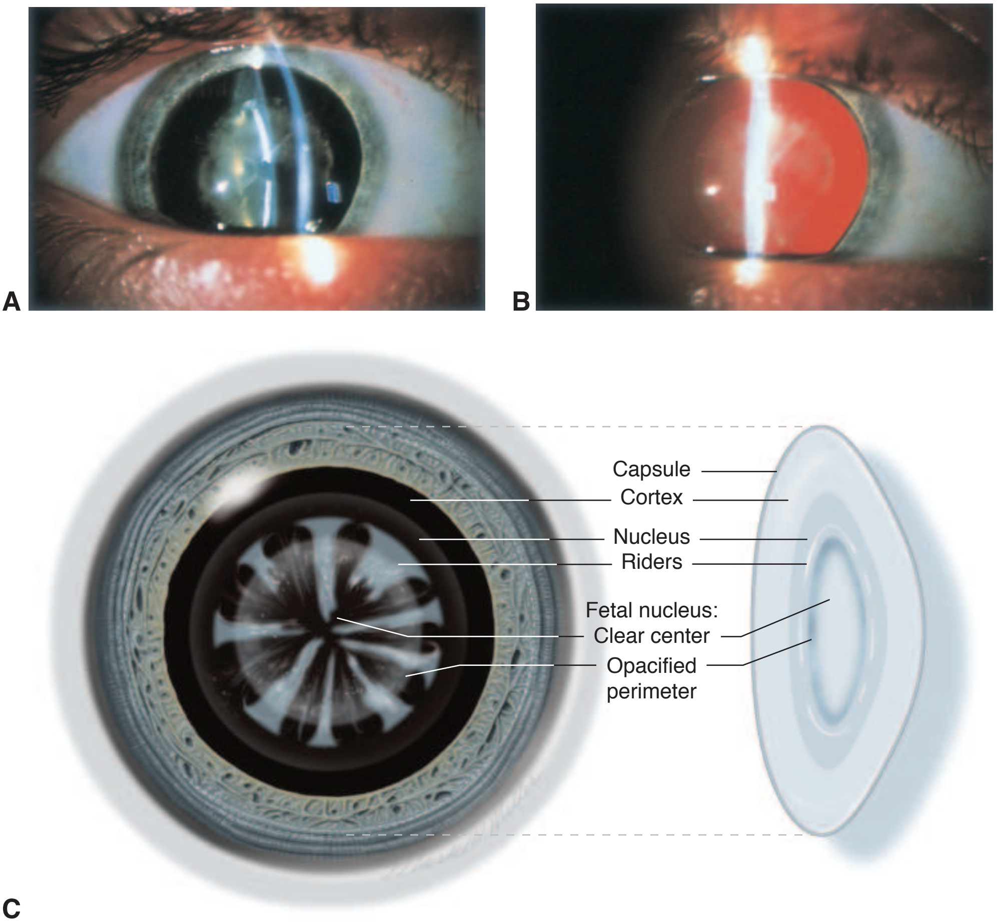


Figure 4-11 Lamellar cataract. **A,** Lamellar cataract, slit-lamp view. **B,** Lamellar cataract viewed by retroillumination. **C,** Schematic of lamellar cataract. *(Part C illustration by Mark Miller.)*

varies with the size and density of the opacity. Lamellar cataracts may be inherited as an autosomal dominant trait. In some cases, they may occur as a result of a transient toxic influence during embryonic lens development. The earlier this toxic influence occurs, the smaller and deeper is the resulting lamellar cataract.

Lamellar cataracts are opacifications of specific layers or zones of the lens. Clinically, the cataract is visible as an opacified layer that surrounds a clearer center and is itself surrounded by a layer of clear cortex. Viewed from the front, the lamellar cataract has a disc-shaped configuration. Often, additional arcuate opacities within the cortex straddle the equator of the lamellar cataract; these horseshoe-shaped opacities are called *riders.*

Polar

Polar cataracts are lens opacities that involve the subcapsular cortex and capsule of the anterior or posterior pole of the lens. *Anterior polar cataracts* are usually small,

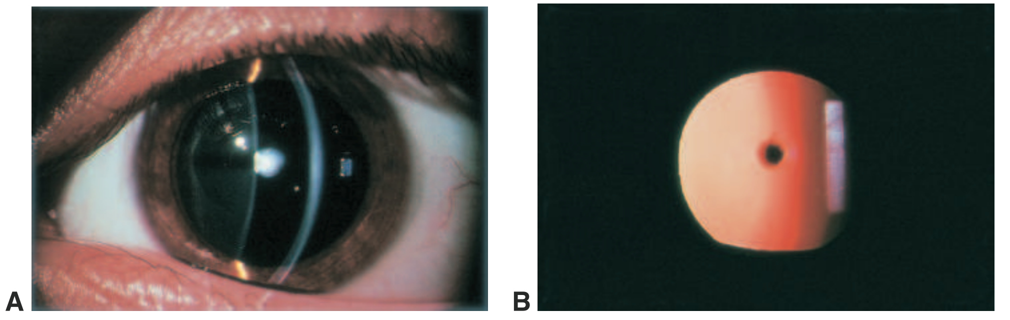


Figure 4-12 Anterior polar cataract. **A,** Anterior polar cataract, slit-lamp view. **B,** Anterior polar cataract viewed by retroillumination.

bilateral, symmetric, nonprogressive opacities that do not impair vision (Fig 4-12). Most commonly, they are congenital and sporadic, but they may be inherited in an autosomal dominant pattern. Anterior polar cataracts are sometimes seen in association with other ocular abnormalities, including microphthalmos, persistent pupillary membrane, and anterior lenticonus. They usually do not require treatment but often cause anisometropia.

Posterior polar cataracts are generally associated with a more profound decrease in vision than anterior polar cataracts are because they tend to be larger and are positioned closer to the nodal point of the eye. Capsular fragility has been reported in association with these cataracts, which are usually stable but occasionally progress. They may be familial or sporadic. Familial posterior polar cataracts are usually bilateral and inherited in an autosomal dominant pattern. Sporadic posterior polar cataracts are often unilateral and may be associated with remnants of the tunica vasculosa lentis or with an abnormality of the posterior lens surface such as lenticonus or lentiglobus.

Sutural

The sutural, or stellate, cataract is an opacification of the Y-sutures of the fetal nucleus (Fig 4-13). It usually does not impair vision. These opacities often have branches or knobs projecting from them. Sutural cataracts are bilateral and symmetric and are frequently inherited in an autosomal dominant pattern.

Coronary

Coronary cataracts are so named because they consist of a group of club-shaped cortical opacities that are arranged around the equator of the lens like a crown, or corona. They cannot be seen unless the pupil is dilated, and they usually do not affect visual acuity. Coronary cataracts are often inherited in an autosomal dominant pattern.

Cerulean

Also known as *blue-dot cataracts,* cerulean cataracts are small bluish opacities located in the lens cortex (Fig 4-14). They are nonprogressive and usually do not cause visual symptoms.

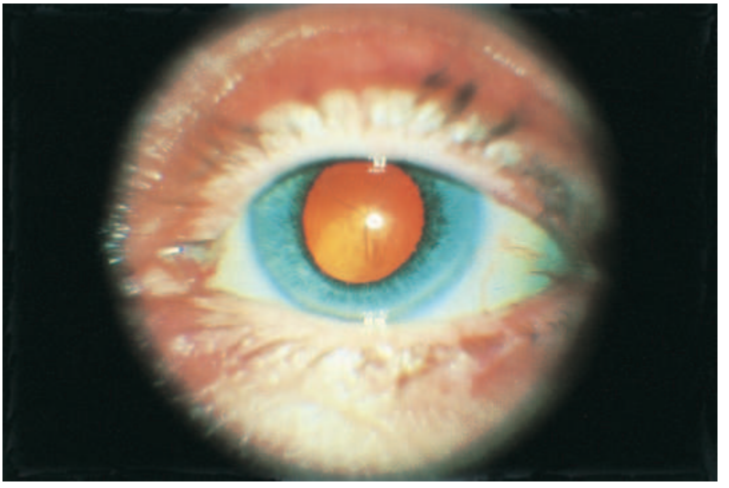


Figure 4-13 Sutural cataract.

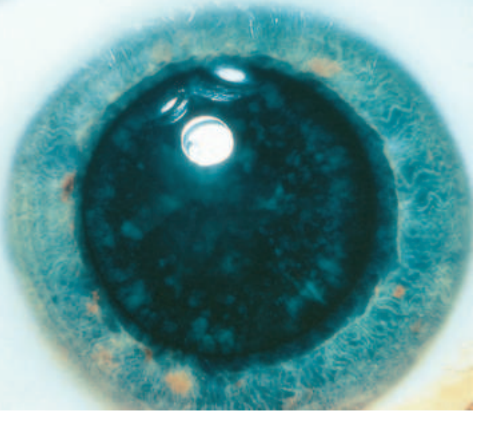


Figure 4-14 Cerulean cataract. *(Courtesy of Karla J. Johns, MD.)*

Nuclear

Congenital nuclear cataracts are opacities of the embryonic nucleus alone or of both embryonic and fetal nuclei (Fig 4-15). They are usually bilateral, with a wide spectrum of severity. Lens opacification may involve the complete nucleus, or it may be limited to discrete layers within the nucleus. Eyes with congenital nuclear cataracts tend to be microphthalmic, and they are at increased risk of developing aphakic glaucoma.

Capsular

Capsular cataracts are small opacifications of the lens epithelium and anterior lens capsule that spare the cortex. They are differentiated from anterior polar cataracts by their protrusion into the anterior chamber. Capsular cataracts generally do not adversely affect vision.

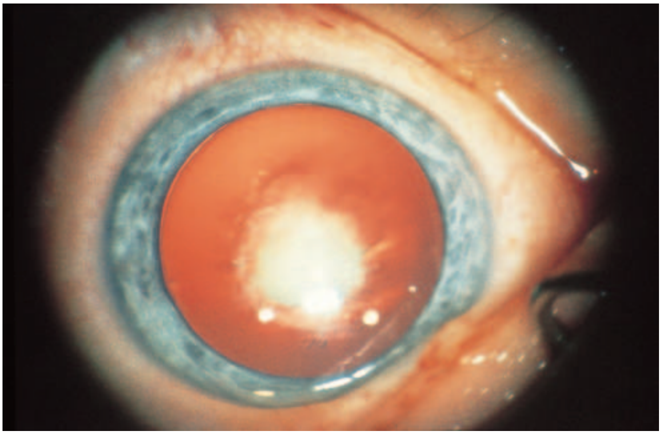


Figure 4-15 Congenital nuclear cataract. *(Reproduced from Day SH.* Understanding and Preventing Amblyopia: Slide & Script Presentation. *Eye Care Skills for the Primary Care Physician Series. American Academy of Ophthalmology; 1987.)*

Complete

In cases of complete, or total, cataract, all of the lens fibers are opacified. The red reflex is completely obscured, and the retina cannot be seen with either direct or indirect ophthalmoscopy. Some cataracts may be subtotal at birth and progress rapidly to become complete cataracts. Complete cataracts may be unilateral or bilateral, and they cause profound visual impairment.

Membranous

Membranous cataracts occur when lens proteins are resorbed from either an intact or a traumatized lens, allowing the anterior and posterior lens capsules to fuse into a dense white membrane (Fig 4-16). The resulting opacity and lens distortion generally cause significant visual disability.

Rubella

Maternal infection with the rubella virus, an RNA rubivirus, can cause fetal damage, especially if the infection occurs during the first trimester of pregnancy. Cataracts resulting from *congenital rubella syndrome* are characterized by pearly white nuclear opacifications. Sometimes the entire lens is opacified (complete cataract), and the cortex may liquefy (Fig 4-17). On histologic examination, lens-fiber nuclei are retained deep within the lens substance. Live virus particles may be recovered from the lens as late as 3 years after the patient's birth. Cataract removal may be complicated by excessive postoperative inflammation caused by release of these particles. (See also BCSC Section 6, *Pediatric Ophthalmology and Strabismus.*) Other ocular manifestations of congenital rubella syndrome include diffuse pigmentary retinopathy, microphthalmos, glaucoma, and transient or permanent corneal clouding. Although congenital rubella syndrome may cause cataract or glaucoma, both conditions are usually not present simultaneously in the same eye.

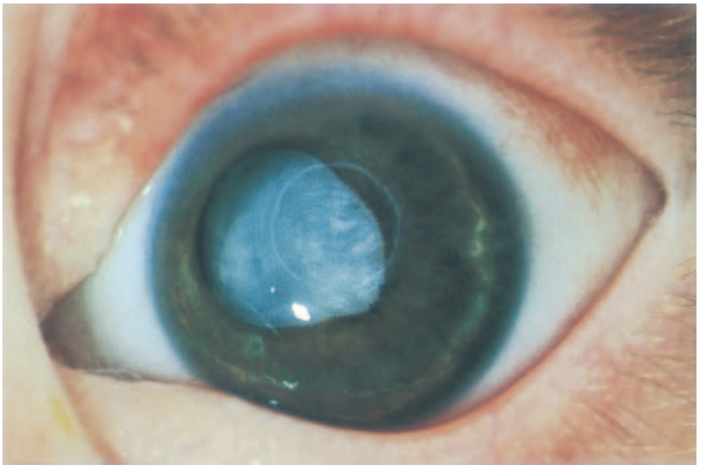


Figure 4-16 Membranous cataract.

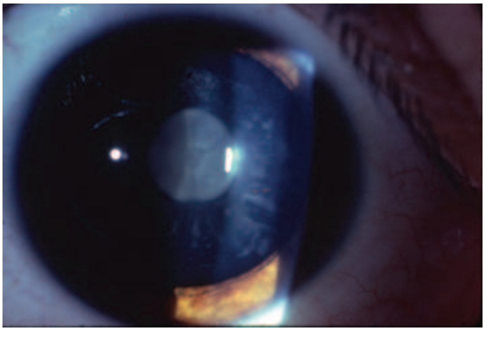


Figure 4-17 Rubella cataract. *(Courtesy of Thomas L. Steinemann, MD.)*

Developmental Anomalies

Ectopia Lentis

Ectopia lentis is a displacement of the lens that may be congenital, developmental, or acquired. A *subluxated* lens is partially displaced from its normal position but remains in the pupillary area. A *luxated,* or *dislocated,* lens is completely displaced from the pupil, implying separation of all zonular attachments. Findings associated with lens subluxation include decreased vision, marked astigmatism, monocular diplopia, and iridodonesis (tremulous iris). Potential complications of ectopia lentis include cataract and displacement of the lens into the anterior chamber or the vitreous space. Dislocation into the anterior chamber or pupil may cause pupillary block and angle-closure glaucoma. Dislocation of the lens posteriorly into the vitreous cavity often has no adverse sequelae aside from a profound change in refractive error.

Trauma is the most common cause of acquired lens displacement. Nontraumatic ectopia lentis is commonly associated with Marfan syndrome, homocystinuria, aniridia, and congenital glaucoma. Less frequently, it appears in association with Ehlers-Danlos syndrome, hyperlysinemia, Weill-Marchesani syndrome, and sulfite oxidase deficiency. Ectopia lentis may occur as an isolated anomaly (simple ectopia lentis), which is usually inherited as an autosomal dominant trait. Ectopia lentis can also be associated with pupillary abnormalities in the ocular syndrome ectopia lentis et pupillae (discussed later in this chapter).

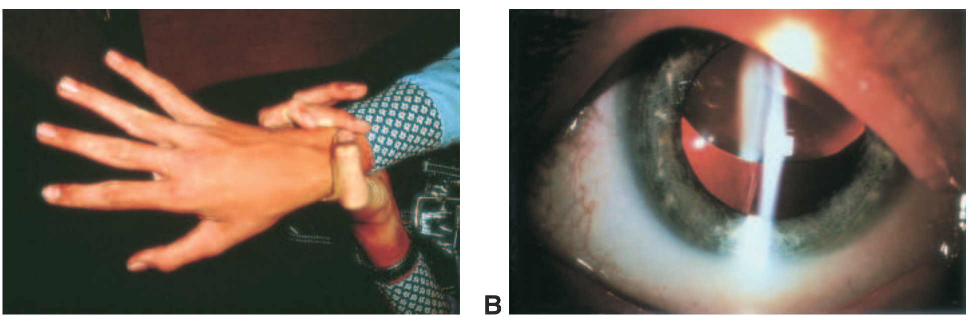
Marfan syndrome

Marfan syndrome is a heritable disorder with ocular, cardiovascular, and skeletal manifestations. Though usually inherited as an autosomal dominant trait, the disorder appears in individuals with no family history in approximately 15% of cases. Marfan syndrome is caused by alterations in the fibrillin gene, *FBN1,* on chromosome 15. Affected individuals are tall, with arachnodactyly (Fig 4-18A) and chest wall deformities. Associated cardiovascular abnormalities include dilated aortic root and mitral valve prolapse.

Between 50% and 80% of patients with Marfan syndrome exhibit ectopia lentis (Fig 4-18B). The lens subluxation tends to be bilateral and symmetric (usually superior and temporal), but variations do occur. The zonular attachments commonly remain intact but become stretched and elongated. Ectopia lentis in Marfan syndrome is probably congenital in most cases. Progression of lens subluxation occurs in some patients over time, but in many patients the lens position remains stable.

Other ocular abnormalities associated with Marfan syndrome include axial myopia, an increased risk of retinal detachment, and open-angle glaucoma. Patients with Marfan syndrome may develop pupillary block glaucoma if the lens dislocates into the pupil or anterior chamber. Amblyopia may develop in children with lens subluxation if their refractive errors show significant asymmetry or remain uncorrected in early childhood. Spectacle or contact lens correction of the refractive error provides satisfactory vision in most cases. Pupillary dilation is sometimes helpful. The clinician may refract both the phakic and the aphakic portions of the pupil to determine the optimum visual acuity. A reading add is often necessary because the subluxated lens lacks sufficient accommodation.

In some cases, adequate visual acuity cannot be obtained with spectacle or contact lens correction, and removal of the lens may be indicated. Lens extraction—either extracapsular or intracapsular—in patients with Marfan syndrome is associated with a high



A B

Figure 4-18 Marfan syndrome. **A,** Arachnodactyly in a patient with Marfan syndrome. **B,** Subluxated lens in Marfan syndrome. *(Part A courtesy of Karla J. Johns, MD.)*

rate of complications such as vitreous loss and complex retinal detachment. Advanced surgical techniques, including the use of capsular tension rings and capsular tension segments, are increasingly being used to improve outcomes in these cases (see Chapter 12).

Homocystinuria

Homocystinuria is an inborn error of methionine metabolism caused by a deficiency of cystathionine β-synthase in which serum levels of homocysteine and methionine are elevated. Homocystinuria is transmitted in an autosomal recessive pattern. Affected individuals are healthy at birth; however, seizures and osteoporosis typically develop within the first year of life, and cognitive impairment soon becomes apparent. These individuals are usually tall and have light-colored hair. Persons with homocystinuria are prone to thromboembolic episodes, and surgery and general anesthesia are thought to increase the risk of thromboembolism.

Lens dislocation in individuals with homocystinuria tends to be bilateral and symmetric. The dislocation appears in infancy in approximately 30% of affected individuals, and by the age of 15 years, it appears in 80% of those affected. The lenses are usually subluxated inferiorly and nasally, but variations have been reported. Because zonular fibers of the lens are known to have a high concentration of cysteine, deficiency of cysteine is thought to disrupt normal zonular development; affected fibers tend to be brittle and easily disrupted. In studies of infants with homocystinuria treated with a low-methionine, high-cysteine diet and vitamin supplementation with the coenzyme pyridoxine (vitamin B_6), the incidence of sequelae, including ectopia lentis, was reduced in some patients. (See also BCSC Section 6, *Pediatric Ophthalmology and Strabismus.*)

Hyperlysinemia

Hyperlysinemia, an inborn error of metabolism of the amino acid lysine, is associated with ectopia lentis. Affected individuals also show cognitive impairment and muscular hypotony.

Genetic Contributions to Age-Related Cataracts

Studies of identical and fraternal twins and of familial associations suggest that a large proportion of the risk of age-related cataracts is inherited. It is estimated that inheritance accounts for more than 50% of the risk of cortical cataracts. Studies have identified alterations in the gene associated with congenital and age-related cortical cataracts, *EPHA2,* which has been mapped to 1p36. This is the first gene known to cause hereditary, nonsyndromic age-related cortical cataracts, although alterations at this locus account for only a small fraction of cortical opacities. Similarly, 35%–50% of the risk of nuclear cataracts can be traced to inheritance. Other genes associated with age-related cataracts are *GALK1* and *CRYAA*. Identification of the genes associated with increased risk of cortical and nuclear cataracts is important, because understanding the biochemical pathways in which they function may suggest ways to slow the progression or prevent the development of age-related cataracts in a large proportion of cases.

Jun G, Guo H, Klein BE, et al. *EPHA2* is associated with age-related cortical cataract in mice and humans. *PLoS Genet.* 2009;5(7):e1000584.

Shiels A, Bennett TM, Knopf HL, et al. The *EPHA2* gene is associated with cataracts linked to chromosome 1p. *Mol Vis.* 2008;14:2042–2055.

Shiels A, Hejtmancik JF, Mutations and mechanisms in congenital and age-related cataracts. *Exp Eye Res.* 2017;156:95–102.

Ectopia Lentis et Pupillae

In the autosomal recessive disorder ectopia lentis et pupillae, the lens and the pupil are displaced in opposite directions. The pupil is irregular, usually slit shaped, and displaced from the normal position. The dislocated lens may bisect the pupil or may be completely absent from the pupillary space. This disorder is usually bilateral but not symmetric. Characteristically, the iris dilates poorly. Associated ocular anomalies include severe axial myopia, retinal detachment, enlarged corneal diameter, cataract, and abnormal iris transillumination.

Beebe DC. The lens. In: Kaufman PL, Alm A, Levin LA, Nilsson SFE, Ver Hoeve J, Wu S, eds. *Adler's Physiology of the Eye: Clinical Application.* 11th ed. Mosby; 2011:131–163.

Congdon NG, Chang MA, Botelho P, Stark WJ, Datiles MB III. Cataract: clinical types. In: Tasman W, Jaeger EA, eds. *Duane's Clinical Ophthalmology.* Lippincott Williams & Wilkins; 2006; vol 1, chapter 73.

Maltry AC, Cameron JD. Pathology of the lens. In: Albert DM, Miller JW, Azar DT, Young LH, eds. *Albert & Jakobiec's Principles and Practice of Ophthalmology.* 4th ed. Springer; 2022.

CHAPTER 5

Pathology

Highlights

- The lens changes color, density, and clarity in response to increasing age, trauma, and toxic exposures.
- Age-related cataract development takes several forms, causing varying degrees of visual impairment.
- Smoking, use of smokeless tobacco, and excessive alcohol consumption are modifiable risk factors for developing cataract; no medication or nutritional supplement has been consistently correlated with decreased cataract development.

Age-Related Lens Changes

As the lens ages, it increases in mass and thickness and decreases in accommodative power. As new layers of cortical fibers form concentrically, the lens nucleus compresses and hardens (a process known as nuclear sclerosis). Chemical modification and proteolytic cleavage of crystallins (lens proteins) create high-molecular-mass protein aggregates. These aggregates may become large enough to cause abrupt fluctuations in the local refractive index of the lens, thereby scattering light and reducing transparency. Chemical modification of lens nuclear proteins also increases opacity, resulting in increasing yellowing or browning of the lens with age (Fig 5-1). Other age-related changes include decreased concentrations of glutathione and potassium and increased concentrations of sodium and calcium in the lens cell cytoplasm.

A frequent cause of visual impairment in older adults is *age-related cataract,* the pathogenesis of which is multifactorial and not completely understood. There are 3 main types of age-related cataract: (1) nuclear, (2) cortical, and (3) posterior subcapsular. In many patients, components of more than 1 type are present. (See also BCSC Section 4, *Ophthalmic Pathology and Intraocular Tumors.*)

Nuclear Cataracts

Some degree of nuclear sclerosis and yellowing is normal in patients older than 50 years. Nuclear sclerosis only minimally affects visual function until the condition becomes more severe. Central opacities cause an increased amount of light scattering; these opacities are

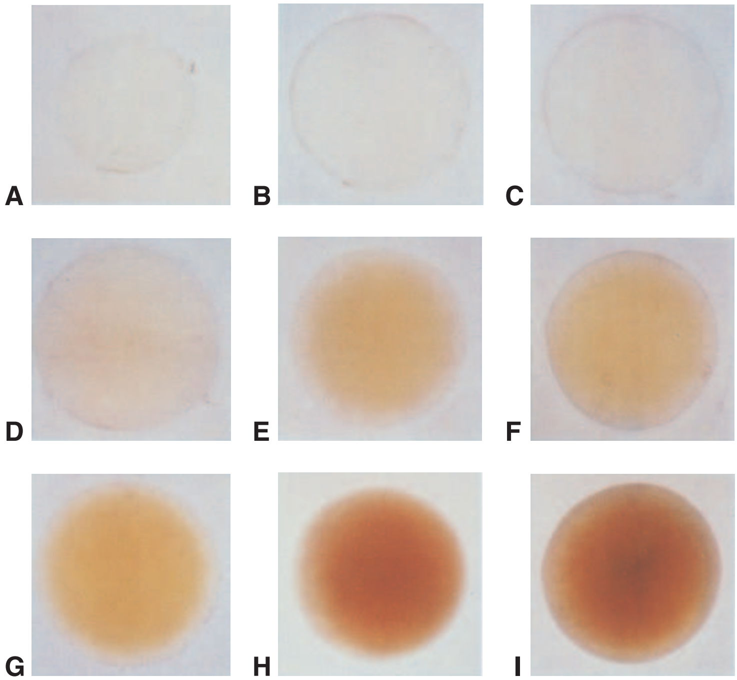


Figure 5-1 Increasing yellow-to-brown coloration of the human lens from age 6 months **(A)** to 8 years **(B),** 12 years **(C),** 25 years **(D),** 47 years **(E),** 60 years **(F),** 70 years **(G),** 82 years **(H),** and 91 years **(I).** *(Reproduced with permission from Lerman S. Phototoxicity: clinical considerations.* Focal Points: Clinical Modules for Ophthalmologists. *American Academy of Ophthalmology; 1987, module 8.)*

visible as a yellow-brown central lens nucleus. A nuclear cataract (Fig 5-2) is best evaluated by using a slit-lamp biomicroscope with off-axis illumination through a dilated pupil.

Nuclear cataracts are slowly progressive. They are usually bilateral but may be asymmetric. In the early stages of cataract development, the progressive hardening of the lens nucleus frequently causes an increase in the refractive index of the lens and a myopic shift in refraction *(lenticular myopia).* In hyperopic or emmetropic eyes, the myopic shift enables individuals to have improved distance vision or near vision without the use of spectacles, a condition referred to as "second sight." A change in astigmatism and, in rare instances, a hyperopic shift can occur as the nucleus matures. Occasionally, the abrupt change in refractive index between the sclerotic nucleus (or other lens opacities) and the lens cortex can cause monocular diplopia. Progressive yellowing or browning of the lens causes patients to have poor color discrimination, especially at the blue end of the visible-light spectrum. In bilateral cases, patients are frequently unaware of their altered color discrimination.

Visual dysfunction in low light often occurs with advancing nuclear cataract. In the most advanced cases, the lens nucleus becomes increasingly opaque and brown and is called a *brunescent nuclear cataract.* An increased number of lamellar membrane whorls can be seen in some nuclear cataracts under electron microscopy. The degree to which

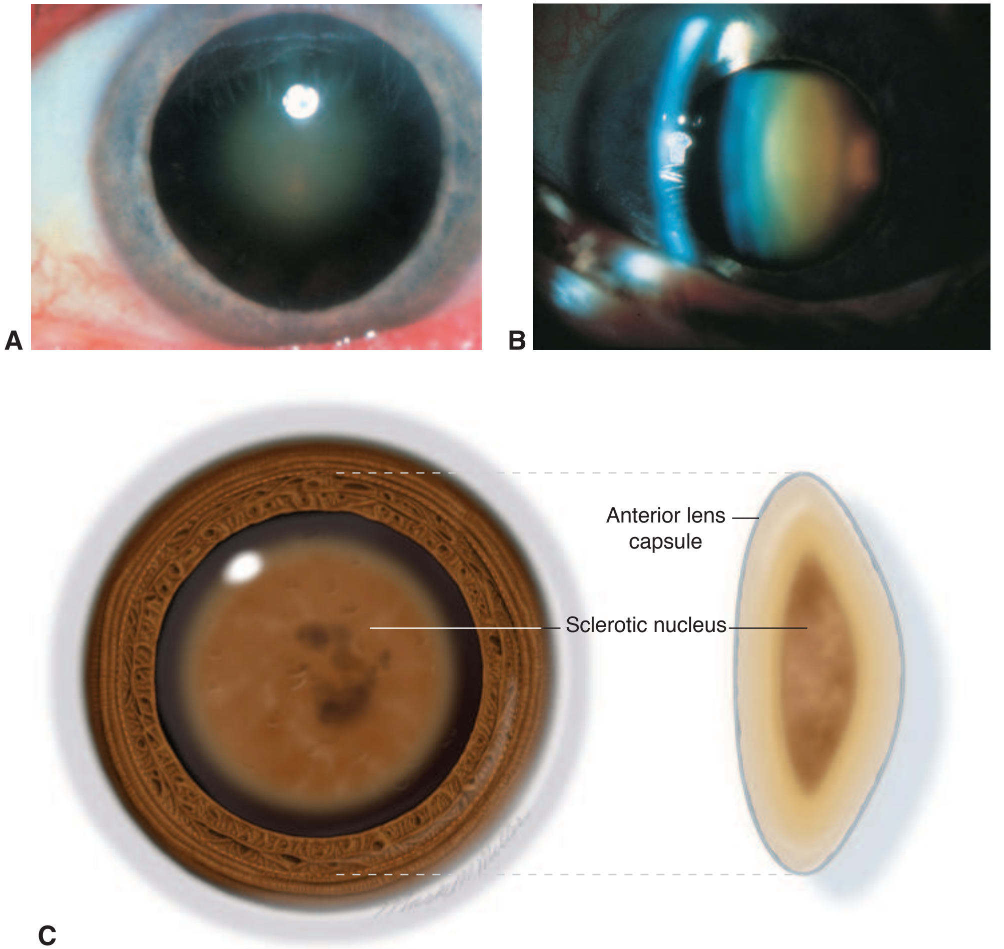


Figure 5-2 Nuclear cataract viewed with diffuse illumination **(A)** and with a slit beam **(B)**. **C,** Schematic of nuclear cataract. *(Part C illustration by Mark Miller.)*

protein aggregates or these membrane changes contribute to the increased light scattering of nuclear cataracts is not yet understood.

Cortical Cataracts

In contrast to nuclear cataracts, cortical cataracts are associated with local disruption of the structure of mature lens fiber cells. Once membrane integrity is compromised, essential metabolites are lost from the affected cells. This loss leads to extensive protein oxidation and precipitation. Like nuclear cataracts, cortical cataracts are usually bilateral but are often asymmetric. Their effect on visual function varies greatly, with more significant visual effect the closer the opacity occurs to the visual axis. A common symptom of cortical cataracts is glare from intense focal light sources, such as car headlights; monocular diplopia is also present in some cases. Cortical cataracts differ considerably in their rate of progression; some cortical opacities remain unchanged for prolonged periods, while others progress rapidly.

On examination with the slit lamp, the first visible signs of cortical cataract formation are vacuoles (Fig 5-3A) and water clefts in the anterior or posterior cortex. The cortical lamellae may be separated by fluid. Wedge-shaped opacities (often called *cortical spokes* or *cuneiform opacities*) form near the periphery of the lens, with the pointed ends of the opacities oriented toward the center (Figs 5-3B, 5-3C). The cortical spokes appear as white opacities when viewed with the slit lamp and as dark shadows when viewed by retroillumination. The wedge-shaped opacities may spread to adjacent fiber cells and along the length of affected fibers, causing the degree of opacity to increase and extend toward the visual axis.

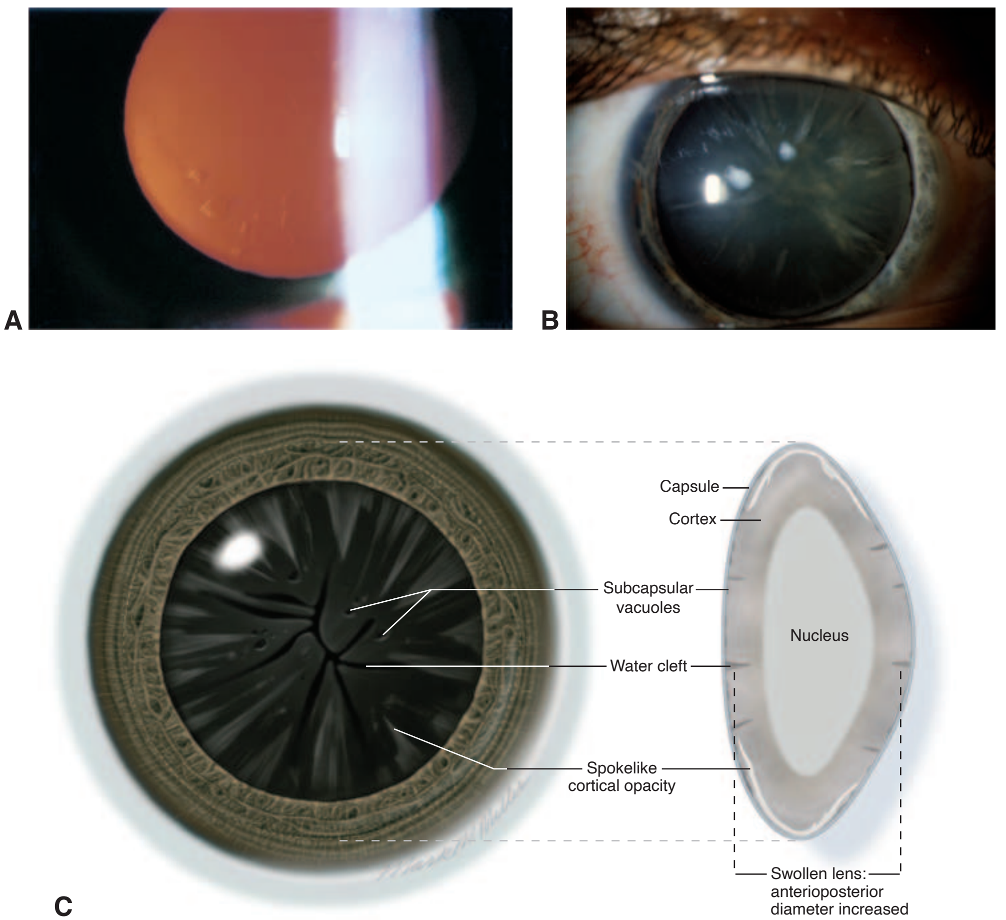


Figure 5-3 Cortical cataract development. **A,** Vacuoles in the periphery of an early cortical cataract. **B,** Cortical cataract viewed by oblique illumination at the slit lamp. **C,** Schematic of immature cortical cataract. *(Part B courtesy of James Gilman, CRA, FOPS; part C illustration by Mark Miller.)*

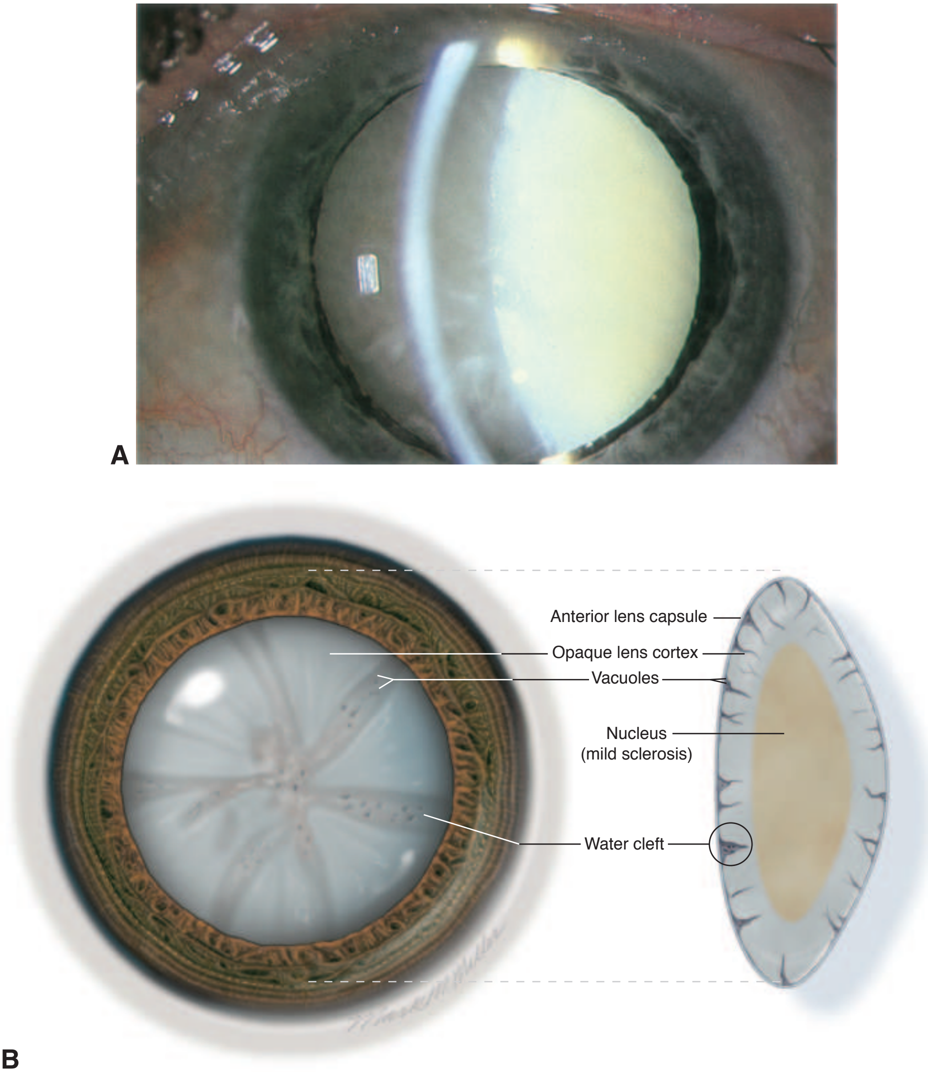
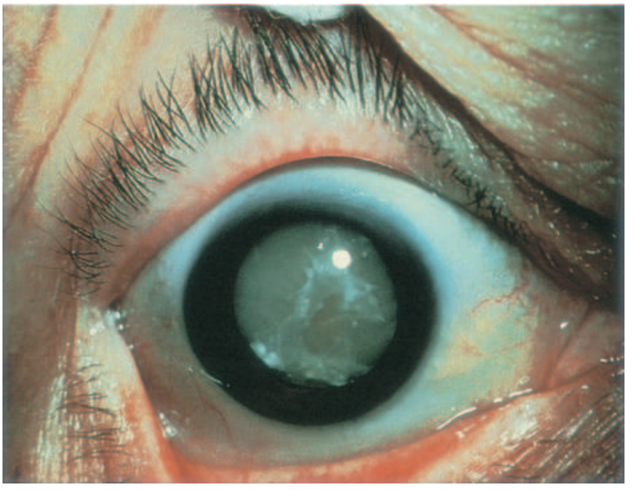


Figure 5-4 Mature cortical cataract. **A,** Mature cortical cataract viewed at the slit lamp. **B,** Schematic of mature cortical cataract. *(Part B illustration by Mark Miller.)*

When the entire cortex, from the capsule to the nucleus, becomes white and opaque, the cataract is said to be *mature* (Fig 5-4). In mature opacities, the lens absorbs water, becoming swollen and enlarged (termed *intumescent* cortical cataract); such cataracts may lead to phacomorphic angle-closure glaucoma. When degenerated cortical material leaks through the lens capsule, leaving the capsule wrinkled and shrunken, the cataract is referred to as *hypermature* (Fig 5-5). When further liquefaction of the cortex allows free movement of the nucleus within the capsular bag, the cataract is described as *morgagnian* (Fig 5-6).



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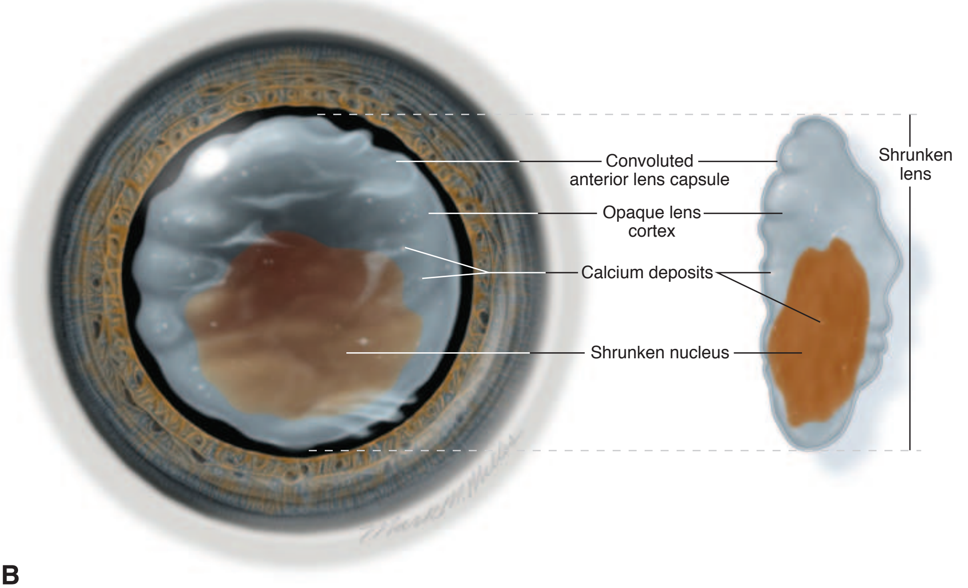


B

Figure 5-5 Hypermature cortical cataract. **A,** Clinical photo of hypermature cortical cataract. **B,** Schematic of hypermature cortical cataract. *(Part B illustration by Mark Miller.)*

On histologic examination, cortical cataracts are characterized by local swelling and disruption of the lens fiber cells. Globules of eosinophilic material (morgagnian globules) are observed in slitlike spaces between lens fibers (see BCSC Section 4, *Ophthalmic Pathology and Intraocular Tumors*).

Posterior Subcapsular Cataracts

Patients who present with posterior subcapsular cataracts (PSCs) are often younger (in their fifth to seventh decade of life) than those who present with visually significant nuclear

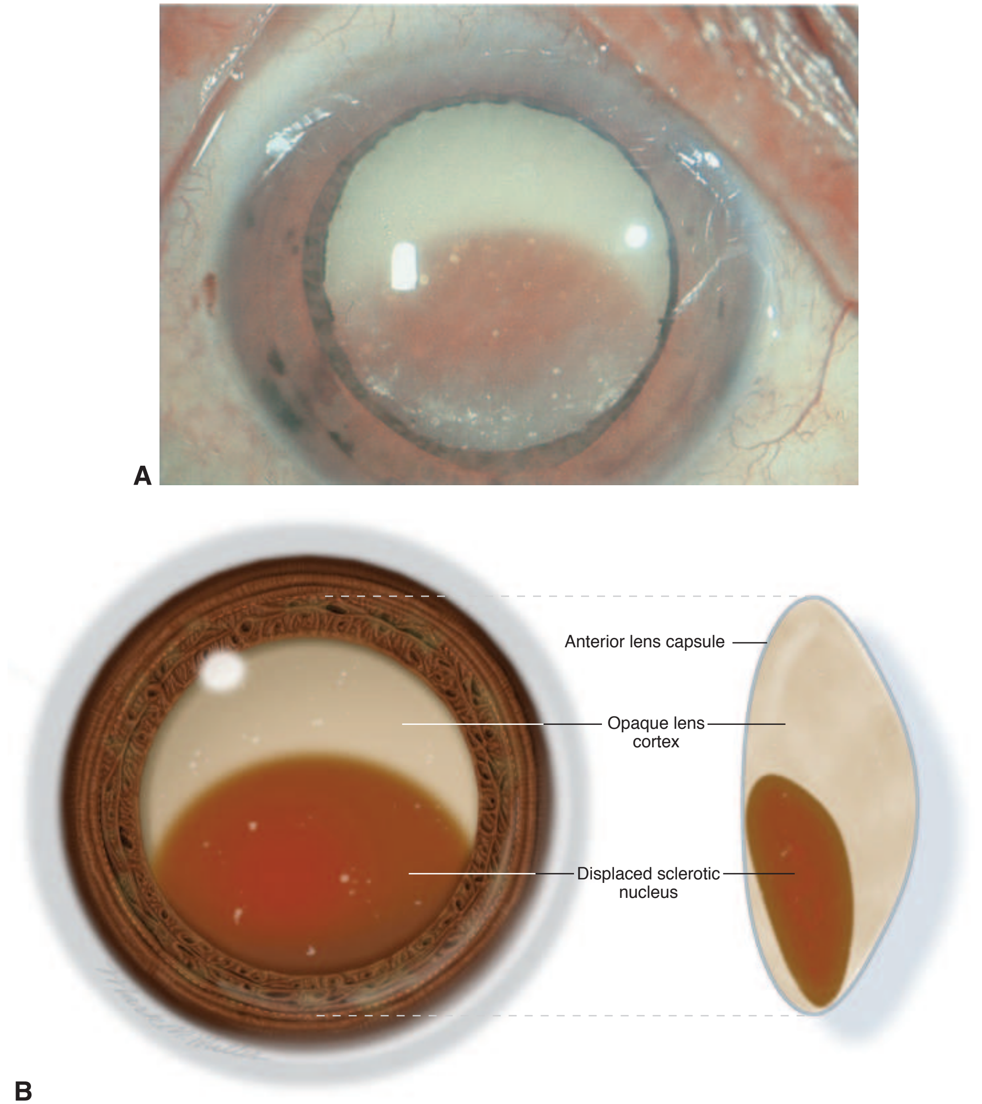


Figure 5-6 Morgagnian cataract. **A,** Clinical photo of morgagnian cataract. **B,** Schematic of morgagnian cataract. *(Part B illustration by Mark Miller.)*

or cortical cataracts. PSCs are located in the posterior cortical layer and are visually significant only when they encroach on the visual axis (Fig 5-7). The first indication of PSC formation is a subtle iridescent sheen in the posterior cortical layer. At later stages, granular opacities and a plaquelike opacity of the posterior subcapsular cortex develop.

Patients with PSCs often report symptoms of glare and poor vision under bright-light conditions because a central PSC obscures more of the pupillary aperture when miosis is induced by bright lights, accommodation, or miotics. Near vision tends to be reduced more than distance vision in these patients. Some patients experience monocular diplopia. PSCs are most visible through a dilated pupil, and retroillumination may be helpful.

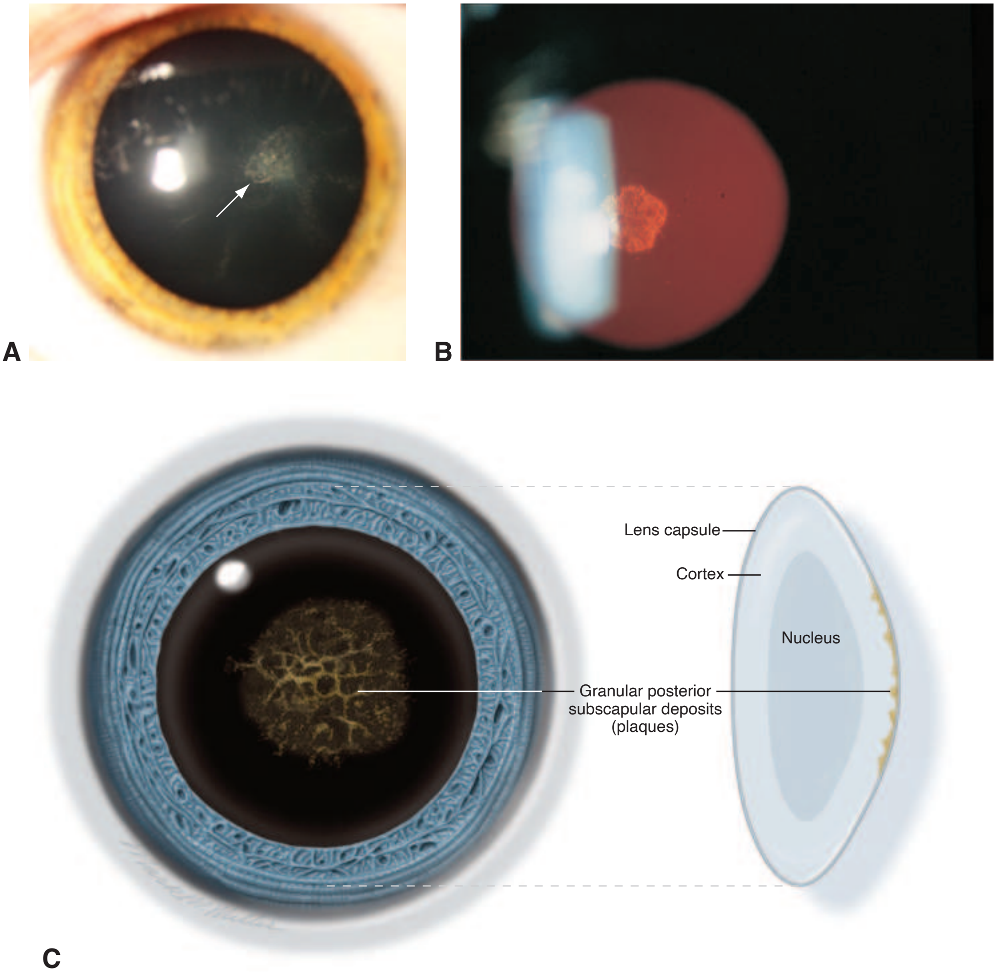


Figure 5-7 Posterior subcapsular cataract (PSC). **A,** Clinical photograph. **B,** Viewed with retroillumination. **C,** Schematic of PSC. *(Part A courtesy of Arlene V. Drack, MD; part C illustration by Mark Miller.)*

Although PSCs are typically related to increasing age, they can also occur after ocular trauma; systemic, topical, inhalational, or intraocular corticosteroid use; inflammation; exposure to ionizing radiation and some medications (such as tamoxifen); and prolonged heavy alcohol use.

On histologic examination, PSCs are associated with posterior migration of the lens epithelial cells from the lens equator to the visual axis on the inner surface of the posterior capsule. During their migration to or after their arrival at the posterior axis, the cells undergo aberrant enlargement. These swollen cells are called *Wedl* (or *bladder*) cells (see BCSC Section 4, *Ophthalmic Pathology and Intraocular Tumors*).

Keel S, He M. Risk factors for age-related cataract. *Clin Exp Ophthalmol.* 2018;46(4):327–328.

Pesudovs K, Elliott DB. Refractive error changes in cortical, nuclear, and posterior subcapsular cataracts. *Br J Ophthalmol.* 2003;87(8):964–967.

Drug-Induced Lens Changes

Corticosteroids

Long-term use of corticosteroids has been correlated with cataract development, especially PSC formation. The development of corticosteroid-induced PSCs is related to the dosage and duration of treatment. Cataract formation can occur with the use of oral, intravenous, topical, inhaled, or intraocular corticosteroids. The advent of slow-release steroid repositories, including subconjunctival and intravitreal implants, has not altered the risk of adverse ocular effects (including ocular hypertension and PSC development) associated with these medications.

On histological and clinical examination, PSC formation that occurs subsequent to corticosteroid use cannot be distinguished from age-related PSC formation. Some corticosteroid-induced PSCs in children may resolve with cessation of the drug.

Fraunfelder FT, Fraunfelder FW, Chambers WA, Jensvold-Vetsch B. *Drug-Induced Ocular Side Effects.* 7th ed. Elsevier, Inc.; 2015.

Gaballa SA, Kompella UB, Elgarhy O, et al. Corticosteroids in ophthalmology: drug delivery innovations, pharmacology, clinical applications, and future perspectives. *Drug Deliv Transl Res.* 2021;11(3):866–893. doi: 10.1007/s13346-020-00843-z

Phenothiazines

Phenothiazines, a group of medications used to treat psychiatric disorders, can cause pigmented deposits in the anterior lens epithelium in an axial stellate configuration (Fig 5-8). The occurrence of these deposits appears to depend on both drug dosage and duration of treatment. In addition, the deposits are more likely to occur with chlorpromazine and thioridazine than other drugs in this class. The vision changes associated with phenothiazine deposition in the lens are generally insignificant.

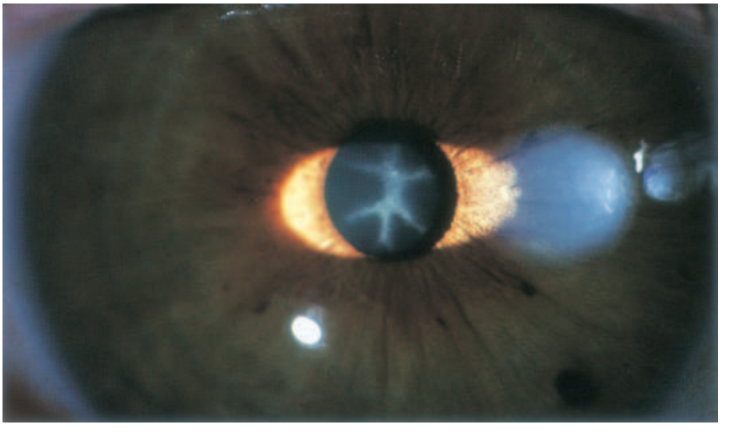


Figure 5-8 Slit-lamp image of pigmented deposits on anterior lens capsule in a patient treated with phenothiazines.

Miotics

Topical anticholinesterases, which are used to treat glaucoma and presbyopia, can cause cataract formation. The incidence of cataract has been reported to be as high as 20% in patients after 55 months of pilocarpine use and 60% in patients after the same period of echothiophate iodide use.

Usually, this type of cataract first appears as small vacuoles within and posterior to the anterior lens capsule and epithelium. The cataract may progress to posterior cortical and nuclear lens changes. Cataract formation is more likely in patients receiving anticholinesterase therapy over a long period and in those whose dosage is more frequent.

Amiodarone

Amiodarone, an antiarrhythmic medication, has been reported to cause stellate pigment deposition in the anterior cortical axis. Only in very rare instances does this condition become visually significant. Amiodarone can also result in corneal verticillata and optic neuropathy.

Statins

Studies performed in dogs have shown that some 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase inhibitors, known as *statins,* are associated with cataract when taken in excessive doses. Conflicting human studies have indicated that statins are both a risk factor for development of nuclear sclerotic cataracts and protective against them. The latest meta-analysis of human observational studies suggests an increased risk of cataract development associated with taking statins, but the magnitude of the effect is low. However, concomitant use of simvastatin and erythromycin, which increases circulating statin levels, may be associated with approximately a twofold increased risk of cataract.

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(6):e12480.

Leuschen J, Mortensen EM, Frei CR, Mansi EA, Panday V, Mansi I. Association of statin use with cataracts: a propensity score-matched analysis. *JAMA Ophthalmol.* 2013;131(11): 1427–1434.

Tamoxifen

Tamoxifen, an antiestrogen drug used in the prevention and adjuvant treatment of breast cancer, is another medication with conflicting data on its effect on cataract formation. Although some researchers found no association between tamoxifen use and cataract, other studies have shown up to a fourfold increase in the risk of developing cataracts, especially PSCs, associated with tamoxifen use. Crystalline maculopathy and cystoid macular edema have been reported in patients receiving high-dose tamoxifen therapy (see BCSC Section 12, *Retina and Vitreous*).

Nelson HD, Fu R, Zakher B, Pappas M, McDonagh M. Medication use for the risk reduction of primary breast cancer in women: updated evidence report and systematic review for the US Preventive Services Task Force. *JAMA.* 2019; 322(9):868–886.

Procedure-Induced Lens Changes

Intraocular Procedures

Virtually any intraocular procedure may be associated with cataract formation, either shortly after surgery or following a longer period of healing. Pars plana vitrectomy, especially with gas tamponade of the retina, is strongly associated with nuclear sclerotic cataract formation. A visually significant nuclear sclerotic cataract develops in 80%–100% of phakic eyes within 2 years but is less common in patients younger than 50 years.

The formation of nuclear cataracts after vitrectomy is associated with increases in oxygen tension in the vitreous intraoperatively and postoperatively. (See Chapter 3 for a discussion of oxygen tension in the lens.) Retinal surgery performed without vitrectomy is not associated with increased nuclear sclerosis, but any disturbance of the capsule during a vitreous procedure may precipitate a PSC.

Intravitreal injections may be associated with cataract formation either as a result of direct trauma to the lens or as an adverse effect of specific medications injected into the vitreous space.

Trabeculectomy and glaucoma drainage device insertion are known risk factors for development of visually significant cataract. The Collaborative Initial Glaucoma Treatment Study found that glaucoma patients who were initially treated with trabeculectomy were 8 times more likely to need early cataract surgery than those patients who were initially treated with medications. The risk decreased at 5 years after trabeculectomy, with patients undergoing trabeculectomy only 3 times more likely to require cataract surgery than those undergoing medical management.

Nuclear sclerotic cataract formation also occurs at significantly higher rates in patients who have received penetrating keratoplasty or Descemet stripping endothelial keratoplasty.

Burkhart ZN, Feng MT, Price FW Jr., Price MO. One-year outcomes in eyes remaining phakic after Descemet membrane endothelial keratoplasty. *J Cataract Refract Surg.* 2014; 40(3):430–434.

Feng H, Adelman RA. Cataract formation following vitreoretinal procedures. *Clin Ophthalmol.* 2014;8:1957–1965.

Gedde SJ, Feuer WJ, Lim KS, et al. Postoperative complications in the primary tube versus trabeculectomy study during 5 years of follow-up. *Ophthalmology.* 2022;129(12): 1357–1367.

Musch DC, Gillespie BW, Niziol LM, et al; Collaborative Initial Glaucoma Treatment Study Group. Cataract extraction in the Collaborative Initial Glaucoma Treatment Study: incidence, risk factors, and the effect of cataract progression and extraction on clinical and quality-of-life outcomes. *Arch Ophthalmol.* 2006;124(12):1694–1700.

Radiation

Ionizing radiation

The lens is extremely sensitive to ionizing radiation; however, up to 20 years may pass after exposure before a cataract becomes clinically apparent. This period of latency is related to the dose of radiation and to the patient's age; younger patients are more susceptible to cataract formation because they have more lens cells that are actively growing. Ionizing radiation in the X-ray range (0.001–10.0-nm wavelength) can cause cataracts in some individuals in doses as low as 2 Gy in a single fraction. (For reference, a routine chest x-ray equals 0.01–Gy exposure to the thorax.) A single computed tomography (CT) scan of the brain may expose the lens to as much as 0.025–0.050 Gy.

Radiation-induced cataracts begin as punctate opacities within the posterior capsule and feathery anterior subcapsular opacities that radiate toward the equator of the lens; they may progress to complete lenticular opacification.

Infrared radiation

Exposure of the eye to infrared (IR) radiation and intense heat over time can cause the outer layers of the anterior lens capsule to peel off as a single layer. Such true exfoliation of the lens capsule, in which the exfoliated outer lamella tends to scroll up on itself, is rare. Cortical cataracts may be associated with this condition, known as *glassblower's cataract* (Fig 5-9). (See the section Pseudoexfoliation Syndrome later in this chapter.)

Ultraviolet radiation

Experimental evidence suggests that the lens is susceptible to damage from ultraviolet (UV) radiation. Epidemiologic evidence suggests that long-term exposure to sunlight is associated with an increased risk of cortical cataracts and accounts for 10% of the total risk of cortical cataract in the general population in temperate climates. Because exposure to UV radiation can lead to other morbidity, clinicians should encourage their patients to avoid excessive sunlight exposure. Lenses sold in the United States must conform to the American National Standards Institute (ANSI) requirements aimed at reducing UV transmission. Using prescription corrective lenses and nonprescription sunglasses decreases UV exposure by more than 80%, and wearing a hat with a brim decreases ocular sun exposure by 30%–50%.

Modenese A, Gobba F. Cataract frequency and subtypes involved in workers assessed for their solar radiation exposure: a systematic review. *Acta Ophthalmol.* 2018;96(8):779–788.

Vashist P, Tandon R, Murthy GVS, et al; ICMR-EYE SEE Study Group. Association of cataract and sun exposure in geographically diverse populations of India: the CASE study. First report of the ICMR-EYE SEE Study Group. *PLoS One.* 2020;15(1):e0227868. doi: 10.1371/journal.pone.0227868

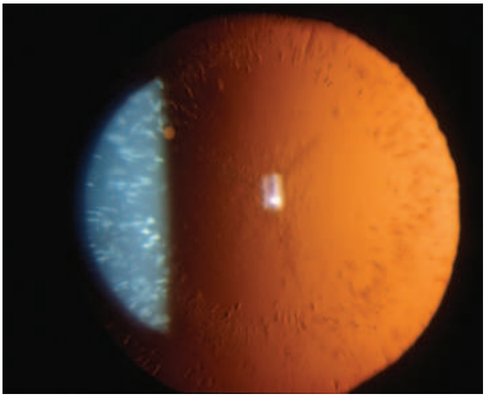


Figure 5-9 Infrared radiation may cause cortical changes, such as this glassblower's cataract. *(Courtesy of James Gilman, CRA, FOPS.)*

Hyperbaric Oxygen

A myopic shift seems to occur universally during the course of treatment with hyperbaric oxygen (HBO) therapy. This change, thought to be due to a refractive change in the crystalline lens, usually reverses after cessation of HBO treatment. However, several reports have documented the development of nuclear cataract over the course of multiple HBO treatment sessions.

Riedl P, Škiljić D, Arnell P, Wannholt R, Zetterberg M, Andersson Grönlund M. Myopic shift and lens turbidity following hyperbaric oxygen therapy–a prospective, longitudinal, observational cohort study. *Acta Ophthalmol.* 2019;97(6):596–602.

Trauma-Related Lens Changes

Traumatic lens damage may be caused by mechanical injury and by physical forces such as chemicals and electrical current.

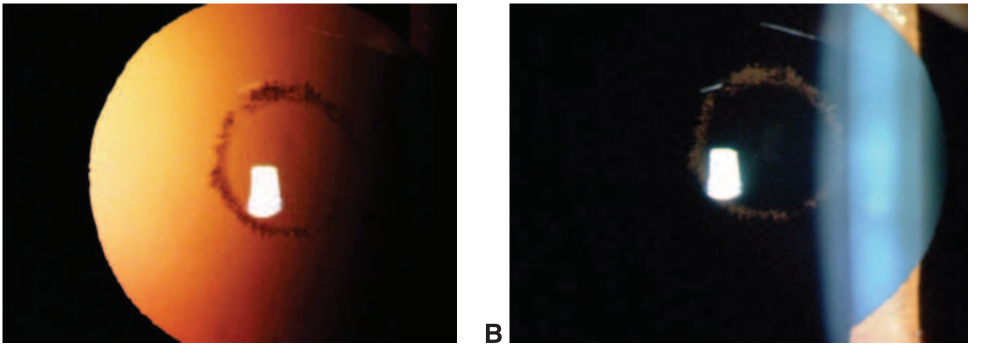
Contusion

Vossius ring

Blunt injury to the eye can sometimes cause a ring of pigment (known as a *Vossius ring*) from the pupillary ruff to be imprinted on the anterior surface of the lens (Fig 5-10). Although a Vossius ring is visually insignificant and gradually resolves with time, its presence indicates prior blunt trauma, and it may be associated with other ocular injuries, including damage to angle structures. Its presence should alert the surgeon to possible traumatic damage to the lenticular apparatus, such as zonular instability.

Traumatic cataract

A blunt, nonperforating injury may cause lens opacification either as an acute event or as a late sequela. A contusion cataract may involve the entire lens or only a portion of the lens. Often, the initial manifestation of a contusion cataract is a stellate or rosette-shaped opacification *(rosette cataract),* usually axial in location, that involves the posterior lens



A B

Figure 5-10 Vossius ring. **A,** On retroillumination. **B,** On indirect illumination. *(Reproduced with permission from Seth NG, Thattaruthody F, Pandav SS. Vossius ring after blunt ophthalmic trauma.* Ophthalmol Glaucoma. *2019;2[1].)*

capsule. In some cases, blunt trauma causes both dislocation and cataract formation. In rare cases, mild contusion cataracts can improve spontaneously.

Shah M, Shah S, Upadhyay P, Agrawal R. Controversies in traumatic cataract classification and management: a review. *Can J Ophthalmol.* 2013;48(4):251–258.

Smith MP, Colyer MH, Weichel ED, Stutzman RD. Traumatic cataracts secondary to combat ocular trauma. *J Cataract Refract Surg.* 2015;41(8):1693–1698.

Dislocation and subluxation

During a blunt injury to the eye, the globe is compressed and then rapidly expands in the equatorial plane. This rapid equatorial expansion can disrupt the zonular fibers, causing dislocation or subluxation of the lens. The lens may be dislocated posteriorly into the vitreous cavity or anteriorly into the anterior chamber (Fig 5-11).

Symptoms and signs of traumatic lens subluxation include fluctuation of vision, impaired accommodation, monocular diplopia, and high astigmatism. Often, iridodonesis or phacodonesis is present. Retroillumination of the lens at the slit lamp through a dilated pupil may demonstrate zonular disruption.

Perforating or Penetrating Injury

A perforating or penetrating injury of the lens often causes opacification of the cortex at the site of the rupture (Fig 5-12), which usually progresses rapidly to complete opacification.

Figure 5-11 A cataractous lens has dislocated into anterior chamber following blunt trauma. *(Courtesy of James Gilman, CRA, FOPS.)*

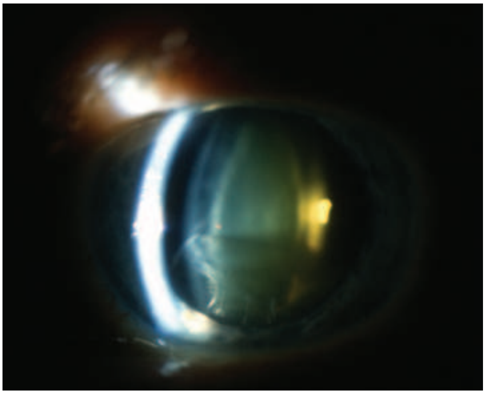
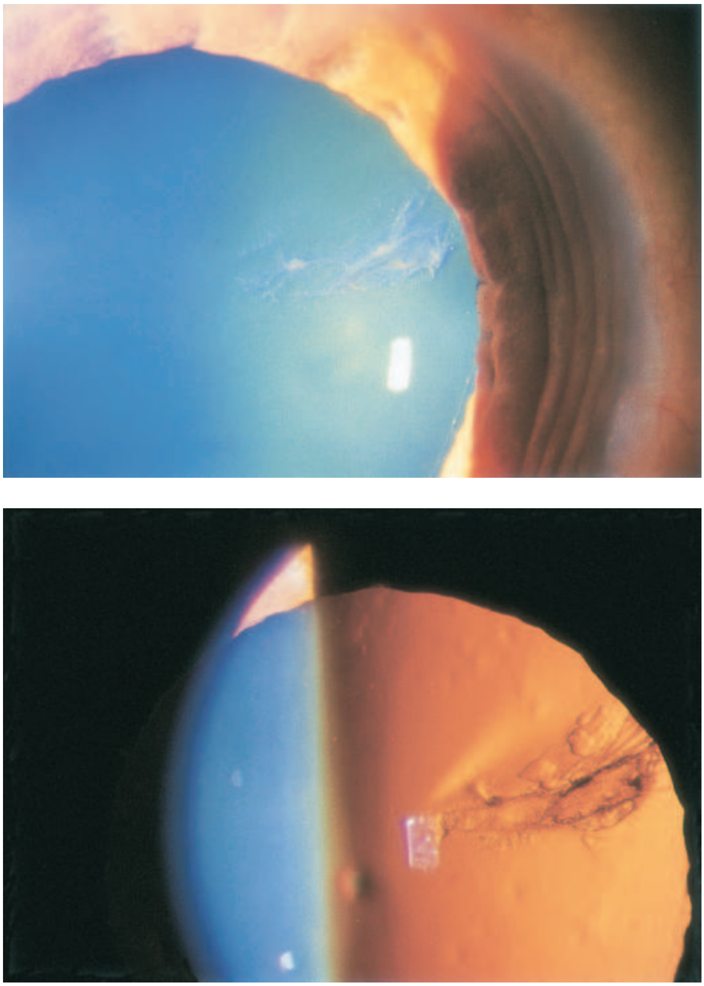


Figure 5-12 Inferior cortical opacification after capsule disruption by perforating injury. *(Courtesy of James Gilman, CRA, FOPS.)*

Occasionally, a small perforating injury of the lens capsule heals, resulting in a stationary focal cortical cataract (Fig 5-13).



A

B

Figure 5-13 Focal cortical cataract. **A,** Focal cortical cataract from a small perforating injury to the lens capsule as viewed by direct illumination. **B,** Focal cortical cataract viewed by retroillumination.

Intralenticular Foreign Bodies

In rare instances, a small foreign body can perforate the cornea and the anterior lens capsule and become lodged within the lens. If the foreign body is not composed of iron or copper and the anterior lens capsule seals the perforation site, the foreign body may be retained within the lens without significant complication. Intralenticular foreign bodies may cause cataract formation in some cases but do not always lead to complete lens opacification.

Metallosis

Siderosis bulbi

Intraocular iron-containing foreign bodies can cause siderosis bulbi, a condition in which iron molecules are deposited in the trabecular meshwork, lens epithelium, iris, and retina (Fig 5-14A). Deposits of hemosiderin may be noted under the anterior capsule, creating a "leopard spot" appearance. The epithelium and cortical fibers of the affected lens at first show a yellowish tinge, followed by a rusty brown discoloration (Fig 5-14B). Lens involvement occurs more rapidly if the retained foreign body is embedded close to the lens. Later manifestations of siderosis bulbi are complete cortical cataract formation and retinal dysfunction. (See also BCSC Section 12, *Retina and Vitreous.*)

Chalcosis

Chalcosis occurs when an intraocular foreign body deposits copper in Descemet membrane, the anterior lens capsule, or other intraocular basement membranes. The resulting *"sunflower" cataract* is a petal-shaped deposition of yellow or brown pigment in the lens capsule that radiates from the anterior axial pole of the lens to the equator. Usually, this cataract causes no significant loss of vision; however, intraocular foreign bodies containing almost pure copper (more than 90%) can cause a severe inflammatory reaction and intraocular necrosis.

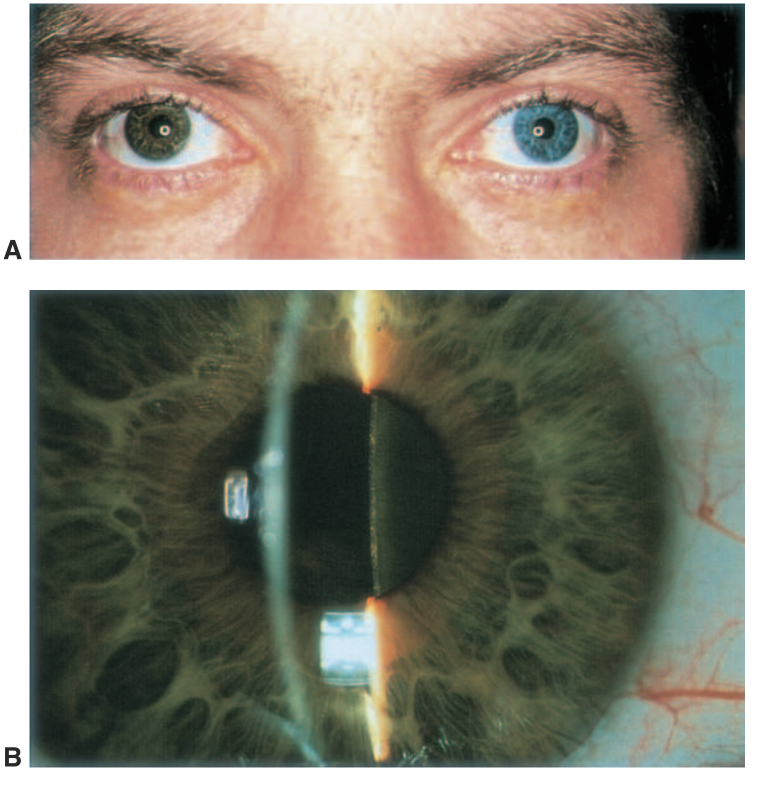


Figure 5-14 Siderosis bulbi. **A,** Heterochromia iridis caused by siderosis bulbi. **B,** Discoloration of the lens capsule and cortex.

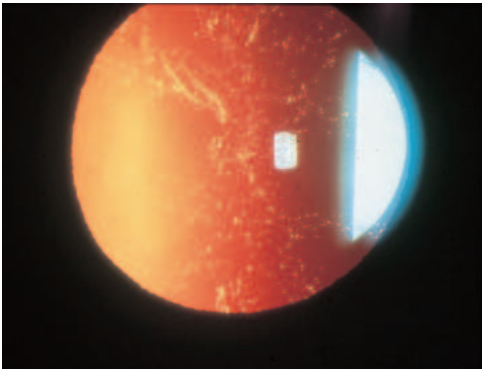


Figure 5-15 Cataract induced by electrical injury. *(Courtesy of Karla J. Johns, MD.)*

Electrical Injury

Electrical shock can cause protein coagulation and cataract formation. Lens manifestations are more likely when the transmission of current involves the patient's head. Initially, lens vacuoles appear in the anterior midperiphery of the lens, followed by linear opacities in the anterior subcapsular cortex. A cataract induced by an electrical injury may regress, remain stationary, or mature to become a complete cataract over months or years (Fig 5-15).

Chemical Injuries

Alkali injuries to the ocular surface often result in cataract, in addition to damaging the cornea, conjunctiva, and iris. Alkali compounds penetrate the eye readily, causing an increase in aqueous pH and a decrease in the levels of aqueous glucose and ascorbate. Cortical cataract formation may occur acutely or as a delayed effect of chemical injury. Because acid tends to penetrate the eye less easily than does alkali, acid injuries are less likely to result in cataract formation.

Lens Changes Associated with Systemic Disease

Metabolic Disease

Diabetes mellitus

Diabetes mellitus can affect lens clarity as well as the refractive index and accommodative amplitude of the lens. As the blood glucose level increases, so does the glucose content in the aqueous humor (see Chapter 3 in this volume for a discussion of glucose-induced lens changes). Acute myopic shifts may indicate undiagnosed or poorly controlled diabetes mellitus; conversely, hyperopic shifts can occur with insulin treatment. Patients with type 1 diabetes mellitus have a decreased amplitude of accommodation compared with age-matched controls, and presbyopia may present at a younger age in these patients.

Cataract is a common cause of visual impairment in patients with diabetes mellitus. Acute *diabetic cataract,* or *"snowflake" cataract,* refers to bilateral, widespread subcapsular lens changes of abrupt onset and typically occurs in young individuals with uncontrolled diabetes mellitus (Fig 5-16). Multiple gray-white subcapsular opacities that have a snowflake appearance are seen initially in the superficial anterior and posterior lens cortex. Vacuoles and clefts form in the underlying cortex. Intumescence and maturity of the cortical cataract follow shortly thereafter. Although acute diabetic cataracts are encountered in clinical practice only in rare cases today, rapidly maturing bilateral cortical cataracts in a child or young adult may indicate the presence of diabetes mellitus.

Patients with diabetes mellitus develop age-related lens changes that are histologically indistinguishable from nondiabetic age-related cataracts. The increased risk or earlier onset of age-related cataracts in diabetic patients may be a result of the accumulation of sorbitol within the lens and accompanying changes in hydration, increased nonenzymatic glycosylation of lens proteins, or greater oxidative stress from alterations in lens metabolism. These stressors may promote an increase in nuclear sclerotic cataract, cortical cataract, and PSC formation.

Cataract is the leading cause of visual impairment among children and adolescents with diabetes mellitus and may be the first sign of the disorder. In various studies, the incidence of cataract among pediatric patients with diabetes was between 0.7% and 3.4% of those studied. There is no consensus guideline for screening pediatric patients with diabetes for cataract; practitioners should follow screening guidelines for diabetic retinopathy.

Geloneck MM, Forbes BJ, Shaffer J, Ying GS, Binenbaum G. Ocular complications in children with diabetes mellitus. *Ophthalmology.* 2015;122(12):2457–2464.

Li L, Wan XH, Zhao GH. Meta-analysis of the risk of cataract in type 2 diabetes. *BMC Ophthalmol.* 2014;14:94.

Šimunović M, Paradžik M, Škrabić R, Unić I, Bućan K, Škrabić V. Cataract as early ocular complication in children and adolescents with type 1 diabetes mellitus. *Int J Endocrinol.* 2018;2018:6763586.

Galactosemia

Galactosemia is an inherited autosomal recessive inability to convert galactose to glucose. As a consequence of this inability, excessive galactose accumulates in body tissues, with further metabolic conversion of galactose to galactitol (dulcitol), the sugar alcohol product of galactose. Galactosemia can result from defects in 1 of the 3 enzymes involved in the

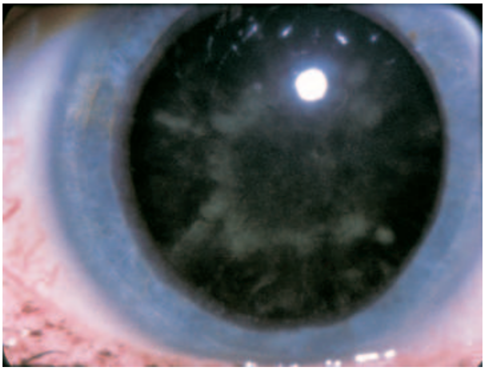


Figure 5-16 Diabetic cataract, or "snowflake" cataract, consists of gray-white subcapsular opacities. *(Courtesy of Karla J. Johns, MD.)*

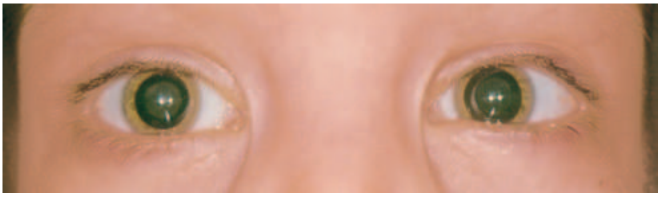


Figure 5-17 "Oil-droplet" bilateral cataracts in a patient with galactosemia.

metabolism of galactose. The most common and the most severe form, known as *classic galactosemia,* is caused by a defect in galactose-1-phosphate uridyltransferase.

In cases of classic galactosemia, symptoms of malnutrition, hepatomegaly, jaundice, and intellectual deficiency present within the first few weeks of life. The disease is fatal if undiagnosed and untreated. The diagnosis of classic galactosemia can be confirmed by demonstration of galactose in the urine.

Initially, the refractive index of the lens increases, inducing lenticular myopia. If left untreated, the nucleus and deep cortex become increasingly opacified in individuals with this condition, causing an "oil-droplet" appearance on retroillumination (Fig 5-17). The cataracts can progress to total opacification.

Treatment of galactosemia includes elimination of milk and milk products from the diet. In the majority of cases, early cataract formation can be reversed by timely diagnosis and dietary intervention; other cases may require cataract surgery. The oil-droplet appearance in classic galactosemia differs markedly from the similarly named oil-droplet cataract of posterior lenticonus. In posterior lenticonus, it is a bulge in the posterior capsule that causes the oil-droplet appearance on red reflex examination.

Karadag N, Zenciroglu A, Eminoglu FT, et al. Literature review and outcome of classic galactosemia diagnosed in the neonatal period. *Clin Lab.* 2013;59(9–10):1139–1146.

Hypocalcemia

Cataract may develop in association with any condition that results in hypocalcemia. Hypocalcemia may be idiopathic, or it may occur as a result of unintended destruction of the parathyroid glands during thyroid surgery. Usually bilateral, hypocalcemic (tetanic) cataracts are punctate iridescent opacities in the anterior and posterior cortex. They lie beneath the anterior lens capsule and are usually separated from it by a zone of clear lens. These discrete opacities may remain stable or may mature into complete cortical cataracts.

Wilson disease

Wilson disease (hepatolenticular degeneration) is an inherited autosomal recessive disorder of copper metabolism. The characteristic ocular manifestation of Wilson disease is the Kayser-Fleischer ring, a golden-brown discoloration of Descemet membrane around the periphery of the cornea (Fig 5-18A). In addition, a characteristic sunflower cataract often develops. Reddish-brown pigment (cuprous oxide) is deposited in the anterior lens capsule and subcapsular cortex in a stellate shape that resembles the petals of a sunflower (Fig 5-18B). In most cases, the sunflower cataract does not cause serious visual

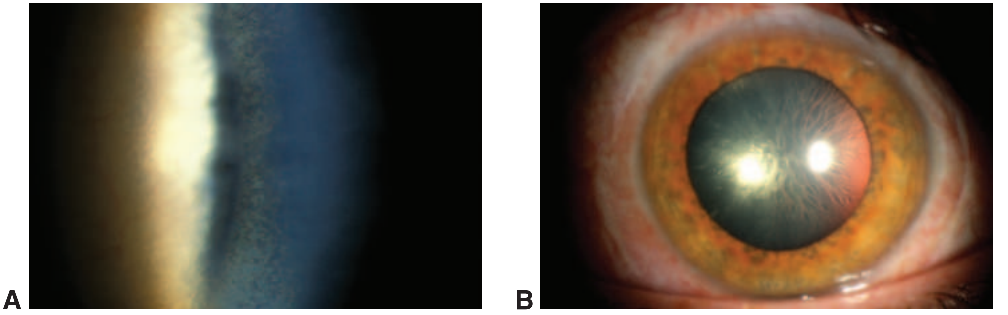


Figure 5-18 Ocular manifestations of Wilson disease. **A,** Slit-lamp image of Kayser-Fleischer ring, a golden-brown staining of Descemet membrane in corneal periphery. **B,** Clinical photo of reddish cuprous oxide deposited in the anterior lens capsule in a "sunflower" cataract. *(Courtesy of James Gilman, CRA, FOPS.)*

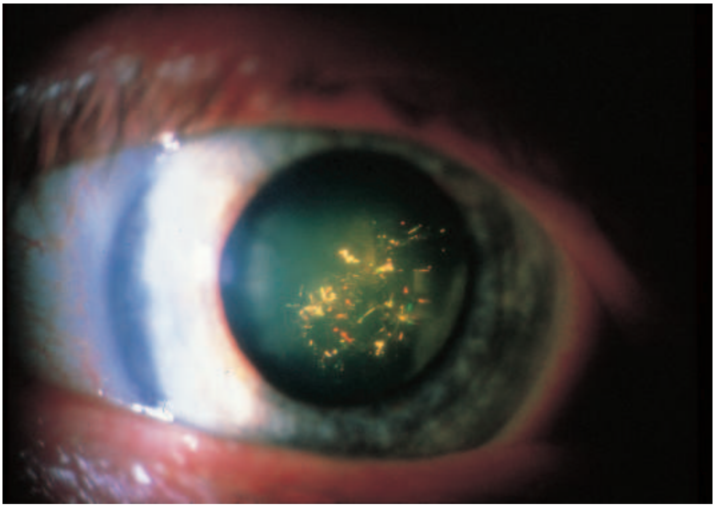


Figure 5-19 Polychromatic iridescent crystals in a patient with myotonic dystrophy. *(Courtesy of Karla J. Johns, MD.)*

impairment. These changes are similar to those seen in chalcosis. See also BCSC Section 8, *External Disease and Cornea*.

Myotonic Dystrophy

Myotonic dystrophy is an inherited autosomal dominant condition characterized by delayed relaxation of contracted muscles, ptosis, weakness of the facial musculature, cardiac conduction defects, and prominent frontal balding in affected male patients. There are 2 main types of this disease; the more severe type 1 and the milder type 2. Patients with this disorder typically develop polychromatic iridescent crystals in the lens cortex (Fig 5-19), with a sequential PSC that progresses to complete cortical opacification. These polychromatic iridescent crystals are composed of whorls of plasmalemma from the lens fibers. These cataracts occur in both forms of the disease and can be a presenting sign of the disease in patients with type 2 myotonic dystrophy. If a capsulotomy is performed due to posterior capsular opacification, the laser opening can close due to excessive proliferation of lens cells.

Iridescent crystals that are similar in appearance are occasionally seen in the lens cortices of patients who do not have myotonic dystrophy; these crystals are thought to be caused by cholesterol deposition in the lens. Iridescence occurs when the structure of an object causes light waves to combine, a process known as interference. In constructive interference, the light waves in the same phase combine to increase the vibrancy of the reflected color.

Atopic Dermatitis

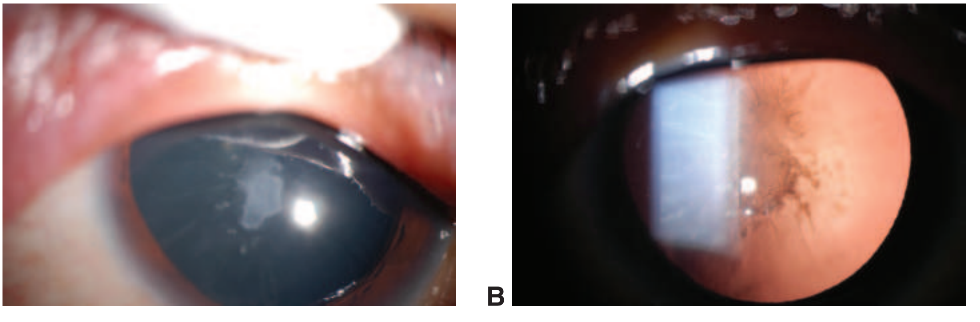
Atopic dermatitis (AD) is a chronic, eczematous dermatitis, accompanied by itching and often seen in conjunction with increased levels of immunoglobulin E (IgE) and a history of allergic rhinitis and asthma. Cataract formation has been reported in 5%–38% of patients with AD. The cataracts are usually bilateral, and onset occurs most often in the second to third decade of life, although cases in young children have been reported. Typically, these cataracts are anterior or posterior subcapsular opacities in the pupillary area that resemble shieldlike plaques (Fig 5-20). Although the pathogenesis of these cataracts is unclear, there appears to be decreased inhibition of free radical formation from decreased inducibility of superoxide dismutase in AD patients with cataracts.

Patients with AD are at higher risk of carrying *Staphylococcus aureus* on their eyelids, and thus surgeons administering topical or intraocular antibiotics to prevent postoperative endophthalmitis should ensure that appropriate antibacterial coverage is obtained.

Hsu JI, Pflugfelder SC, Kim SJ. Ocular complications of atopic dermatitis. *Cutis.* 2019;104(3):189–193.

Ischemia

Ischemic ocular conditions, such as pulseless disease (Takayasu arteritis), thromboangiitis obliterans (Buerger disease), anterior segment necrosis, and carotid occlusive disease can cause PSC. The cataract may progress rapidly to total opacification of the lens.



A B

Figure 5-20 Atopic dermatitis. **A,** Characteristic subcapsular cataract. **B,** Slit-lamp retroillumination image of the same eye.

Effects of Nutrition, Alcohol, and Smoking

Although nutritional deficiencies have been demonstrated to cause cataracts in animal models, this etiology has been difficult to confirm in humans. Initial population-based studies have found that increased prevalence of age-related cataracts has been associated with lower socioeconomic status, lower education level, and poorer overall nutrition. Severe episodes of dehydration caused by diarrhea may be linked to an increased risk of cataract formation. More recent studies of supplementation with vitamins, antioxidants, and estrogen have not consistently correlated these supplements with a decreased risk for cataract development. High-dose vitamin B supplementation of more than 10 times the recommended daily allowance is associated with increased risk of cataract.

Tobacco smoking, the use of smokeless tobacco products, and excessive alcohol consumption (more than 14 standard drinks per week for men and 7 standard drinks per week for women) are significant, avoidable risk factors for cataract. In numerous studies performed worldwide, these practices have been consistently associated with an increase in the frequency of nuclear opacities. Although patients may know the general health risks of smoking and excessive alcohol consumption, they may not know about the associated increased risks of ocular conditions, including macular degeneration and cataract. Ophthalmologists can inform their patients about these risks, and they are in a strong position to encourage individuals to stop smoking and reduce alcohol consumption.

Gong Y, Feng K, Yan N, Xu Y, Pan CW. Different amounts of alcohol consumption and cataract: a meta-analysis. *Optom Vis Sci.* 2015;92(4):471–479.

Selin JZ, Lindblad BE, Bottai M, Morgenstern R, Wolk A. High-dose B-vitamin supplements and risk for age-related cataract: a population-based prospective study of men and women. *Br J Nutr*. 2017;118(2):154–160.

Sella R, Afshari NA. Nutritional effect on age-related cataract formation and progression. *Curr Opin Ophthalmol.* 2019;30(1):63–69.

Cataract Associated With Ocular Disorders

Uveitis

Lens changes may occur as a result of chronic uveitis or associated corticosteroid therapy; typically, a PSC develops, but anterior lens opacification may also occur. These lenticular changes can progress to a mature cataract. The formation of posterior synechiae is common in uveitis, often with thickening of the anterior lens capsule, which may have an associated fibrous pupillary membrane. Calcium deposits may be observed on the anterior capsule or within the lens.

Cortical cataract formation occurs in up to 70% of cases of Fuchs uveitis syndrome (Fig 5-21; also known as Fuchs heterochromic uveitis). Posterior synechiae are uncommon, and formation of pupillary membranes is unlikely; long-term corticosteroid therapy is not indicated. Cataract extraction generally has a favorable prognosis. Intraoperative

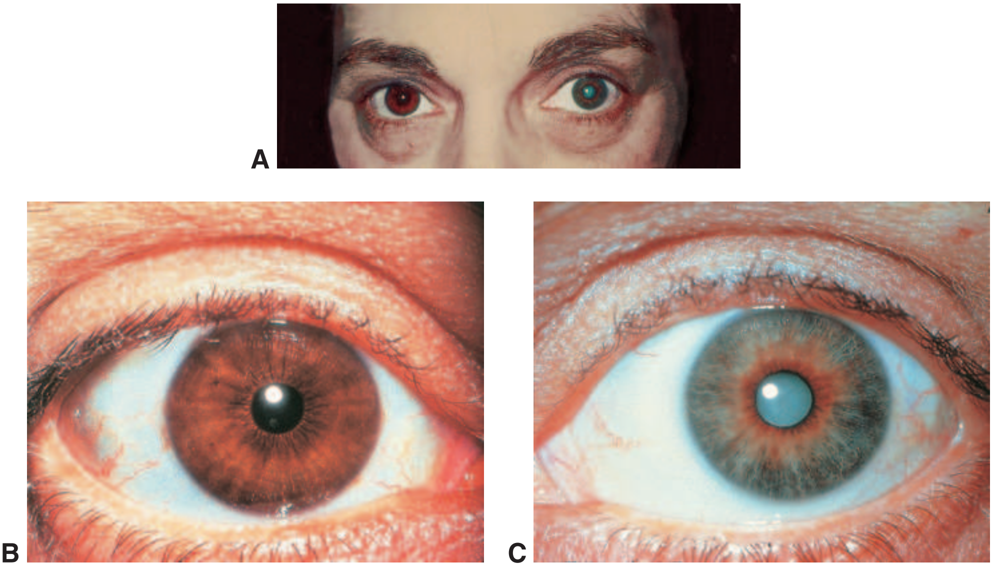


Figure 5-21 Clinical photographs from a patient with Fuchs uveitis syndrome. **A,** The affected eye is lighter. **B,** Normal right eye. **C,** Cataract formation in the affected left eye. *(Courtesy of Karla J. Johns, MD.)*

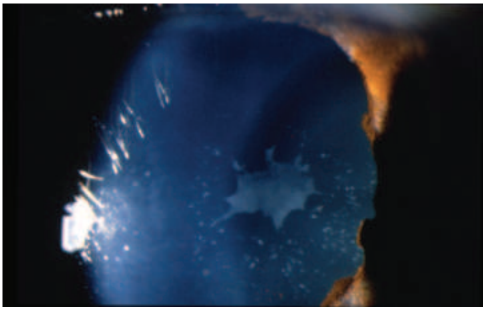


Figure 5-22 Glaukomflecken in the lens of a patient following recovery from acute angle-closure glaucoma. *(Courtesy of Thomas L. Steinemann, MD.)*

anterior chamber hemorrhage at the time of cataract surgery (Amsler sign) occurs in 8%–25% of cases.

Keles S, Ondas O, Ates O, et al. Phacoemulsification and core vitrectomy in Fuchs' heterochromic uveitis. *Eurasian J Med.* 2017;49(2):97–101.

Glaukomflecken

Glaukomflecken are gray-white epithelial and anterior cortical lens opacities that occur following an episode of markedly elevated intraocular pressure (IOP), as in acute angle-closure glaucoma (Fig 5-22). As can be seen on histologic examination, glaukomflecken are composed of necrotic lens epithelial cells and degenerated subepithelial cortex.

Pseudoexfoliation Syndrome

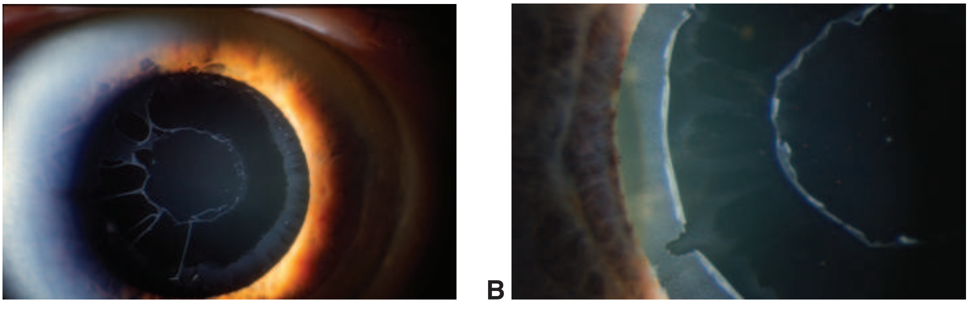
Pseudoexfoliation syndrome is a systemic disease in which a matrix of fibrotic material is deposited in many organs in the body. (See also discussion in BCSC Section 10, *Glaucoma*.) In the eye, a basement membrane–like fibrillogranular, whitish material is deposited on the cornea, iris, lens, anterior hyaloid face, ciliary processes, zonular fibers, and trabecular meshwork. These deposits, believed to comprise elastic microfibrils, appear as grayish-white flecks that are prominent at the pupillary margin and on the midperipheral anterior lens capsule (Fig 5-23). Associated with this condition are atrophy of the iris at the pupillary margin, deposition of pigment on the anterior surface of the iris, a poorly dilating pupil, increased pigmentation of the trabecular meshwork, capsular fragility, zonular weakness, and secondary open-angle glaucoma. Pseudoexfoliation syndrome is a unilateral or bilateral disorder that becomes more apparent with increasing age. There is an association between lifetime UV light exposure and the development of pseudoexfoliation syndrome.

Increased oxidative stress caused by abnormalities in transforming growth factor β (TGF-β) contributes to the formation of cataracts. Weakness of the zonular fibers and spontaneous lens subluxation and phacodonesis also occur. Poor zonular integrity may affect cataract surgery technique and intraocular lens implantation. (See Chapter 12 in this volume for a discussion of cataract surgery in special situations.) Over time, and even after cataract surgery, zonular instability can progress and cause pseudophacodonesis or lens-capsular bag complex dislocation. The exfoliative material will continue to be produced even after the crystalline lens is removed.

Nazarali S, Damji F, Damji KF. What have we learned about exfoliation syndrome since its discovery by John Lindberg 100 years ago? *Br J Ophthalmol.* 2018;102(10): 1342–1350.

Ong AY, Shalchi Z. Outcomes of cataract surgery in pseudoexfoliation syndrome in England: 10-year retrospective cohort study. *J Cataract Refract Surg.* 2021;47(2):165–171.

Pasquale LR, Jiwani AZ, Zehavi-Dorin T, et al. Solar exposure and residential geographic history in relation to exfoliation syndrome in the United States and Israel. *JAMA Ophthalmol.* 2014;132(12):1439–1445.



A B

Figure 5-23 Pseudoexfoliation syndrome. **A,** Deposition of white fibrillar material in targetlike distribution on the anterior capsule. **B,** Slit-lamp photograph demonstrates atrophy of the iris margin, deposition of pigment on the anterior lens capsule, and fibrillar deposits on iris margin. *(Courtesy of James Gilman, CRA, FOPS.)*

Cataracts Associated With Degenerative Ocular Disorders

Cataracts can occur in association with many degenerative ocular disorders, such as retinitis pigmentosa, essential iris atrophy, and chronic hypotony. These secondary cataracts usually begin as PSCs and may progress to total lens opacification. The mechanisms responsible for cataractogenesis in degenerative ocular disorders are not well understood.

Phacoantigenic Uveitis

In the normal eye, minute quantities of lens proteins leak out through the lens capsule. The eye appears to have immunologic tolerance to this limited antigenic stimulus. However, the release of a large quantity of lens proteins into the anterior chamber disrupts the immunologic tolerance and may trigger a severe inflammatory reaction. Phacoantigenic uveitis, previously termed *phacoanaphylactic endophthalmitis,* is an immune-mediated granulomatous inflammation initiated by lens proteins released through a ruptured lens capsule. This condition usually occurs following traumatic rupture of the lens capsule or after cataract surgery when cortical material is retained within the eye. Onset occurs days to weeks after the injury or surgery.

Phacoantigenic uveitis is characterized by a red, painful eye with injection, chemosis, anterior chamber cell and flare, and keratic precipitates. Occasionally, glaucoma develops due to obstruction of the trabecular meshwork and formation of synechiae. Late complications include cyclitic membrane, hypotony, and phthisis bulbi. In rare instances, phacoantigenic uveitis can give rise to an inflammatory reaction in the fellow eye. Histologic examination shows a zonal granulomatous inflammation surrounding a breach of the lens capsule. Lens extraction is the definitive therapy.

See also BCSC Section 4, *Ophthalmic Pathology and Intraocular Tumors,* and Section 9, *Uveitis and Ocular Inflammation.*

Guffey Johnson J, Margo CE. Intraocular inflammatory mass associated with lens-induced uveitis. *Surv Ophthalmol.* 2017;62(4):541–545.

Lens-Induced Glaucoma

See BCSC Section 10, *Glaucoma,* for additional discussion, including images.

Phacolytic Glaucoma

Phacolytic glaucoma is a complication of a mature or hypermature cataract. Denatured, liquefied high-molecular-weight lens proteins leak through an intact but permeable lens capsule. Macrophages ingest these lens proteins, and the trabecular meshwork becomes clogged with both the lens proteins and the engorged macrophages. The usual clinical presentation of phacolytic glaucoma consists of abrupt onset of pain and redness in a cataractous eye that has had poor vision for years. The cornea may be edematous, and significant flare reaction occurs in the anterior chamber. The lack of keratic precipitates helps distinguish phacolytic glaucoma from phacoantigenic glaucoma. White flocculent material appears in the anterior chamber and often adheres to the lens capsule as well. IOP is markedly elevated, and the anterior chamber angle is open, although the same material may be seen in the trabecular meshwork. Initial treatment of phacolytic glaucoma consists of controlling the IOP with IOP-lowering medications and managing the inflammation with topical corticosteroids. Definitive treatment includes surgical removal of the lens.

Lens Particle Glaucoma

Following a penetrating lens injury or surgical procedure (ie, extracapsular cataract extraction, phacoemulsification with retained cortical material, or in rare instances, Nd:YAG laser capsulotomy or vitrectomy), particles of lens cortex may migrate into the anterior chamber, where they obstruct aqueous outflow through the trabecular meshwork. In most instances, glaucoma occurs within weeks of the initial surgery or trauma, but it may occur months or years later. Gonioscopy shows that the angle is open, and cortical material can often be seen deposited along the trabecular meshwork. Medical therapy to lower IOP and reduce intraocular inflammation is indicated. If the IOP and inflammation do not respond within days to weeks with this treatment, the retained lens material is removed surgically.

Phacomorphic Glaucoma

As the lens thickens in the anterior–posterior dimension it can cause pupillary block and induce secondary angle-closure glaucoma, or it can physically push the iris forward and cause shallowing of the anterior chamber. Often, the patient presents with a red, painful eye and a history of vision changes as a result of cataract formation prior to the acute event (Fig 5-24). The cornea may be edematous, and gonioscopy reveals a closed anterior chamber angle. Initial management includes medical treatment to lower the IOP. The condition may respond to laser iridotomy, but definitive treatment consists of cataract extraction.

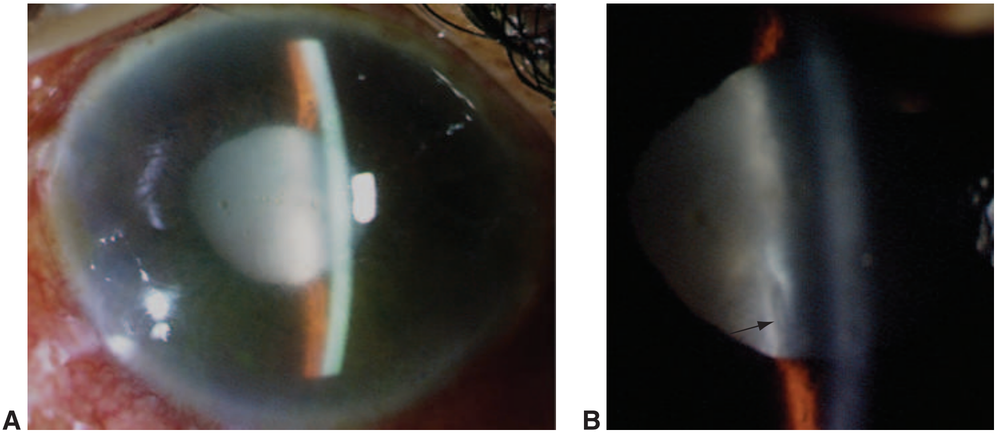


Figure 5-24 Phacomorphic glaucoma. **A,** White, intumescent lens with narrow anterior chamber. **B,** Water clefts present in the intumescent lens. *(Reproduced with permission from Seth NG, Akella M, Pandav SS. Phacomorphic glaucoma.* Ophthalmol Glaucoma. *2019;2[3]:187.)*

CHAPTER 6

Evaluation and Management of Cataract

Highlights

- In most cases, cataract surgery is an elective procedure. Not every cataract requires or warrants surgery.
- Preoperative evaluation is important for identifying and addressing any significant conditions that could impact the surgery or the postoperative recovery.
- Routine medical testing before routine cataract surgery has not been shown to increase the safety of the procedure.

Introduction

When evaluating a patient with cataract, the ophthalmologist must assess the degree to which the lens opacity affects the patient's vision and determine whether surgery will improve the patient's quality of life. Considering the answers to the following questions is important in the evaluation and management of cataract:

- What is the functional impact of the cataract?
- What are the morphological characteristics of the cataract?
- Is surgery indicated either to improve the patient's quality of life or to aid in the management of other ocular conditions?
- What are the patient's expectations regarding the refractive results of surgery?
- Does the patient have ocular or systemic comorbidities that might affect the decision to proceed with surgery or alter the surgical plan?
- What are the possible barriers to obtaining informed consent or to ensuring good postoperative care?

In most cases, cataract surgery is an elective procedure. Thus, in addition to answering the preceding questions, it is important for the ophthalmologist to inform the patient or the patient's surrogate about the impact of the cataract, the risks and benefits of surgical management, the alternatives to surgery, and the options regarding the intraocular lens (IOL) to be used if surgery takes place. Ultimately, it is important that the patient or surrogate and physician be satisfied that surgery is an appropriate choice for improving vision.

This chapter focuses on the evaluation and management of cataract in adults. For discussion of cataract in pediatric patients, refer to BCSC Section 6, *Pediatric Ophthalmology and Strabismus*.

Clinical History: Symptoms and Correlating Signs

Decreased Visual Acuity

Often, the clinical history of a patient with decreased vision and function due to cataract is straightforward, and the patient tells the ophthalmologist which activities have been curtailed or abandoned. Some patients, however, learn of the decline in their visual acuity only after being examined. Others deny that they are having any problems until their limitations are demonstrated or privileges are withdrawn because they are no longer visually competent.

Different types of cataract may affect vision in different ways, depending on incident light, pupil size, and refractive error (Table 6-1). The presence of even small posterior subcapsular cataracts (PSCs) can greatly disturb near vision (reading vision) without necessarily affecting distance visual acuity. Color vision disturbances may be noted by the patient, especially with unilateral or asymmetric cataract.

Glare and Altered Contrast Sensitivity

Cataract patients often report an increase in glare, which may vary from increased photosensitivity in brightly lit environments to disabling glare in the daytime or with headlights from oncoming cars. Shorter wavelengths of light cause the most scatter; the color, intensity, and direction of light also affect glare. Glare is particularly prominent in eyes with PSCs and, occasionally, with anterior cortical lens changes.

Contrast sensitivity is the ability to detect subtle variations in shading. Because patients with ocular abnormalities have altered contrast sensitivity in low light, measurement of contrast sensitivity may provide a more comprehensive estimate of the visual resolution of the eye. A significant loss in contrast sensitivity may occur without a similar loss in Snellen acuity. However, loss in contrast sensitivity is not a specific indicator of vision loss due to cataract.

Table 6-1 Characteristics and Effects of the Most Common Cataracts in Adults

Type	Growth Rate	Glare	Effect on Distance Vision	Effect on Near Vision	Induced Myopia
Cortical	Moderate	Moderate	Mild	Mild	None
Nuclear	Slow	Mild	Moderate	None	Moderate
Posterior subcapsular	Variable (rapid>slow)	Marked	Mild	Marked	None

Refractive Changes

The development of nuclear sclerotic cataract may increase the dioptric power of the lens, resulting in a myopic shift. Hyperopic and emmetropic patients find that their need for distance or reading spectacles diminishes as they experience this "second sight." This phenomenon disappears when the optical clarity of the crystalline lens further deteriorates. Less commonly, hyperopic or astigmatic refractive errors can be induced by cataractous lens changes. Asymmetric development of lens-induced myopia may produce intolerable anisometropia.

Monocular Diplopia or Polyopia

Patients may experience monocular diplopia or polyopia, as well as ghost images. Occasionally in cataractous eyes, nuclear changes are localized to the inner layers of the lens nucleus, resulting in multiple refractile areas at the center of the lens. Such areas may best be seen as irregularities in the red reflex on retinoscopy or direct ophthalmoscopy. Use of a pinhole occluder can eliminate symptoms and be helpful in evaluation. (For more on the pinhole test, see the section Potential Acuity Estimation later in this chapter.) Monocular diplopia can also occur with abnormalities of the tear film, cornea, and retina (see BCSC Section 5, *Neuro-Ophthalmology*).

Decreased Visual Function

Assessing the overall effect of the cataract on visual function is a more appropriate way to determine visual disability than is acuity testing alone. This assessment includes asking patients whether their vision (at near, at distance, and under different lighting conditions) is adequate to allow them to perform relevant activities of daily living and participate in any hobbies they may have. Questionnaires for measuring visual function may be useful; examples of these are the Activities of Daily Vision Scale (ADVS), the Visual Function Index (VF-14), the National Eye Institute Visual Function Questionnaire (NEI-VFQ), Catquest-9SF questionnaire, and the Visual Disability Assessment (VDA).

de Souza RG, Golla A, Khan M, de Oca IM, Khandelwal S, Al-Mohtaseb Z. Association of optical cataract indices with cataract severity and visual function. *Int Ophthalmol.* 2022;42(1):27–33.

Grimfors M, Lundström M, Hammar U, Kugelberg M. Patient-reported visual function outcome in cataract surgery: test-retest reliability of the Catquest-9SF questionnaire. *Acta Ophthalmol.* 2020;98(8):828–832.

Nonsurgical Management

Nonsurgical approaches may be attempted to improve visual function in cataract patients who do not desire surgery or for whom surgical management is not feasible. Careful refraction may improve spectacle correction for distance and near vision. Use of specialized tints on spectacles may reduce glare, and brighter illumination can improve the contrast of reading material. Handheld monoculars may facilitate spotting objects at a distance;

high-plus spectacles, magnifiers, closed-circuit televisions, and telescopic loupes may be used for reading and close work. See Chapter 10 in BCSC Section 3, *Clinical Optics and Vision Rehabilitation,* for more information on tools and technology that can aid in non-surgical management of lower visual function.

Referral to low vision services may be appropriate. The American Academy of Ophthalmology's Initiative in Vision Rehabilitation page on the ONE Network (aao.org/low-vision-and-vision-rehab) provides resources for low vision management, including a patient handout and information about additional vision rehabilitation opportunities beyond those provided by the ophthalmologist.

In patients with small axial cataracts, dilating the pupils either pharmacologically or by laser pupilloplasty may improve visual function by allowing more light to pass through peripheral portions of the lens. However, there is a risk of inducing additional glare with this approach.

American Academy of Ophthalmology Cataract and Anterior Segment Panel, Hoskins Center for Quality Eye Care. Preferred Practice Pattern® Guidelines. *Cataract in the Adult Eye.* American Academy of Ophthalmology; 2021. aao.org/ppp

Indications for Surgery

Although patients with visually significant cataract may express the desire for improved vision, the decision to operate is not based solely on a specific level of reduced acuity. Key to the decision is determining whether the patient's visual function would improve enough to warrant cataract surgery. Some governmental agencies and industries have minimum standards of visual function for their workers for tasks such as driving, flying, and operating complex equipment; a patient whose best-corrected visual acuity (BCVA; also called "corrected distance visual acuity") does not meet these visual requisites may need to consider cataract surgery. The ophthalmic surgeon must determine whether cataract surgery is advisable, through discussion with the patient and/or the patient's surrogate and analysis of the results of subjective and objective testing.

Some third-party payers require that patients have a certain level of vision loss before approving reimbursement for cataract surgery; in such cases, glare testing may be useful for documenting loss of visual function beyond that measured by Snellen acuity. In some cases, patients have lens changes that cause unwanted refractive errors or symptoms but do not meet criteria for third-party reimbursement. After a careful discussion of the risks, benefits, alternatives, and costs, surgery may be offered to patients who would benefit from the procedure.

Medical Indications

Medical indications for cataract surgery include phacolytic glaucoma, phacomorphic glaucoma, phacoantigenic uveitis, anatomic narrow angle, and dislocation of the lens. An additional indication for surgery is cataract that is sufficiently opaque so as to obscure the view of the fundus and impair the diagnosis or management of other ocular diseases, such as retinal diseases and optic neuropathies, including glaucoma.

Functional Indications

Cataract in older adults, especially those with significant deafness or early dementia, may lead to isolation. The quality of life of such patients may be greatly improved following cataract surgery. Cataract extraction has been shown to decrease the frequency of falls and hip fractures and reduce morbidity and mortality; it may also improve the ability of patients to perform activities of daily living.

Treatment of Unilateral Cataract

Common indications for surgery in a patient with unilateral cataract include loss of stereopsis, diminished peripheral vision, disabling glare, and symptomatic anisometropia. The presence of cataract in one eye has a negative effect on driving performance and accident avoidance.

Treatment of Bilateral Cataract

There are many possible treatment strategies for a patient with bilateral, visually significant cataract. The strategy ultimately chosen and how much time elapses before surgery is performed on the second eye are based on a combination of the surgeon's preference and the patient's needs, expectations, and visual potential. Surgery is usually performed first in the eye with the more advanced cataract, although the dominant or more ametropic eye may be addressed first in order to facilitate the patient's adaptation after surgery. In patients with active or severe systemic illness, or in those with other ocular diseases contributing to decreased vision, it may be appropriate to operate only on the eye with better visual potential.

Traditionally, before proceeding with the second surgery, the physician and the patient allow some time to confirm the success and safety of the first operation and to assess the refractive outcome. However, symptomatic anisometropia may occur as a result of the first cataract surgery, and the patient may find this disabling enough to justify prompt surgery on the second eye, even if the cataract in that eye is at a relatively early stage of development. After undergoing second-eye cataract surgery, patients have been shown to experience significant improvements not only in acuity and satisfaction with their vision but also in measures of bilateral visual function, such as stereopsis and contrast sensitivity.

Immediate Sequential Bilateral Cataract Surgery

Interest has increased in immediate sequential (same-day) bilateral cataract surgery (ISBCS). ISBCS might be indicated in patients with bilateral or unilateral cataract who have high refractive errors that could result in significant postoperative anisometropia or in patients who require general anesthesia and for whom the risks of a second anesthesia event are high. ISBCS may be most useful in regions with limited surgical access or for patients with transportation issues or high anesthesia risk, but it is increasingly being considered in high-resource areas. If same-day surgery is performed, each eye is treated as an entirely separate case: new gloves, draping, instruments, and tubing are used for the procedure on the second eye. When proper safety techniques are used, ISBCS has a demonstrated record of safety. ISBCS has no clinically significant difference in outcomes, compared to delayed surgery on the second eye, and a retrospective cohort study of the AAO Intelligent Research in Sight (IRIS) registry database found no increased risk of postoperative endophthalmitis. However, many ophthalmologists still do not use this approach due to the unlikely possibility of bilateral complications. The inability of the surgeon to incorporate information regarding refractive outcome into planning for the second eye is another concern, but this may be ameliorated with the use of intraoperative aberrometry and improved refractive formulas. Reduced third-party payment for the second procedure performed on the same day may also hamper widespread acceptance of ISBCS.

Dickman MM, Spekreijse LS, Winkens B, et al. Immediate sequential bilateral surgery versus delayed sequential bilateral surgery for cataracts. *Cochrane Database Sys Rev.* 2022;4(4): CD013270.pub2.

Lacy M, Kung TH, Owen JP, IRIS® Registry Analytic Center Consortium, 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(2): 129–138.

Malwankar J, Son HS, Chang DF, et al. Trends, factors, and outcomes associated with immediate sequential bilateral cataract surgery among Medicare beneficiaries. *Ophthalmology.* 2022;129(5):478–487.

Preoperative Evaluation

To determine whether cataract surgery is advisable, the following information is obtained, and the suggested parameters are tailored to the individual patient.

General Health of the Patient

A complete medical history is the starting point for the preoperative evaluation. The ophthalmologist can work with the patient's primary care physician to achieve optimal management of all medical problems, especially diabetes mellitus, ischemic heart disease, chronic obstructive pulmonary disease, bleeding disorders, or adrenal suppression caused by systemic corticosteroid use. The ophthalmologist should be aware of the patient's drug sensitivities and use of medications that might alter the outcome of surgery, such as immunosuppressants and anticoagulants. Given the low risk of significant hemorrhage with scleral tunnel or clear corneal incisions, anticoagulant medications generally do not need to be discontinued prior to routine cataract surgery. Any alteration in the patient's use of these medications is ideally done in consultation with the prescribing physician.

It is important to ask the patient specifically about the use of systemic α_1-adrenergic antagonist medications (including prazosin, terazosin, doxazosin, silodosin, alfuzosin, and tamsulosin, as well as herbal supplements, such as saw palmetto) for the treatment of benign prostatic hyperplasia, urinary incontinence, urolithiasis, and hypertension. These medications are strongly associated with intraoperative floppy iris syndrome (IFIS) and fluctuations in pupil size. All α_1-blockers can bind to postsynaptic nerve endings of the iris dilator muscle for a prolonged period, causing excessive iris mobility and diffuse atrophy of the iris dilator smooth muscle. This effect may occur after only one dose of the medication and may persist indefinitely, even after discontinuation of the drug. Anecdotal reports document potential α_1-antagonist properties and potential associations with IFIS in other medications, including certain antipsychotic and antihypertensive medications. See Chapter 10 in this volume for further discussion of IFIS.

It is important for the ophthalmologist to inquire about and document any allergies, adverse reactions, and sensitivities to sedatives, narcotics, anesthetics, povidone-iodine, and latex. Factors limiting the patient's ability to cooperate in the operating room or to lie comfortably on the operating room table (eg, deafness, language barriers, dementia, claustrophobia, restless legs syndrome, head tremor, musculoskeletal disorders, and psychiatric disorders) will influence the choice of anesthesia and the surgical plan. The patient's ability to follow instructions is key if the patient is to be awake during surgery. Accommodations for patients who may have more advanced anesthesia requirements or are at high risk of anesthesia complications should be discussed with the anesthesia provider prior to the date of surgery.

The extent of the formal medical preoperative evaluation is based on the patient's overall health and may be guided by requirements of the facility where the procedure is to take place. Screening with self-reported information gained from health questionnaires may help identify patients who are at higher risk for medical difficulties related to surgery, but this method should not be the only form of evaluation used. Certainly, for all patients with risk factors related to their ability to undergo surgery, a history should be obtained, and a physical examination and relevant laboratory work should be performed. However, routine medical testing before routine cataract surgery has not been shown to increase the safety of the procedure.

For information on social determinants of health, see Chapter 1 in BCSC Section 1, *Update on General Medicine*. For specific recommendations for preoperative cataract surgery planning in patients with special medical conditions, see Chapter 12 in this volume as well as BCSC Section 1.

American Academy of Ophthalmology Quality of Care Secretariat, Hoskins Center for Quality Eye Care. Routine preoperative laboratory testing for patients scheduled for cataract surgery—2014. *Clinical Statement.* American Academy of Ophthalmology; 2014. Accessed December 20, 2023. aao.org/clinical-statement/routine-preoperative-laboratory-testing-patients-s

Pertinent Ocular History

The ocular history helps the ophthalmologist identify conditions that could affect the surgical approach and the visual prognosis. Trauma, inflammation, amblyopia, strabismus, glaucoma, optic nerve abnormalities, or retinal disease might affect the visual outcome after cataract removal. In addition, an understanding of the patient's history of refractive error and spectacle or contact lens correction, as well as the patient's experience with monovision or progressive lenses, may aid refractive planning for cataract surgery.

Controlling active uveitis before cataract surgery is performed helps minimize the risk of complications from postoperative inflammation, such as macular edema and iris adhesion to the lens implant. Ideally, the eye is quiet without the use of topical corticosteroids for at least 3 months before surgery. Systemic immunomodulation may be necessary to achieve remission. Systemic steroids may be required perioperatively to manage ocular inflammation, even in eyes that were quiet prior to surgery. The presence of zonular abnormalities, fibrin membranes, or synechiae may require the surgeon to adjust their surgical technique, as discussed in Chapter 12 of this volume.

A family history of retinal detachment or a history of retinal detachment in either of the patient's eyes is a risk factor for postoperative retinal detachment. Previous vitrectomy for the treatment of retinal disease or vitreous hemorrhage may cause intraoperative anterior chamber fluctuations, which increase the risk of posterior capsule disruption and loss of nuclear fragments posteriorly.

Ideally, in patients with glaucoma, optimal control of intraocular pressure (IOP) is achieved prior to cataract surgery. The surgeon may wish to consider a combined operation of cataract surgery and a procedure to lower IOP in patients with glaucoma who either need improved IOP control or would like to decrease their medication burden. New techniques combining cataract surgery with micro-invasive glaucoma surgery (MIGS) allow surgeons to maintain a risk profile similar to that of cataract surgery alone. See Chapter 12 in this volume and BCSC Section 10, *Glaucoma.*

Past records document the patient's visual acuity before the development of cataract. If the patient has had cataract surgery in the fellow eye, it is important to obtain information about the operative and postoperative course. If problems such as IFIS, elevated IOP, vitreous loss, cystoid macular edema, endophthalmitis, hemorrhage, or a refractive surprise occurred during or after the first operation, the surgical approach and postoperative follow-up could be modified for the second eye in order to reduce the risk of similar complications.

If the patient has previously undergone refractive surgery, it is helpful to perform additional ocular measurements prior to the cataract surgery. See Chapters 7 and 12 for further discussion on surgical preparation.

Llop SM, Papaliodis GN. Cataract surgery complications in uveitis patients: a review article. *Semin Ophthalmol.* 2018;33(1):64–69.

Social History

As discussed earlier, the decision to undertake cataract surgery is based not only on the patient's visual acuity but also on the ramifications of reduced vision on the individual's quality of life. Many factors affect postoperative recovery, including the patient's occupation, hobbies, and lifestyle; these may influence the desired postoperative refractive outcome, as well. Any surrogate decision makers must be identified and included in preoperative planning.

Measurements of Visual Function

Visual Acuity Testing

It is useful to measure Snellen acuity under lighted and darkened examination conditions. Although visual acuity testing in the ophthalmologist's office is commonly performed in a darkened room, diminished Snellen acuity from a symptomatic cataract is sometimes demonstrated only in a lighted room. Distance and near visual acuity must be tested and careful refraction performed so that BCVA can be determined. Visual acuity may improve after pupillary dilation, especially in patients with a PSC.

Refraction

Careful refraction must be performed on both eyes. This assessment is useful for discussion of the desired postoperative refraction, as well as for determining whether a refractive shift has occurred due to cataract progression. If the fellow eye is without significant cataract and has a high refractive error that requires correction, achieving emmetropia in the surgical eye may result in bothersome postoperative anisometropia. The patient must be informed of this possibility and of management options, including refractive surgery or use of a contact lens for the noncataractous eye. Postoperative anisometropia may be an indication to proceed with surgery on the second eye, even in the instance of minimal cataract. To avoid postoperative anisometropia, the surgeon could aim for a refractive result similar to the refractive error of the fellow eye, but this ensures long-term dependence on refractive correction. A planned monovision outcome may optimize spectacle independence, but the patient either must have experience with monovision or must be tested to find out whether adapting to unequal refractive errors will be tolerated.

Rigid contact lens overrefraction is a useful technique to assess the degree to which irregular astigmatism or other corneal irregularity is contributing to a patient's visual disability.

Glare Testing

With glare testing, the clinician attempts to measure the degree of visual impairment caused by the presence of a light source located in the patient's visual field. Testing can be done with a nonprojected eye chart in ambient light conditions or with a projected eye chart and an off-axis bright light directed at the patient. Various instruments are available to standardize and facilitate this measurement. Patients with significant cataract commonly show a decrease of 3 or more lines under these conditions, compared with results obtained when visual acuity is tested in a darkened room. This assessment should be performed prior to dilation; if performed afterward, the result must be adjusted to account for the change in visual acuity after dilation, and the results may be less accurate.

Contrast Sensitivity Testing

Patients with cataract may experience diminished contrast sensitivity even when Snellen acuity is preserved. Various specialized charts have been developed to test contrast sensitivity. Some charts are mounted on a wall; others are handheld or incorporate the use of a monitor. Certain contrast sensitivity charts feature sine wave gratings to allow evaluation of different spatial frequencies. However, no instrument is currently considered the standard for contrast sensitivity testing. Of note, contrast sensitivity may be decreased by a wide variety of ophthalmic conditions affecting the cornea, optic nerve, and retina. It is therefore essential that the ophthalmologist identify any comorbidities before attributing an irregularity in test results solely to cataract.

External Examination

The preoperative evaluation of a patient with cataract includes the body habitus and any abnormalities of the external eye and ocular adnexa. Conditions that may affect the surgical approach include extensive neck fat, kyphosis, ankylosing spondylitis, generalized obesity, and head tremor. The presence of enophthalmos or a prominent brow may affect not only the surgical approach but also the chosen route of anesthesia.

Entropion, ectropion, and eyelid closure abnormalities, as well as abnormalities in the tear film, may have an impact on the ocular surface and thus adversely affect postoperative recovery if not addressed preoperatively. Severe blepharitis or acne rosacea may pose an increased risk of endophthalmitis and should be treated before cataract surgery. Active nasolacrimal disease should also be treated, particularly if there is a history of infection or obstruction.

Motility and Ocular Dominance

Ocular motility can be determined by evaluating ocular alignment and testing the range of movement of the extraocular muscles. Cover testing helps determine any muscle deviation. Abnormal motility may suggest preexisting strabismus with amblyopia as a cause of vision loss. Patients must be made aware that they may experience diplopia after cataract surgery if they have a significant tropia resulting in disruption of fusion. Removal of a dense cataract may improve vision but make the patient aware of ocular misalignment.

The examination can also include an assessment of ocular dominance. Ocular dominance can be important if the patient is considering monovision; however, the importance of this in the planning of monovision is debatable.

Pupils

In addition to checking direct and consensual constriction of the pupil to light, the physician performs the swinging flashlight test to detect a *relative afferent pupillary defect* (*RAPD*), the presence of which indicates optic nerve dysfunction or extensive retinal disease. (See also BCSC Section 5, *Neuro-Ophthalmology.*) Although the vision of a patient with a RAPD in the cataractous eye may improve after cataract surgery, the visual outcome may be limited by optic nerve dysfunction. The patient must be made aware of the possibility of less than complete restoration of vision.

It is important to measure the size of the pupil under different lighting conditions, because this information may affect selection of the IOL. For example, small-optic lenses may be inappropriate for a patient who has a large pupil in moderate or dim illumination. The edge of the optic can fall inside the pupil border, allowing light to pass around the optic edge, with resultant glare or dysphotopsias. Also, the function of a multifocal IOL may be affected by a pupil that is small, atonic, or eccentric. It is helpful to assess pupil size before and after dilation, because the risk of surgical complications is higher in small pupils that do not dilate adequately (eg, in patients with diabetes mellitus, posterior synechiae, pseudoexfoliation syndrome, opioid use, or a history of systemic α_1-adrenergic antagonist use or long-term topical miotic use). In such cases, the surgeon may need to use pupil-expansion devices, which are discussed in Chapter 12.

Slit-Lamp Examination

Conjunctiva

Vascularization or scarring of the conjunctiva due to previous inflammation, injury, or ocular surgery may indicate compromised healing and limit surgical exposure. Symblepharon or shortening of the fornices may be associated with underlying systemic or ocular surface diseases. It is important that infectious processes receive appropriate treatment before cataract surgery in order to ensure optimal postoperative healing.

Cornea

Examination of the cornea includes an assessment of corneal thickness and whether corneal abnormalities, including edema, ectasia, guttae, scarring, opacities, and dystrophy, are present. Abnormalities could increase the risk of poor healing and decompensation postoperatively. Specular reflection with the slit lamp may provide an estimate of the endothelial cell count and information regarding cell morphology. Descemet membrane irregularity associated with cornea guttae, as well as any central opacity, may affect the surgeon's view of the lens during surgery and limit visual acuity after surgery. In patients with pannus due to long-term contact lens use or other conditions, the surgeon will avoid making corneal incisions in areas of vascularization, if possible. Also, weakened or thinned areas in the cornea should be identified so that they can be avoided intraoperatively.

The ocular surface is the first and principal refracting interface of the eye. Tear film quantity and quality are thus critical to visual results. Diagnosis and management of keratitis sicca, blepharitis, and epithelial basement membrane dystrophy are of critical importance in cataract patients, particularly if multifocal or toric IOLs are being considered. The tear film should be optimized prior to obtaining IOL measurements, as an abnormal tear film can result in measurement errors.

If areas of scarring consistent with a history of herpetic eye disease are present, prophylactic antiviral medication and careful monitoring of steroid therapy in the perioperative period may be advisable to prevent reactivation.

If the patient has undergone previous corneal refractive surgery, it is important to document the type of surgery and any associated corneal findings, including haze or iron lines (which can indicate a steep central island) after photorefractive keratectomy (PRK), the location of a laser in situ keratomileusis (LASIK) flap, and the placement of radial or astigmatic incisions. The presence of corneal implants is also important to evaluate. Any apparent problems with healing should be noted. See also Chapters 7 and 12 in this volume and BCSC Section 13, *Refractive Surgery.*

Anterior Chamber and Iris

Knowing the depth of the anterior chamber and the axial thickness of the lens aids in surgical planning. A shallow anterior chamber may indicate anatomically narrow angles, nanophthalmos, short axial length, an intumescent lens, or weak zonules.

Gonioscopy can be used preoperatively to rule out angle abnormalities, such as peripheral anterior synechiae, neovascularization, or a prominent major arterial circle, and also to help plan angle-based procedures if microinvasive glaucoma surgery is performed. Use of a 3-mirror lens helps in the evaluation of the lens zonules for traumatic or congenital dehiscence. Gonioscopy is essential if anterior chamber IOL implantation is anticipated.

The presence of transillumination defects, iridodonesis, or pseudoexfoliation at the margin of the undilated pupil may indicate weakened or absent zonular attachments and may affect the surgical plan. In addition, careful examination of the iris is important, because iris coloboma is often accompanied by lens coloboma and associated localized absence of zonular attachments.

Crystalline Lens

When examining the lens, the clinician notes its appearance both before and after pupillary dilation. The impact of "oil-droplet" nuclear cataracts and small PSCs is most closely correlated with visual symptoms before pupil dilation. After dilation, nuclear density can be evaluated, pseudoexfoliation syndrome and Vossius rings can be detected, and opacities and distortion of the retinoscopic reflex can be visualized more easily.

To assess the lenticular contribution to the visual deficit, the clarity of the media in the visual axis is evaluated with the slit lamp. Dense, brunescent nuclear sclerotic cataract may permit remarkably good vision, especially at near distances, whereas vacuolar cortical cataracts can cause surprisingly severe vision loss. When dense cortical opacification is present, the intraoperative use of capsular dye to enhance visualization of the capsulorrhexis may be helpful. The presence of a congenital posterior polar opacity is associated with a significant risk of capsule rupture and should be identified before surgery.

The position of the lens and the integrity of the zonular fibers are also evaluated. Lens coloboma, lens decentration, phacodonesis, or excessive distance between the lens and the pupillary margin indicates zonular disruption due to conditions such as lens subluxation as a result of previous trauma, metabolic disorders, or hypermature cataract. An indentation or flattening of the lens periphery may indicate focal loss of zonular support. For patients with these types of zonular disruption, the surgeon can alter surgical technique, for example, by using capsular tension rings or other capsular or iris support devices intraoperatively (see Chapter 12).

Cataract Grading and Classification

Several systems have been proposed for grading cataract severity. The Lens Opacities Classification System III (LOCS III), which is widely used today, consists of 6 slit-lamp reference photographs used for evaluating nuclear coloration and opalescence, 5 comparison retroillumination images used for grading cortical cataract, and 5 reference retroillumination photos used for evaluating PSC. A recent review suggests that although LOCS III is often used in research and clinical practice, it likely has little impact on the decision of when to perform cataract surgery. New systems that incorporate lens density measurements taken from anterior segment optical coherence tomography (OCT) and fundus photography and that utilize machine learning and artificial intelligence may enable researchers and clinicians to better evaluate and communicate lens pathology in a standardized and objective way. See Figure 6-1 for the LOCS III grading of cataract.

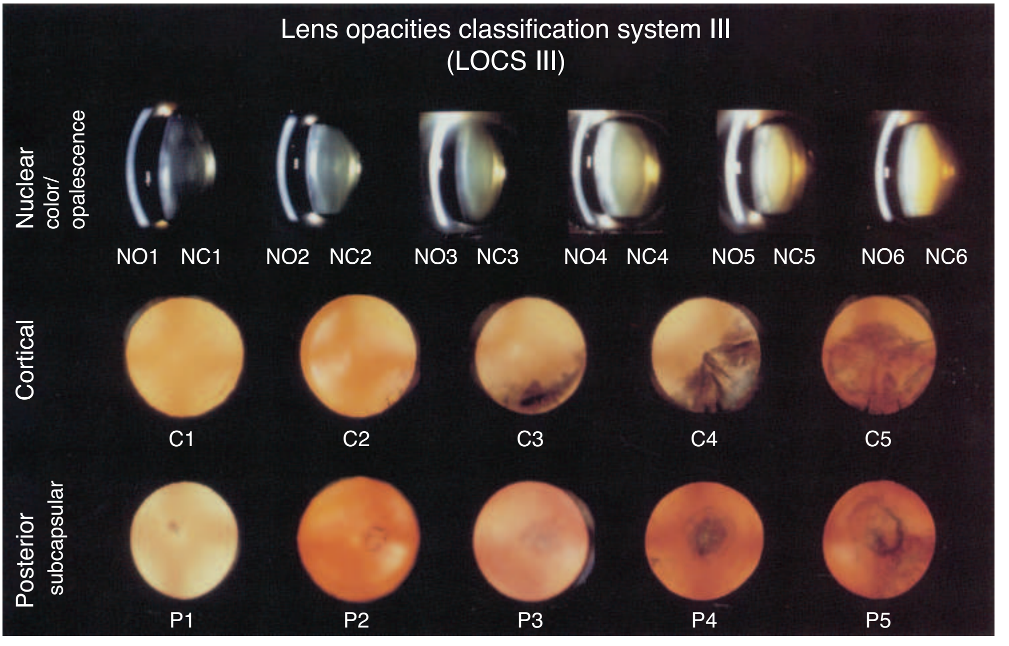


Figure 6-1 Lens Opacities Classification System III (LOCS III) for standardized grading of cataract. The image above is not suitable for use as the LOCS III standard image for in vivo human cataract classification; the actual standard LOCS III transparency on an appropriate light source must be used for this purpose. In addition, the image is copyrighted nationally and internationally and may not be reproduced in any form. ©Chylack Inc. www.chylackinc.com

Chylack LT Jr, Wolfe JK, Singer DM, et al. The Lens Opacities Classification System III. The Longitudinal Study of Cataract Study Group. *Arch Ophthalmol.* 1993;111(6):831–836.

Gali HE, Sella R, Afshari NA. Cataract grading systems: a review of past and present. *Curr Opin Ophthalmol.* 2019;30(1):13–18.

Limitations of Slit-Lamp Examination

Some visually significant cataracts may appear minimal on slit-lamp biomicroscopy. However, examination of the lens with the retinoscope may clarify the lenticular contribution to the patient's vision changes. By examining the retinoscopic reflex, the clinician may detect posterior subcapsular opacities, refractile nuclear changes, or even diffuse cataracts. Similarly, examination using the direct ophthalmoscope through a +10.00 diopter (D) lens at a distance of 2 feet will enhance the portions of the cataractous lens that are producing optical aberrations. This technique is particularly useful for identifying oil-droplet cataracts.

Fundus Evaluation

Ophthalmoscopy

The ophthalmologist must perform a full fundus examination to evaluate the macula, optic nerve, vitreous, retinal vessels, and retinal periphery. Macular degeneration or other maculopathy may limit visual outcome after an otherwise successful cataract extraction. The indirect ophthalmoscope is not generally useful for judging the visual significance of cataract, except in severe cases such as when the cataract is white. Direct ophthalmoscopy can help confirm lenticular opacity in eyes in which a clear view to the fundus is not possible.

Patients with diabetes mellitus are examined carefully for the presence of macular edema, retinal ischemia, and diabetic retinopathy prior to cataract surgery, but even in patients with minimal or no retinopathy, diabetic eye disease can progress postoperatively. Retinal ischemia may potentiate posterior or anterior neovascularization postoperatively, especially if the surgeon uses an intracapsular technique or ruptures the posterior capsule during extracapsular cataract extraction. Careful examination of the retinal periphery may reveal the presence of vitreoretinal traction or preexisting retinal holes and lattice degeneration that may warrant preoperative treatment.

Jeng CJ, Hsieh YT, Yang CM, Yang CH, Lin CL, Wang IJ. Development of diabetic retinopathy after cataract surgery. *PLoS One.* 2018;13(8):e0202347. doi:10.1371/journal.pone.0202347

Optic Nerve

Examination of the optic nerve includes assessment of cupping and pallor, as well as any other abnormalities. Visual acuity, measurement of IOP, and the results of confrontation testing and the pupillary examination will help determine whether other adjunctive testing is warranted.

Fundus Evaluation With Opaque Media

B-scan ultrasonography of the posterior segment of the eye is useful whenever a dense cataract makes visualization of the retina difficult. Ultrasonography can elucidate whether a retinal detachment, vitreous opacity, posterior pole tumor, or staphyloma is present. Tests such as light projection, 2-point discrimination, gross color vision, photostress recovery, and the Maddox rod test may be useful in detecting retinal pathology. Electroretinography and visual evoked response may also be considered when other modalities are inconclusive and the surgeon must decide whether cataract removal would provide any benefit.

See BCSC Section 12, *Retina and Vitreous,* for discussion of electroretinography, and Section 5, *Neuro-Ophthalmology,* and Section 3, *Clinical Optics and Vision Rehabilitation,* for discussion of electroretinography and the Maddox rod test.

Special Tests

Potential Acuity Estimation

Potential acuity estimation can be helpful in assessing lenticular contribution to vision loss. The potential acuity pinhole test is a simple but accurate method of evaluation for patients who do not have other ocular pathology and whose visual acuity is better than 20/200. For this test, the patient is asked to read a brightly illuminated near card through a pinhole aperture. The Retinal Acuity Meter, or RAM (AMA Optics), functions in a similar manner.

The potential acuity meter, or PAM, is one of several instruments that projects a numerical or Snellen vision chart through a small entrance pupil. The image is projected onto the retina, around lenticular opacities, allowing for an estimate of what the BCVA would be if the media abnormality were absent.

It is important to note that these tests can be misleading in patients with certain disorders, including age-related macular degeneration, amblyopia, macular edema, glaucoma, small macular scars, and serous retinal detachment. An accurate clinical examination of the eye is often the best predictor of visual outcome.

Visual Field Testing

It is important to perform confrontation field testing in all cataract patients, but formal visual field testing is not indicated for every patient with lens opacity. Visual field testing may help the ophthalmologist identify vision loss resulting from disease processes other than cataract. Patients with a history of glaucoma, optic nerve disease, retinal abnormality, or stroke may benefit from visual field evaluation to document the degree of visual field loss. Because the visual field may have decreased sensitivity due to the cataractous media opacity, preoperative visual field loss does not preclude improvement in visual function following cataract.

Corneal Evaluation

In patients with a history of endothelial dystrophy, previous ocular surgery, or trauma, additional corneal measurements may be useful. These data may aid the surgeon in counseling the patient regarding the possibility of postoperative corneal decompensation. In some cases, consideration of a combined procedure incorporating removal of the cataract and transplantation of corneal tissue may be in order.

Corneal pachymetry, a method employed to measure corneal thickness, is useful for indirectly assessing the function of the endothelium. Significantly increased central corneal thickness (>640 μm) in patients with endothelial dysfunction is associated with a greater risk of postoperative corneal decompensation.

Specular microscopy is used to determine corneal endothelial cell density per square millimeter and evaluate these cells' regularity. Because cataract surgery results in some loss of endothelial cells, the risk of postoperative corneal decompensation is increased if the preoperative endothelial cell count is low. Abnormal endothelial cell morphology, including enlargement (polymegathism) and irregularity (pleomorphism), may limit the cornea's ability to maintain its clarity after the stress of cataract surgery. (See also BCSC Section 8, *External Disease and Cornea.*)

Topography and/or *tomography* can be helpful in patients who have undergone prior refractive surgery, have high astigmatism, or who are planning for multifocal IOL implantation. Topography can assist with surgical planning of astigmatism correction as well as identifying conditions such as keratoconus that may affect the postoperative outcome.

Objective Tests of Macular Function

OCT is increasingly performed as part of the preoperative testing regimen for cataract surgery in the United States. It may be useful in the assessment or detection of macular pathology, including choroidal neovascularization, edema, holes, and traction. Screening macular OCT to detect occult macular pathology may be of particular benefit for patients undergoing surgery with premium IOLs or when their vision is poorer than the degree of cataract would suggest. Fluorescein angiography can be used to assess vascular and exudative abnormalities.

CHAPTER 7

Preoperative Considerations for Cataract Surgery and Improving Refractive Outcomes

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This chapter includes case studies. Go to aao.org/bcsccasestudy_section11 or scan the QR codes in the text to access this content.

Highlights

- Modern intraocular lenses (IOLs) are typically made of either acrylic or silicone, are foldable and injectable, and have a biconvex aspheric optic with a square posterior edge.
- IOL-based strategies for correcting presbyopia include pseudophakic monovision, multifocal IOLs, extended depth of focus IOLs, and accommodating IOLs. Toric platforms of presbyopia-correcting IOLs are available.
- Approximately 40% of cataract surgery patients have 1.00 diopter (D) or more of preoperative keratometric astigmatism. Over 85% of adults have posterior corneal astigmatism that introduces against-the-rule corneal astigmatism.
- Modern IOL power formulas incorporate advanced optics, artificial intelligence, and/or ray tracing to improve accuracy. These formulas, along with improvements in optical biometers and the ability to measure posterior corneal curvature, allow surgeons to target refractive results more effectively through cataract surgery.

Intraocular Lens Technology

In addition to removing a cloudy lens, today's cataract surgeons can effectively correct refractive error and in some cases provide presbyopia correction with image clarity at multiple foci (distance, intermediate, and/or near). Improvements in preoperative biometry, surgical techniques and instrumentation, IOL technology and power calculations, and postoperative enhancement options have all yielded more accurate refractive outcomes following cataract surgery. Successful refractive cataract surgery requires informed discussion of lens options with the patient to determine what lens technology and refractive target would be most appropriate to achieve their goals. However, the surgeon is also responsible for identifying and discussing any ocular comorbidities that may limit lens selection, such as the need to consider zonular instability for a lens that requires careful alignment or centration for proper effect (Case Study 7-1).

CASE STUDY 7-1 Refractive target selection.
Courtesy of Karen Christopher, MD.
Available at: aao.org/bcsccasestudy_section11

IOLs have undergone remarkable development in the decades since their introduction. For a discussion of the history of IOL design and development, see the Introduction in this volume. For additional detailed clinical discussion of IOLs and surgical presbyopia correction, see BCSC Section 3, *Clinical Optics and Vision Rehabilitation*, and Section 13, *Refractive Surgery*. For a discussion of cataract surgery and IOL selection in pediatric cases, see BCSC Section 6, *Pediatric Ophthalmology and Strabismus*.

Intraocular Lens Characteristics

Modern posterior chamber IOLs (PCIOLs) typically have the characteristics presented in Table 7-1. Foldable IOLs allow for a smaller incision size, which minimizes surgically induced corneal astigmatism and decreases postoperative wound complications. Injectable IOLs (either manually loaded into the injector cartridge or preloaded by the manufacturer) reduce IOL exposure to possible ocular surface contamination. Both silicone (which is hydrophobic) and acrylic (which can be either hydrophobic or hydrophilic) IOLs are suitable for most patients.

Because silicone oil can adhere to the surface of a silicone IOL (Fig 7-1), the surgeon may prefer to use an IOL made of other material in patients who will likely later require vitrectomy with silicone oil injection (eg, those with proliferative diabetic retinopathy or retinal detachment in the fellow eye). In addition, postoperative optic calcification of hydrophilic acrylic IOLs has been associated with exposure to air or gas. In patients who will be undergoing future intraocular surgeries that require the intraoperative use of gas (eg,

Table 7-1 Modern IOL Characteristics

Characteristic	Benefit
Foldable	Allows for a smaller incision
Injectable	Minimizes IOL exposure to ocular surface contamination
Aspheric optic	Improves contrast sensitivity by minimizing spherical aberration
Square posterior optic edge	Minimizes PCO
Biconvex optic	Allows for a thinner optic (and a smaller incision)
Acrylic or silicone material	Higher index of refraction allows for thinner optic

IOL = intraocular lens; PCO = posterior capsule opacification

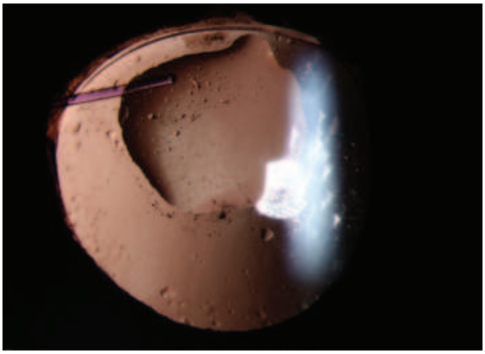


Figure 7-1 A large silicone oil droplet is adherent to the posterior surface of this 3-piece silicone intraocular lens (IOL). *(Courtesy of Christopher Kirkpatrick, MD, and Anna Kitzmann, MD. Photographer: Toni Venckus, CRA. Available at https://webeye.ophth.uiowa.edu/eyeforum/atlas/pages/silicone-oil-drop-IOL.htm)*

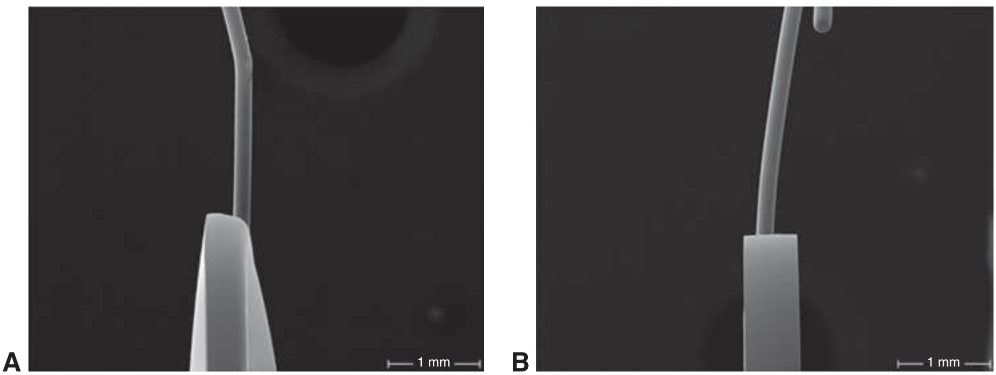


Figure 7-2 IOL design. **A,** An IOL with a round anterior optic edge and a square posterior optic edge. **B,** An IOL with square anterior and posterior optic edges. *(Reproduced with permission from Werner L. Intraocular lenses: overview of designs, materials, and pathophysiologic features.* Ophthalmology. *2021;128(11):e74–e93.)*

endothelial keratoplasty, vitrectomy), considering a different material may be advisable. Nd:YAG laser capsulotomy is not effective in treating this opacification, which may require IOL explantation.

IOL optic geometry has evolved from earlier plano-convex models to newer biconvex designs. The addition of a square posterior optic edge has reduced posterior capsule opacification (PCO) by blocking cell migration behind the optic (Fig 7-2). For more discussion of IOL design and PCO, including photos and illustrations, see BCSC Section 3, *Clinical Optics and Vision Rehabilitation.*

Most corneas have some degree of positive spherical aberration. Older IOL designs were spherical, which added positive spherical aberration to the eye's optical system and so decreased contrast sensitivity. Newer IOLs are aspheric, with zero or varying degrees of negative spherical aberration (ranging from 0 to –0.27 µm) to offset any positive spherical aberration of the cornea and thus improve contrast sensitivity. Note that corneas with prior *hyperopic* laser in situ keratomileusis (H-LASIK) or photorefractive keratectomy (PRK) treatments often have *negative* spherical aberration, and that surgeons should consider IOLs with zero spherical aberration for these eyes so as to not worsen the existing negative spherical aberration. In any eye, a decentered IOL that has any positive or negative spherical aberration will induce coma (see BCSC Section 3, *Clinical Optics and Vision Rehabilitation* for additional discussion on coma and other types of aberration).

Almost all modern IOLs also incorporate UV-absorbing chromophores into their material to protect the retina from UV radiation. Some IOLs also incorporate blue-light filtering to attenuate blue-wavelength light (the optic of these IOLs therefore appears yellow to the surgeon). Proponents of these "blue-blocking" IOLs contend that they protect the macula and decrease the risk of age-related macular degeneration. Others claim, however, that there is no evidence of benefit from blue-blocking IOLs. In addition, they are concerned that these lenses might create problems with circadian rhythms or with mesopic or scotopic vision, although there is no definitive evidence of such problems.

Presbyopia- and astigmatism-correcting IOLs have been developed to reduce a patient's dependence on eyeglasses after cataract surgery. The specialized IOL designs include multifocal, extended depth of focus, accommodating, and toric IOLs, which are discussed later in this chapter. There is a trend toward increased usage of these specialty lenses. These lenses, as well as phakic IOLs, are also discussed in BCSC Section 13, *Refractive Surgery*.

Downie LE, Busija L, Keller PR. Blue-light filtering intraocular lenses (IOLs) for protecting macular health. *Cochrane Database Syst Rev.* 2018;5(5).

Srinivasan S. Intraocular lens opacification: What have we learned so far. *J Cataract Refract Surg.* 2018;44(11):1301–1302.

IOL Classifications

Monofocal IOLs

A monofocal IOL is designed to give crisp vision in one focal plane. Many patients who undergo cataract surgery have both eyes targeted for emmetropia with monofocal IOLs and rely on eyeglasses for their intermediate- and near-vision tasks. Alternatively, most often in patients who are nearsighted before cataract surgery or prefer to perform near tasks without eyeglasses, a monofocal lens targeted for myopia can be placed in both eyes. These patients will rely on eyeglass correction for distance vision. Myopic targets often vary between −1.50 D and −3.00 D and are chosen based on the visual needs of the particular patient.

Pseudophakic monovision is a surgical presbyopia-correcting technique in which different refractive targets are set for each eye to provide a broader range of vision and minimize the need for eyeglass correction. Typically, the dominant eye is targeted for emmetropia. The fellow eye is targeted for some degree of myopia. The term *modified monovision* (or *minimonovision*) refers to a milder myopic target (eg, −0.50 to −1.50 D), compared with "traditional" monovision (−1.50 to −2.50 D).

Hayashi K, Ogawa S, Manabe S, Yoshimura K. Binocular visual function of modified pseudophakic monovision. *Am J Ophthalmol.* 2015;159(2):232–240.

Multifocal IOLs

Multifocal IOLs (MFIOLs) achieve both distance and intermediate/near vision by dividing light into 2 or more focal points (Fig 7-3). This is achieved by either refractive or

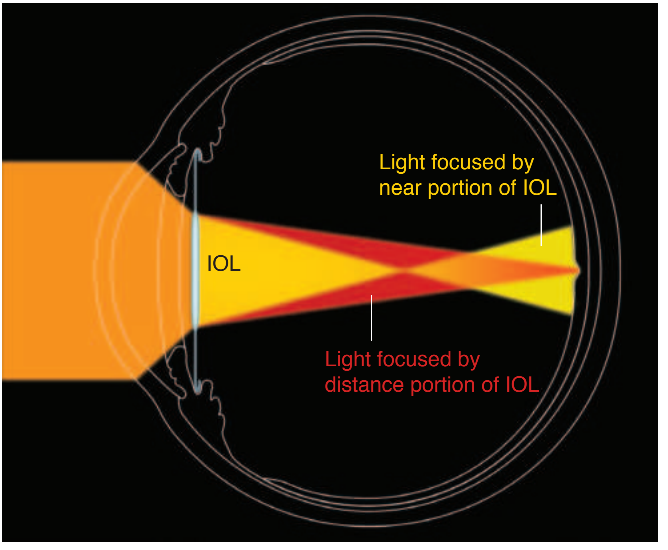


Figure 7-3 Diffractive optics of a multifocal (bifocal) IOL. Note the unfocused light rays hitting the retina, which can contribute to dysphotopsias. *(Illustration by Mark Miller.)*

Figure 7-4 A multifocal IOL. *(Illustration by Mark Miller.)*

diffractive optics, or a combination of them. Several multifocal lenses (including toric MFIOLs and a trifocal IOL) have been approved by the US Food and Drug Administration (FDA) for use in the United States (Fig 7-4). Some models are available in various power adds.

The advantage of MFIOLs is reduced dependence on eyeglasses. Disadvantages include reduction in contrast sensitivity (which patients may perceive as dimmer vision), the presence of glare and halos (particularly in mesopic or scotopic conditions), and the presence of multiple images. Lower-add MFIOLs (ie, with their "near" focal point farther from the eye) may reduce some of these symptoms compared to higher-add MFIOLs.

Clinical Pearl Patients with preoperative hyperopia may be less bothered by some of the visual aberrations associated with MFIOLs than patients with preoperative myopia. The cataract surgeon should counsel patients receiving MFIOLs about the intended postoperative visual outcome and limitations; a specialized consent process can be used.

MFIOLs are most suitable for use in patients with excellent ocular health; they can cause reduced quality of vision and unsatisfactory outcomes in patients with ocular pathology, such as amblyopia or diseases of the cornea (eg, dry eye), optic nerve (eg, glaucoma), or macula (eg, epiretinal membrane, macular degeneration). Many surgeons obtain macular optical coherence tomography (OCT) preoperatively to evaluate for subtle macular disease. MFIOLs work best when implanted bilaterally and when minimal postoperative astigmatism can be achieved. Options for patients unhappy with their uncorrected visual outcome due to residual postoperative refractive error include eyeglass or contact lens correction, keratorefractive surgery, or IOL exchange, preferably performed before capsular fibrosis increases the difficulty of explantation.

Schallhorn JM, Pantanelli SM, Lin CC, et al. Multifocal and accommodating intraocular lenses for the treatment of presbyopia: a report by the American Academy of Ophthalmology. *Ophthalmology*. 2021;128(10):1469–1482.

Extended Depth of Focus IOLs

Extended depth of focus (EDOF) IOLs are a class of presbyopia-correcting IOLs that can have various potential mechanisms of action. The FDA has approved EDOF IOLs as well as their corresponding toric versions for use in the United States; there is also an approved monofocal lens that extends the depth of focus, although to a lesser extent than the traditional EDOF lenses (Table 7-2).

Instead of 2 distinct focal points, the EDOF IOLs use either diffractive or non-diffractive optics to create an elongated focal range (Figs 7-5, 7-6). These lenses provide a range of vision from distance through intermediate, with a low level of dysphotopsias such as glare and halos.

Clinical Pearl Some surgeons employ mini-monovision with EDOF IOLs, setting the nondominant eye for mild residual myopia (eg, –0.50 D) and the dominant eye for emmetropia. These adjustments can enable the EDOF IOL to provide better near vision in the nondominant eye.

Table 7-2 Examples of Presbyopia-Correcting Intraocular Lenses Available in the United States

Multifocal (Bifocal or Trifocal)	Extended Depth of Focus	Accommodating
PanOptix Trifocal (Alcon Laboratories) ReSTOR (Alcon Laboratories) Synergy (Johnson & Johnson Vision) TECNIS Multifocal (Johnson & Johnson Vision)	Eyehance (Johnson & Johnson Vision)[a] RayOne EMV (Rayner)[a] Symfony (Johnson & Johnson Vision) Vivity (Alcon Laboratories)	Crystalens AO (Bausch + Lomb)

[a] Has extended depth of focus (EDOF) properties but does not meet FDA criteria for EDOF.

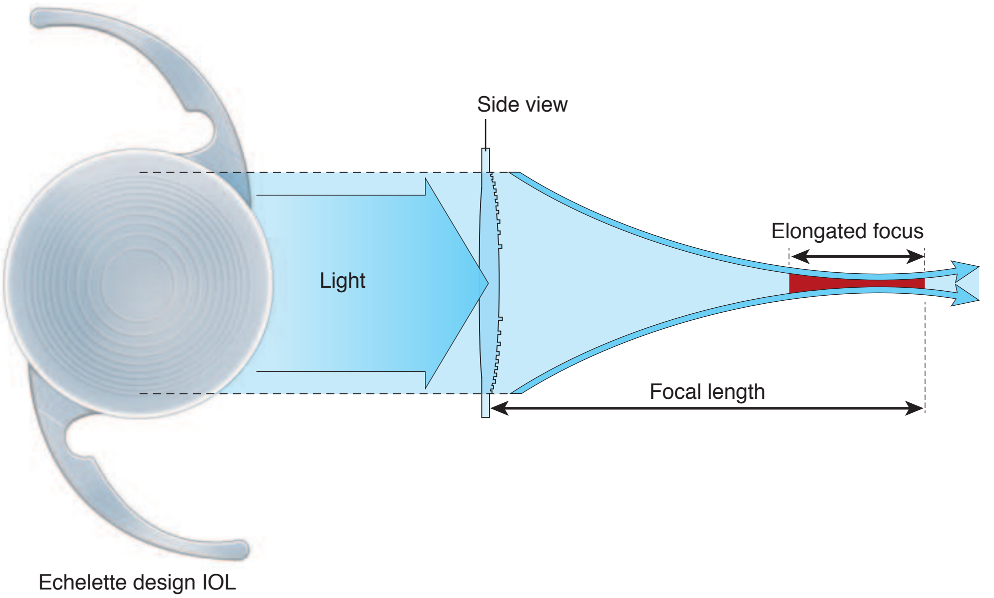


Figure 7-5 An extended depth of focus (EDOF) IOL. *(Illustration by Mark Miller.)*

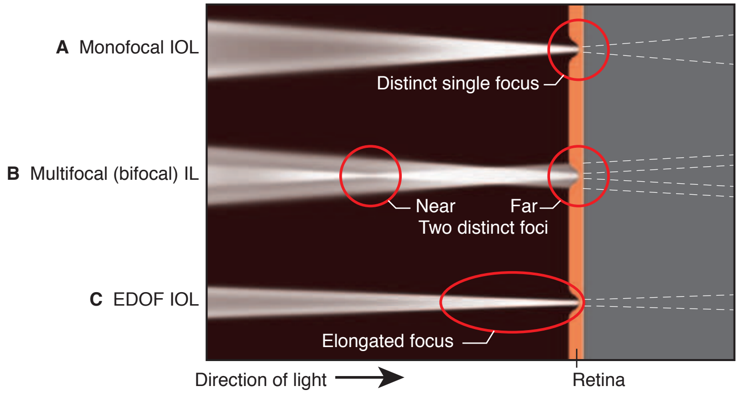


Figure 7-6 Comparison of focal points. **A,** Monofocal IOL. **B,** Multifocal (bifocal) IOL. **C,** EDOF IOL. *(Illustration by Mark Miller.)*

The advantages and disadvantages of EDOF IOLs are similar to those of MFIOLs (discussed in the previous section), including some loss of contrast sensitivity. As with MFIOLs, patient selection and counseling are critically important. (See the section Patient Preparation and Informed Consent later in this chapter for more on this subject.)

Cochener B; Concerto Study Group. Clinical outcomes of a new extended range of vision intraocular lens: International Multicenter Concerto Study. *J Cataract Refract Surg.* 2016;42(9):1268–1275.

Accommodating IOLs

The accommodating IOL was designed to improve distance, intermediate, and near acuity via the movement of its hinged haptics during the accommodative process. Currently, one accommodating IOL design (and a similar toric accommodating IOL) has been approved for use by the FDA. The accommodating IOL provides some degree of improved intermediate vision. A possible mechanism of action for this improvement is that this IOL provides some pseudoaccommodative depth of focus, because there is no clear clinical evidence that these "accommodating" IOLs change axial position in the eye during near-vision tasks.

Dhital A, Spalton DJ, Gala KB. Comparison of near vision, intraocular lens movement, and depth of focus with accommodating and monofocal intraocular lenses. *J Cataract Refract Surg.* 2013;39(12):1872–1878.

Other Presbyopia-Correcting IOLs

There are other presbyopia-correcting IOLs either available outside the United States or in development. These include EDOF IOLs with different mechanisms of action (eg, the pinhole effect) and fluid-filled accommodating lenses that rely on ciliary muscle contraction to change shape and refractive power.

Dick HB, Gerste RD. Future intraocular lens technologies. *Ophthalmology*. 2021;128(11): e206–e213.

IOLs Capable of Postoperative Adjustment

The light-adjustable IOL, which was approved by the FDA in 2017, allows surgeons to adjust its power after implantation. The IOL is irradiated with targeted UV light to induce a change in lens shape that alters its refractive power, allowing for both spherical and cylindrical refractive errors to be corrected postoperatively.

Refractive index shaping, a technique that uses a specialized femtosecond laser to affect the hydrophilicity of an IOL, causing changes in the refractive index, is an additional technology under development. See BCSC Section 13, *Refractive Surgery,* for further discussion of these lens technologies.

Sahler R, Bille JF, Enright S, Chhoeung S, Chan K. Creation of a refractive lens within an existing intraocular lens using a femtosecond laser. *J Cataract Refract Surg*. 2016;42(8): 1207–1215.

Modification of Preexisting Astigmatism

Residual astigmatism after cataract surgery can affect visual function and patient satisfaction. Approximately 40% of cataract patients have 1.00 D or more of preoperative keratometric astigmatism. Residual astigmatism as low as 0.5 D can reduce distance visual acuity in patients following multifocal IOL implantation. Therefore, the correction of regular astigmatism during cataract surgery has become increasingly important for both patients and surgeons. For additional detailed discussions of astigmatism management, see BCSC Section 3, *Clinical Optics and Vision Rehabilitation*, and Section 13, *Refractive Surgery*.

Refractive astigmatism (eg, as found by manifest refraction) is a combination of total corneal astigmatism and lenticular astigmatism. Lenticular astigmatism, which is contributed by the cataract, is eliminated during cataract surgery. Thus, to correct astigmatism, the cataract surgeon needs to address the total corneal astigmatism.

Total corneal astigmatism comprises the sum of anterior and posterior corneal astigmatism. Anterior corneal astigmatism tends to drift from with-the-rule (steeper vertical meridian) toward against-the-rule (steeper horizontal median) with increasing age. In contrast, posterior corneal astigmatism does not tend to change with age. In over 85% of adults, the posterior cornea is steeper in the vertical meridian. Because the posterior cornea is a minus lens, this creates net plus refractive power horizontally, adding against-the-rule astigmatism to the total corneal astigmatism. The average magnitude of posterior corneal astigmatism is approximately 0.30–0.50 D, but there is considerable variation in the general population. Therefore, anterior corneal measurements alone will often overestimate with-the-rule astigmatism and underestimate against-the-rule astigmatism, due to the unmeasured against-the-rule effect of the posterior cornea.

Anterior corneal astigmatism can be accurately measured by a variety of methods, including keratometry (manual or automated), topography, Scheimpflug imaging, and OCT. Keratometry is best combined with other imaging methods, because irregular corneal astigmatism or ectatic disease may not be apparent without the use of topography and/or tomography. Although accurately measuring posterior corneal astigmatism is difficult, Scheimpflug imaging, OCT, and light-emitting diode (LED)-based devices can be used. (See BCSC Section 3, *Clinical Optics and Vision Rehabilitation,* for further discussion of optical instruments.)

When planning surgical astigmatism correction, there are 2 techniques to incorporate posterior corneal astigmatism into the calculations: formulas that use *anterior* corneal astigmatism and then predict *posterior* corneal astigmatism based on modeling, or direct measurement of the posterior corneal astigmatism. Inputting measured posterior corneal astigmatism into toric calculators such as the Barrett toric calculator has been shown to improve accuracy. However, research into the clinical significance of this as well as the optimization of toric calculators is warranted.

Modification of corneal astigmatism can be performed via astigmatic keratotomy, limbal relaxing incisions, toric IOL implantation, or postoperative laser vision correction. Surgical planning requires consideration of these techniques and discussion with the patient whether they would benefit from astigmatic correction and, if so, which technique would provide the optimal outcome (Table 7-3). Although they were previously used as a technique for correcting several diopters of astigmatism, corneal relaxing incisions are now most commonly used for treating lower amounts of astigmatism, and toric IOLs are used instead for treating higher amounts of astigmatism.

Acknowledgment of surgically induced astigmatism (SIA) of the corneal incision(s) used during cataract surgery is also important. A centroid value (ie, vectorial average) for SIA can be input into any available online toric calculator. A 2.4-mm temporal clear corneal incision has been shown to have a centroid value of approximately 0.10 D of flattening in the incision meridian, though the actual magnitude and meridian of SIA in any individual case can vary dramatically. Alternatively, surgeons may choose to use their personally calculated centroid SIA value based on a series of prior cases. If a larger incision is required,

Table 7-3 Corneal Relaxing Incisions Versus Toric IOL Implantation for Astigmatism Correction

Corneal Relaxing Incisions	Toric IOL Implantation
Advantages: • can be performed before, during, or after cataract surgery • manual or femtosecond laser techniques available • may be modifiable (opened later) to titrate undercorrection • can be used in cases where toric placement may be difficult Disadvantages: • reduced reproducibility/accuracy of results due to varying corneal response, especially for high amounts of astigmatism • risk of corneal neuropathy, especially with larger treatments • risk of creating irregular corneal astigmatism • risk of wound gape, ectasia, long-term instability • learning curve required to generate reproducible results	Advantages: • easily corrects higher levels of astigmatism, typically preferred for magnitudes >~1.00 D • minimal additional surgical technique required beyond standard IOL placement Disadvantages: • cost • risk of IOL rotation necessitating additional surgery to correct • over- or undercorrection possible based on IOL power prediction formulas

placing it at the steeper meridian may reduce postoperative astigmatism. Subtle changes in effect may be induced by adjusting the incision location.

Abulafia A, Koch DD, Holladay JT, Wang L, Hill W. Pursuing perfection in intraocular lens calculations: IV. Rethinking astigmatism analysis for intraocular lens-based surgery: suggested terminology, analysis, and standards for outcome reports. *J Cataract Refract Surg.* 2018;44(10):1169–1174.

Hayashi K, Manabe S, Hirata A, Yoshimura K. Changes in corneal astigmatism during 20 years after cataract surgery. *J Cataract Refract Surg.* 2017;43(5):615–621.

Koch DD, Ali SF, Weikert MP, Shirayama M, Jenkins R, Wang L. Contribution of posterior corneal astigmatism to total corneal astigmatism. *J Cataract Refract Surg.* 2012;38(12): 2080–2087.

Wang L, Koch DD. Comparison of accuracy of a toric calculator with predicted vs measured posterior corneal astigmatism. *J Cataract Refract Surg.* 2023;49(1):29–33.

Corneal Relaxing Incisions

Modern corneal relaxing incisions include the use of both astigmatic (or arcuate) keratotomies and limbal relaxing incisions (Fig 7-7). Both of these techniques employ partial-thickness arcuate incisions to reduce regular corneal astigmatism without altering the spherical equivalent power of the cornea. These incisions decrease the curvature of the incised steep meridian and increase the curvature 90° away (a phenomenon known as *coupling*). See Section 13, *Refractive Surgery*, for additional information and video examples.

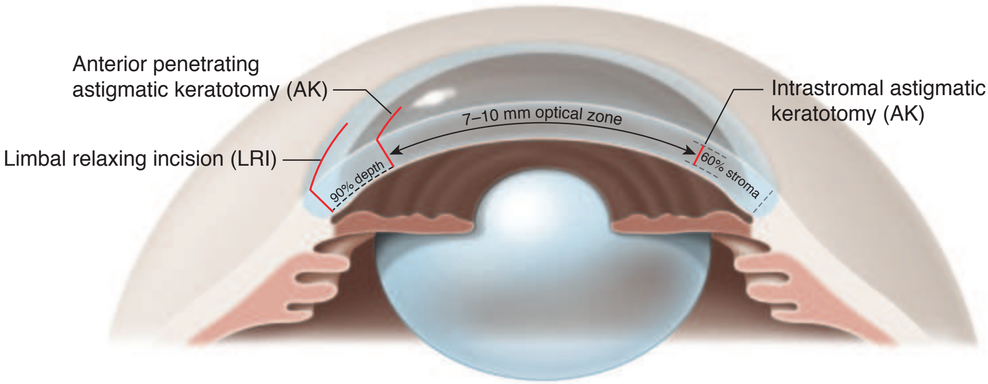


Figure 7-7 Corneal relaxing incisions: limbal relaxing incision, anterior penetrating astigmatic keratotomy, and intrastromal astigmatic keratotomy. *(Illustration by Mark Miller.)*

Astigmatic (arcuate) keratotomy

Astigmatic (or arcuate) keratotomies (AKs) can be single or paired. They are placed centered on the corneal steep meridian, typically in the 7–10-mm optical zone. Placing them too close to the visual axis may result in problematic glare and irregular astigmatism.

AKs can be performed with a surgical blade or with a femtosecond laser platform. Femtosecond lasers can create AKs of a specified arc length, optical zone, and depth. Laser-created AKs that are placed to penetrate anteriorly can be manually opened later, if necessary, to "titrate" the astigmatic effect. Alternatively, the laser can also create intrastromal AKs (ie, AKs that do not penetrate the epithelial surface). Nomograms for both intrastromal and anterior-penetrating AKs have been created; existing nomograms have also been modified for use with the femtosecond laser.

Day AC, Lau NM, Stevens JD. Nonpenetrating femtosecond laser intrastromal astigmatic keratotomy in eyes having cataract surgery. *J Cataract Refract Surg*. 2016;42(1):102–109.

Roberts HW, Wagh VK, Sullivan DL, Archer TJ, O'Brart DPS. Refractive outcomes after limbal relaxing incisions or femtosecond laser arcuate keratotomy to manage corneal astigmatism at the time of cataract surgery. *J Cataract Refract Surg*. 2018;44(8):955–963.

Limbal relaxing incisions

Limbal relaxing incisions (LRIs) can be single or paired and are placed in the peripheral cornea near the limbus. LRIs are more peripheral than AKs, reducing the risk of glare or irregular astigmatism. However, because of their peripheral location, LRIs need to be longer than AKs for the same astigmatic effect.

These incisions are often performed with a diamond blade. Some surgeons place the cataract incision within one of the paired LRIs; others prefer to use a separate location. LRIs may also be done postoperatively in an office setting. Various LRI nomograms have been published, including the Donnenfeld and Nichamin nomograms, which are available online (www.LRIcalculator.com).

Toric IOLs

Toric IOLs are designed to correct regular corneal astigmatism. In the United States, toric IOLs are available in optical powers that can correct from approximately 1.00 D to 4.00 D of corneal astigmatism. Accommodative IOLs, MFIOLs, and EDOF IOLs all also have toric versions.

As will be discussed in this chapter, careful preoperative measurements and calculation of total corneal astigmatism using a modern toric calculator are essential to account for the posterior corneal effect. The orientation and magnitude of astigmatism measurements from optical biometry should be confirmed with corneal topography and/or tomography. These studies are also needed to rule out patients who may not be good candidates for corneal relaxing incisions or toric IOLs (eg, those with irregular astigmatism or corneal ectasia). Typically, the toric lens that will best reduce the measured amount of astigmatism is chosen for implantation (Case Study 7-2).

CASE STUDY 7-2 Toric lens selection.
Courtesy of Karen Christopher, MD.
Available at: aao.org/bcsccasestudy_section11

To properly implant a toric lens, the surgeon aligns the IOL with the desired axis of astigmatism correction. Various techniques can be used to mark the desired axis: While the patient is in the upright position preoperatively, the surgeon can make horizontal and/or vertical reference marks on the cornea that can be used intraoperatively to mark the calculated axis, or they may mark exactly the intended axis of implantation using the slit lamp. Doing this while the patient is upright avoids misalignment errors from any eye cyclotorsion that may occur when the patient is supine. Various marking devices, smartphone apps, and intraoperative alignment systems are also available to assist in proper IOL alignment. The toric IOL is inserted into the capsular bag and rotated so that the IOL axis markings align with the calculated steep corneal meridian (Video 7-1; Fig 7-8).

VIDEO 7-1 Toric IOL implantation and positioning.
Courtesy of Cynthia S. Chiu, MD.
Available at: aao.org/bcscvideo_section11

Unintentional postoperative rotation of the toric IOL can lead to suboptimal correction or even worsening of astigmatism. Each degree of toric IOL rotation away from the optimal meridian reduces the astigmatism correction by 3.3%. Misalignments greater than 30° will therefore increase the astigmatic refractive error. If necessary, a second procedure to rotate the toric IOL to the correct meridian can be considered relatively early in the postoperative period, before capsular fibrosis and tenacious capsular adherence to the IOL occur.

Several factors have been implicated in case reports of postoperative toric IOL rotation (Table 7-4). Longer axial length and larger capsular bag size likely increase the risk of postoperative rotation. In addition, the lower-spherical-power IOLs needed for these myopic patients have thinner optics, which may take up less space in the capsular bag. Alignment of the toric IOL to correct with-the-rule corneal astigmatism may also increase the risk of postoperative rotation.

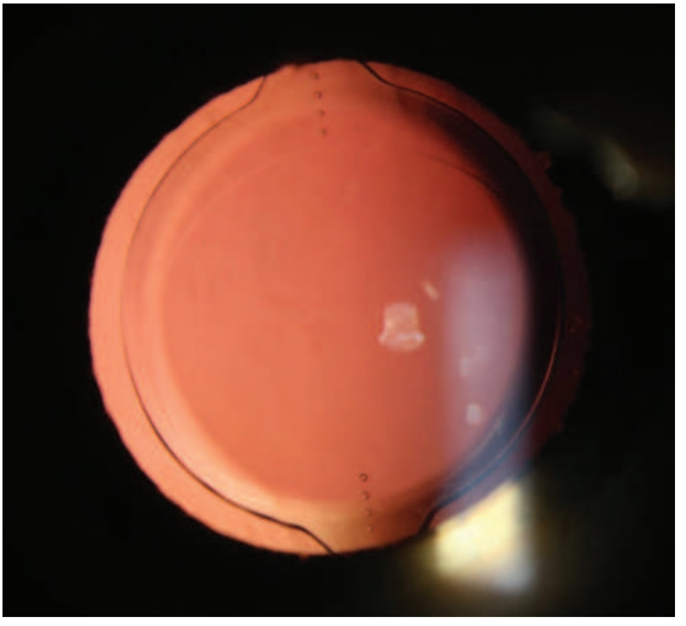


Figure 7-8 A toric IOL in vivo. The axis markings on the IOL are aligned with the calculated steep corneal meridian. *(Courtesy of Aaron Bronner, OD.)*

Table 7-4 Possible Risk Factors for Postoperative Toric IOL Rotation

Anatomical	Intraoperative	Postoperative
Long axial length	OVD retained behind the IOL	Incision leakage
High myopia	Incomplete overlap of anterior capsular rim and IOL optic	Ocular trauma
Large capsular bag	Polishing the anterior capsule	Vigorous physical activity
With-the-rule corneal astigmatism	Low spherical IOL power (ie, thin IOL optic)	

OVD = ophthalmic viscosurgical device.

Intraoperatively, complete overlap of the anterior capsular rim with the toric IOL optic is desirable; some surgeons avoid polishing the anterior capsule in toric IOL cases to promote adherence between the anterior capsule and the IOL. Complete removal of the ophthalmic viscosurgical device (covered in the section Ophthalmic Viscosurgical Devices), including from behind the IOL, may also help minimize the risk of postoperative toric IOL rotation.

Postoperative incision leakage, trauma, or vigorous physical activity may also contribute to IOL rotation. Insertion of a capsular tension ring into the capsular bag may decrease the risk of postoperative IOL rotation, especially in high-risk cases. Despite any of these anecdotal prophylactic measures, postoperative toric IOL rotation may still occur.

Tilting of both toric and nontoric IOLs can contribute to postoperative astigmatic error. For example, horizontal tilting of an IOL around the vertical meridian (with the nasal IOL border tilted anteriorly and the temporal IOL border tilted posteriorly) will induce against-the-rule astigmatism. Larger amounts of tilt and higher IOL powers will lead to greater induced astigmatism.

Intraoperative wavefront aberrometry may assist in more accurate toric IOL selection and placement, especially in situations in which modern IOL formulas and posterior corneal measurements are not used. This technology uses infrared (IR) light and interferometry, both to obtain aphakic refraction as soon as the cataract has been removed (while the patient is on the operating table) and to confirm proper toric IOL alignment. This process allows the surgeon either to rotate the lens to minimize astigmatism or to exchange it immediately if the power is not accurate.

Miyake T, Kamiya K, Amano R, Iida Y, Tsunehiro S, Shimizu K. Long-term clinical outcomes of toric intraocular lens implantation in cataract cases with preexisting astigmatism. *J Cataract Refract Surg*. 2014;40(10):1654–1660.

Wang L, Guimaraes de Souza R, Weikert MP, Koch DD. Evaluation of crystalline lens and intraocular lens tilt using a swept-source optical coherence tomography biometer. *J Cataract Refract Surg*. 2019;45(1):35–40.

Preoperative Measurements

Accurate preoperative or intraoperative eye measurements are essential to achieving the desired postoperative refractive result. Modern IOL power formulas incorporate the measurements for axial length (AL) and corneal power, and may also include other features such as anterior chamber depth (ACD), lens thickness (LT), and corneal diameter ("white-to-white", WTW). The formulas have evolved, becoming increasingly more complex and theoretical to continually improve accuracy. The modalities used to obtain the measurements are also continually improving, providing better data to use for IOL power calculations. Intraoperative aberrometry may also be used to directly determine the optimal IOL power. This technique may be particularly useful for children or adult patients who are unable to cooperate with office-based testing.

Axial Length

Ocular axial length (AL) is a key component of IOL power calculations. An error as small as 1 mm in the AL measurement can lead to significant postoperative refractive error (approximately 1.75 D error in a 30-mm eye, 2.35 D error in a 23.5-mm eye, and 3.75 D error in a 20-mm eye). AL can be measured with several techniques, discussed later in this section. No matter which of these is used, obtaining data for both eyes is helpful, even if surgery is planned for only 1 eye. The difference in AL between the 2 eyes is typically no greater than 0.3 mm; larger differences may indicate measurement inaccuracy, unless there is a refractive difference or other relevant ocular findings. It is important to document and explain any significant AL disparity.

Optical biometers are noncontact instruments that use IR laser light and partial coherence interferometry, swept-source OCT, or optical low-coherence reflectometry to measure multiple parameters, such as AL, corneal curvature, ACD, LT, and WTW. These devices require the patient to fixate on a target, which gives an AL along the visual axis. Newer biometers are increasingly effective at accurately measuring through dense cataracts. Optical biometry is beneficial for patients with posterior staphyloma and is preferred to ultrasonography for all eyes wherever possible. Because the ocular media must be clear enough to allow voluntary fixation and light transmission, in some cases, measurements cannot be obtained with this modality, and ultrasound is required.

In *A-scan ultrasonography,* the transit time of the ultrasound pulse is measured. Using an estimated average velocity through the various ocular media (cornea, aqueous, lens, and vitreous), the biometric software calculates the AL. This value should be altered when velocities differ from the norm (see the Clinical Pearl sidebar). Measurements are obtained via either immersion (Fig 7-9) or contact applanation. See BCSC Section 3, *Clinical Optics and Vision Rehabilitation,* for more information.

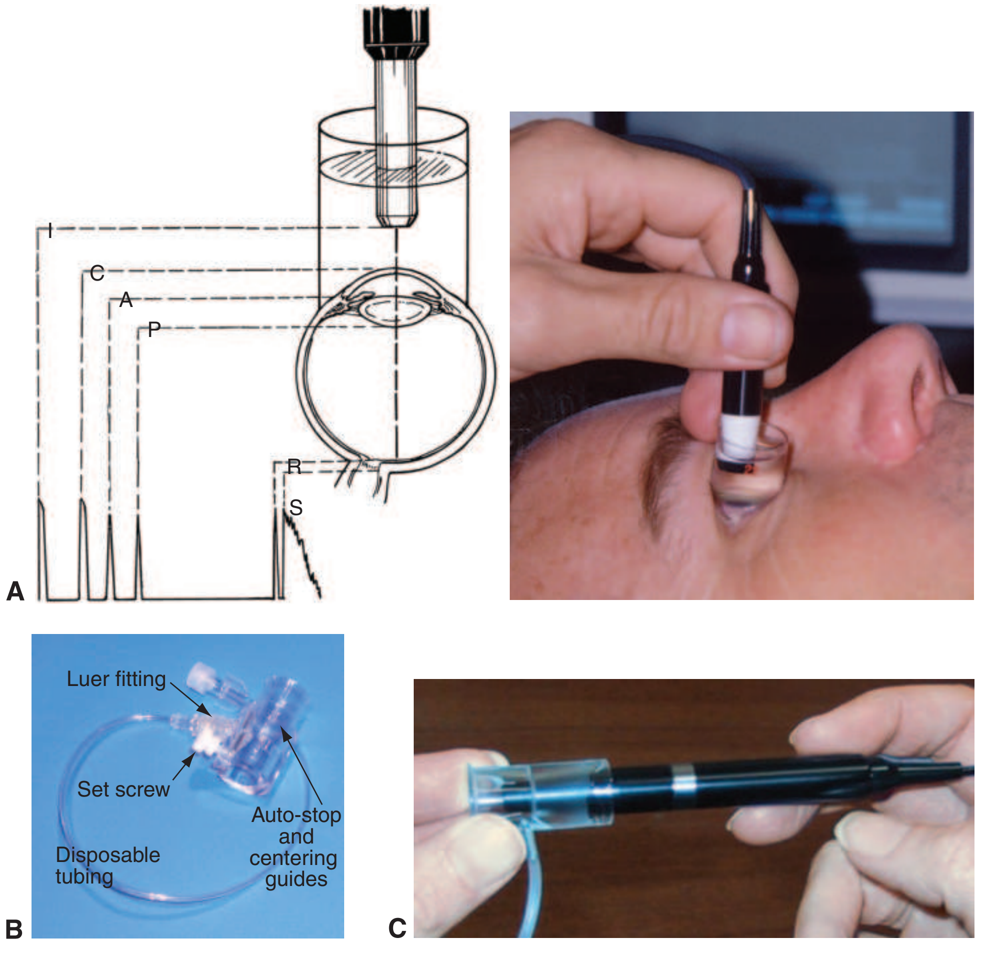


Figure 7-9 Immersion shells. Although there are other immersion shells, they are now rarely used in the United States, as visual axis alignment is more easily achieved with infusion shells than with cup shells. Infusion shells are also easier to use. **A,** In immersion ultrasonography, the probe is immersed in the solution, placing it away from the cornea. **B,** Prager shell for immersion A-scan. **C,** Ultrasound probe and Kohn shell. *(Courtesy of Kenneth J. Hoffer, MD.)*

Clinical Pearl Silicone oil has a different velocity of sound waves than vitreous (980 m/s or 1040 m/s, depending on the oil's viscosity, versus 1532 m/s for vitreous). In a patient's eye with silicone oil in the posterior segment, the transit time will be extended, a change that the clinician must take into account when the eye's AL is measured. Without adjustment, erroneously long ALs would be obtained, which could lead to an incorrect IOL selection that then causes an unexpectedly hyperopic result. In addition, silicone oil's index of refraction is higher than that of vitreous; this must also be considered when IOLs are selected.

Kurian M, Negalur N, Das S, et al. Biometry with a new swept-source optical coherence tomography biometer: repeatability and agreement with an optical low-coherence reflectometry device. *J Cataract Refract Surg.* 2016; 42(4):577–581.

Corneal Power

Corneal power is another major component of IOL power calculations. A 1.00-D error in the calculation of corneal power causes a similar degree of error in the postoperative refraction. The cornea needs to be optimized before measurements are obtained; this includes adequately treating any ocular surface disease, as well as minimizing warpage from contact lens wear. Preferences vary, but most surgeons require the eyes to be several weeks free from rigid gas permeable (RGP) lenses, and less time for soft contact lenses. Calculating corneal power in eyes that have undergone refractive surgery can be problematic; see the section Calculations Following Refractive Surgery later in this chapter. In addition, accounting for posterior corneal curvature is increasingly recognized as an important factor in avoiding postsurgical refractive surprises, especially in patients who will be receiving toric IOLs.

Corneal power may be estimated or measured via several techniques, including manual keratometry, corneal topography, and corneal tomography:

- In *manual keratometry,* a small central portion of the cornea (3.2 mm) is measured, and the radius of curvature is calculated based on the size of a reflected image. This technique, which requires a skilled operator, allows direct visualization of tear film irregularity and can reveal corneal irregularities. It measures only the anterior surface of the cornea and extrapolates the corneal power by assuming a fixed relationship to the posterior surface.
- In *corneal topography,* a corneal contour map is created using one of various map-creation methods. Placido disk–based topography, which measures the anterior corneal surface and can provide additional information about that surface, is particularly helpful in analyzing irregular astigmatism or detecting early keratoconus.
- In *corneal tomography* (ie, Scheimpflug imaging or OCT), the anterior and posterior curvature and corneal thickness can be measured. Scheimpflug imaging is incorporated into platforms to assist in IOL selection. OCT, which has a higher axial resolution, can be useful in the presence of corneal opacities. Tomography and resultant posterior corneal measurements may be particularly useful in patients who have previously undergone keratorefractive surgery, desire astigmatism correction, or have corneal measurements that fall outside the typical parameters.

Anterior Chamber Depth and Effective Lens Position

Historically, ACD was set as a constant (and incorporated into the "*A* constant" value for a lens) and served to represent the expected postoperative IOL position (termed *effective lens position* [*ELP*], sometimes called *estimated lens position*). More recently, preoperative ACD is measured and ELP predicted using various combinations of ACD, AL, LT, and corneal power. Because a significant difference between the predicted ELP and the actual final lens position results in a refractive surprise, ACD is a valuable variable for calculation of IOL power in modern IOL power formulas.

IOL Power Determination

Classic Regression Formula

The classic SRK formula developed by Sanders, Retzlaff, and Kraff in the 1980s for IOL calculation is as follows:

$$P = A - (2.5L) - 0.9K$$

Where

P = lens implant power for emmetropia (diopters)
L = axial length (mm)
K = average keratometric reading (diopters)
A = constant specific to the implant to be used

Although this formula is no longer regularly used, it helps to illustrate the relative importance of AL and keratometric power in attaining the proper implant power. A small error in AL can have a much larger impact than a small error in keratometry.

IOL Calculation

Before surgery, the ophthalmologist discusses the refractive goals with the patient and determines the desired refractive result (see the section Patient Preparation and Informed Consent). This information, with the IOL power calculation formulas, can then be used to determine the power of the IOL to be implanted. It is important to make sure that the patient realizes that the formulas are not perfect. Despite extensive research to determine the optimal IOL calculation formulas, large case series show that 20%–30% of postoperative results miss the refractive target by up to 0.50 D, while smaller percentages (<5%) miss by over 1.00 D. The dependability of the calculations varies among subgroups of patients; the greatest challenges occur in postrefractive patients or patients with axial myopia or axial hyperopia.

Historically, the Hoffer Q formula was used for eyes with short AL and the SRK/T and Haigis were used for eyes with long AL. However, modern formulas now incorporate some combinations of artificial intelligence, ray tracing, theoretical optics, and regression to further improve accuracy (Table 7-5), although they often require additional variables such as age, ACD, and LT. While accuracy within unique groups (such as those with short or long ALs) may

Table 7-5 Partial List of IOL Formulas

Regression	Vergence	Artificial Intelligence	Ray Tracing
SRK SRK II	Holladay 1 SRK/T Hoffer Q Haigis Holladay 2 Barrett Universal II	Hill-RBF (version 3.0) Kane	Olsen

vary, generally the Barrett Universal II formula (https://calc.apacrs.org/barrett_universal2105/) and the Kane formula (https://www.iolformula.com/) have performed most accurately in large studies.

Acknowledging that no single formula is perfect, many surgeons use multiple IOL calculations to narrow in on the best choice. One option to quickly do so is the web application hosted by the European Society of Cataract and Refractive Surgery, which can run simultaneous calculations using several high-performing modern IOL formulas, including Barrett Universal II, Emmetropia Verifying Optical (EVO), Hill-RBF 3.0, and Kane (https://iolcalculator.escrs.org/).

Kane JX, Chang DF. Intraocular lens power formulas, biometry, and intraoperative aberrometry: a review. *Ophthalmology*. 2021;128(11):e94–e114.

Koch DD, Hill W, Abulafia A, Wang L. Pursuing perfection in intraocular lens calculations: I. logical approach for classifying IOL calculation formulas. *J Cataract Refract Surg*. 2017 Jun;43(6):717–718.

Melles RB, Holladay JT, Chang WJ. Accuracy of intraocular lens calculation formulas. *Ophthalmology*. 2018;125(2):169–178.

Melles RB, Kane JX, Olsen T, Chang WJ. Update on intraocular lens calculation formulas. *Ophthalmology*. 2019;126(9):1334–1335.

Calculations Following Refractive Surgery

Accurately calculating the IOL power for eyes that have previously undergone refractive surgery can be challenging. These patients were initially motivated to have refractive surgery because they did not want to depend on eyeglasses, and they may have higher expectations regarding postoperative refractive results. The surgeon should identify postrefractive corneas using topography and/or tomography and inform patients who have undergone previous corneal refractive surgery about potential inaccuracies in IOL selection leading to refractive surprise due to over- or undercorrection. A refractive surprise may necessitate postoperative correction with eyeglasses, contact lenses, refractive surgery, or IOL exchange. Documenting the discussion with the patient is extremely important. Even after properly accounting for prior refractive surgery, eyes with prior radial keratotomy (RK) are most likely to suffer refractive surprise, followed by eyes with prior hyperopic laser vision correction (LVC) and then prior myopic LVC.

Determining the central keratometric power, a key element in IOL power calculations, is complicated in eyes that have undergone previous refractive surgery because of the corneal changes resulting from the original refractive procedure. Variations in central curvature may lead to inaccurate measurements of the anterior corneal power. Also, after LVC, the standardized value for the refractive index of the cornea (1.3375) is no longer accurate for use in estimating total corneal power from anterior corneal curvature.

After myopic LVC, if no adjustments are made, conventional keratometry overestimates corneal power, with subsequent hyperopic results. The converse is true for patients with prior hyperopic LVC. In addition, for eyes in which RK has been performed, a greater flattening of the posterior cornea relative to the anterior cornea can lead to an overestimation of corneal power, with hyperopic results unless properly accounted for. Furthermore, many IOL power calculation formulas rely on corneal power for ELP estimation, which would be erroneous if postrefractive surgery corneal power is used without adjustment.

A variety of methods have been developed to better estimate central corneal power in eyes that have undergone refractive surgery. Initially, many of these methods used historical data (pre–LASIK/PRK *K*-values and the surgically induced change in manifest reaction [ΔMR]). More recent formulas use a combination of current corneal power and ΔMR or use no historical data and base the IOL power only on corneal measurements. Newer corneal topography and/or tomography systems measure both anterior and posterior corneal curvatures, thereby improving the accuracy of central corneal power used in IOL power calculations. Intraoperative aberrometry, which calculates IOL power based on an aphakic refraction measured during surgery, has also been used with results similar to the newest postrefractive IOL power formulas.

The ideal method has not yet been determined; however, expert opinion endorses using multiple techniques and selecting an IOL power based on the consensus of multiple methods, placing more weight on newer formulas such as the Barrett True-K No-History and OCT-based IOL formulas (Case Study 7-3). Some may consider additional power adjustment using the results of intraoperative aberrometry. The American Society of Cataract and Refractive Surgery (ASCRS) hosts a website (http://iolcalc.ascrs.org/) that allows surgeons to run several calculations simultaneously for eyes that have previously undergone refractive surgery. The Barrett True-K No-History formula is also available from the Asia-Pacific Association of Cataract & Refractive Surgeons (www.apacrs.org). For more information, see also BCSC Section 13, *Refractive Surgery.*

CASE STUDY 7-3 Postrefractive IOL power selection.
Courtesy of Karen Christopher, MD.
Available at: aao.org/bcsccasestudy_section11

Christopher KL, Patnaik JL, Miller DC, Lynch AM, Taravella MJ, Davidson RS. Accuracy of intraoperative aberrometry, Barrett True-K with and without posterior cornea measurements, Shammas-PL, and Haigis-L Formulas after myopic refractive surgery. *J Refract Surg.* 2021;37(1):60–68.

Wang L, Koch DD. Intraocular lens power calculations in eyes with previous corneal refractive surgery: review and expert opinion. *Ophthalmology.* 2021;128(11): e121–e131.

Expected Placement of IOL

The intended anatomical location of the IOL within the eye also affects the IOL power selected. As the IOL moves forward from in-the-bag placement to sulcus placement to anterior chamber placement, the distance from the retina increases, and the power required for the implant decreases (Activity 7-1). In general, an anterior chamber IOL (ACIOL) will be about 3.00 D lower in power than a planned in-the-bag PCIOL. This measurement will be different for eyes at the extremes of AL (ie, those with high myopia or high hyperopia). When shifting an IOL planned for the capsular bag to the sulcus, such as for a ruptured posterior capsule, the surgeon can make an adjustment relative to the AL and projected in-the-bag IOL power (Table 7-6). If the IOL is placed in the sulcus and optic capture is performed, no adjustment needs to be made, because the optic is then effectively in the capsular bag. IOLs placed in the sulcus should be restricted to those that are stable in the sulcus and correctly angulated (ie, 3-piece IOLs), as 1-piece IOLs placed in the sulcus will be prone to causing uveitis-glaucoma-hyphema syndrome.

ACTIVITY 7-1 Effect of lens position.
Courtesy of Karen Christopher, MD.
Available at: aao.org/bcscactivity_section11

Tracking Refractive Outcomes

Refractive surgical outcomes may be tracked and evaluated by collecting information such as the following:

- whether overcorrections or undercorrections occur, and whether they happen more often with longer eyes or shorter eyes or roughly equally in both
- whether the incision routinely induces cylinder
- whether toric lenses are correcting as calculated
- whether LRIs have been effective for the correction of astigmatism

Commercially available programs may be useful for tracking outcomes. After the surgeon has analyzed these factors, they may make adjustments to improve refractive outcomes, such as including a "surgeon factor" (a modification of the parameters used that reflects the surgeon's experience) in some IOL power calculations, or changing the calculation software. Improving outcomes is critical for increasing not only patient satisfaction but also surgeon confidence.

Table 7-6 IOL Power Adjustments for Sulcus Placement

IOL Power Calculated for In-the-Bag Placement	IOL Power Adjustment for Sulcus Placement
+28.50 D to +30.00 D	Subtract 1.50 D
+17.50 D to +28.00 D	Subtract 1.00 D
+9.50 D to +17.00 D	Subtract 0.50 D
+5.00 D to +9.00 D	No change

Anesthesia for Cataract Surgery

Considering the options for anesthesia is an important part of preoperative planning. A general review of the advantages and risks of the different types of anesthesia is part of the informed consent process. A discussion of what the patient will experience in the operating room increases the likelihood of their comfort and cooperation on the day of surgery. (See also BCSC Section 1, *Update on General Medicine*, for a discussion of perioperative management in ocular surgery.)

Retrobulbar anesthesia for cataract surgery provides excellent ocular akinesia and anesthesia and reduces sensitivity to the microscope light. The basic technique of retrobulbar injection (Fig 7-10), first described in 1945 by Walter Atkinson, involves the administration of lidocaine into the muscle cone via a 25-gauge, 1.5-inch (38-mm) blunt retrobulbar needle. Many surgeons now use a 27-gauge, 1.25-inch sharp needle and supplement the lidocaine with hyaluronidase and bupivacaine, and sometimes bicarbonate. These modifications can enhance the patient's comfort, speed of onset, and duration of the retrobulbar block. Any preexisting diplopia or ocular misalignment should be documented. Complications resulting from retrobulbar anesthesia are uncommon but include:

- retrobulbar hemorrhage
- globe penetration
- optic nerve trauma
- extraocular muscle toxicity
- inadvertent intravenous injection associated with cardiac arrhythmia
- inadvertent intradural injection with associated seizures, respiratory arrest, and brainstem anesthesia

Peribulbar anesthesia theoretically eliminates the risk of complications such as optic nerve injury and intradural injection. However, this technique is slightly less effective than the retrobulbar method for providing akinesia and anesthesia and is more likely to cause conjunctival chemosis. In this technique, a shorter (1-inch) 25- or 27-gauge needle is used

Figure 7-10 Retrobulbar injection. *(Courtesy of Michael N. Wiggins, MD.)*

to introduce an anesthetic solution external to the muscle cone, underneath the Tenon capsule.

Sub-Tenon infusion of lidocaine has become a popular method of anesthesia during surgery. The risk of muscle injury or toxicity associated with this method is lower. A small, posterior incision is made through the anesthetized conjunctiva and the Tenon capsule, and a small blunt cannula is used to administer the anesthetic posteriorly. This technique may not provide as complete akinesis as a retrobulbar block (Video 7-2, Fig 7-11).

VIDEO 7-2 Sub-Tenon injection.
Courtesy of Karen Christopher, MD.
Available at: aao.org/bcscvideo_section11

The use of *topical and intracameral anesthesia* is widespread. With topical anesthesia, the risk of ocular perforation, extraocular muscle injury, and central nervous system depression is eliminated, and visual recovery is accelerated. Topical anesthesia is administered via proparacaine or tetracaine drops, cellulose pledgets soaked in anesthetic, or lidocaine jelly. The surgeon should ensure that the use of lidocaine jelly does not inhibit contact of povidone-iodine with the ocular surface during surgical preparation. Intracameral preservative-free lidocaine (which may also be mixed with a mydriatic agent) can supplement topical anesthesia; using this with a mydriatic agent has the added advantage of increasing pupil dilation and reducing the effects of intraoperative floppy iris syndrome (IFIS). Only nonpreserved 1% or 2% lidocaine should be used for anterior chamber instillation, because some preservative agents have a toxic effect on intraocular structures. Disadvantages of topical anesthesia include blepharospasm, limited duration of action, lack of akinesia, and potential patient discomfort, which can interfere with the surgeon's ability to perform delicate maneuvers. Topical and intracameral anesthesia is typically reserved for short cataract surgeries, generally under 30 minutes in length, with cooperative patients who are well dilated and can tolerate the microscope light. Topical and intracameral anesthesia can be supplemented with oral or intravenous sedation to help reduce patient anxiety.

A *facial nerve block* may be used when appropriate with small-incision surgery. Patients with essential or reactive blepharospasm may benefit from a facial nerve block to control squeezing during surgery. Types of facial nerve blocks include the O'Brien block, directed proximally and peripherally at the nerve trunk; the van Lint block, directed proximally and peripherally at the terminal branches; and the Atkinson block, directed between these 2 regions (Fig 7-12).

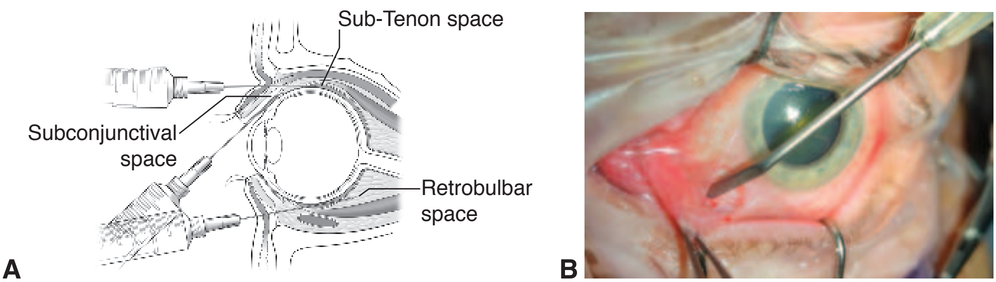


Figure 7-11 Sub-Tenon infusion. **A,** Periocular anesthetic spaces. **B,** Sub-Tenon lidocaine injection. *(Courtesy of Karen Christopher, MD)*

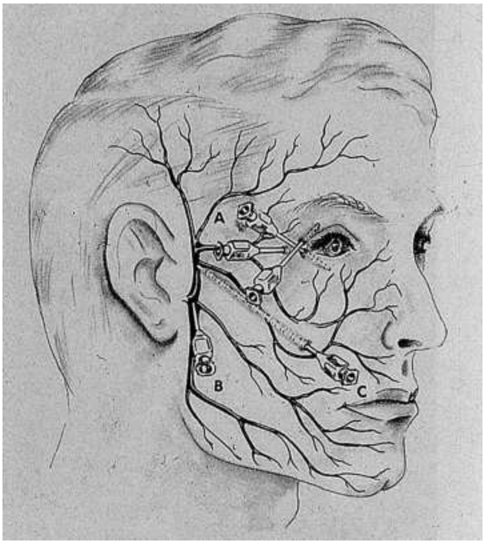


Figure 7-12 Akinesia of orbicularis oculi. Van Lint akinesia **(A)**, O'Brien akinesia **(B)**, Atkinson akinesia **(C)**. *(Reproduced with permission from Jaffe NS, Jaffe MS, Jaffe GF.* Cataract Surgery and Its Complications. *5th ed. Mosby; 1990.)*

Conscious IV or *oral sedation* can be used, often with one of the previously discussed anesthetics, to provide systemic relaxation or pain control and to reduce patient anxiety. Common IV agents include midazolam or fentanyl, and oral diazepam or sublingual midazolam/ketamine/ondansetron are effective alternatives.

General anesthesia can be considered for pediatric patients and for adult patients who have any condition that would prevent their cooperation and ability to lie flat during surgery, including dementia, head tremor, deafness, language barrier, musculoskeletal disorder, restless legs syndrome, claustrophobia, or psychiatric disorder (including anxiety). Patient preference can also be considered as an indication. General anesthesia may require clearance from the patient's primary care physician or an anesthesiologist.

Zhao LQ, Zhu H, Zhao PQ, Wu QR, Hu YQ. Topical anesthesia versus regional anesthesia for cataract surgery: a meta-analysis of randomized controlled trials. *Ophthalmology.* 2012;119(4):659–667.

Antimicrobial Therapy

Endophthalmitis remains one of the most serious complications of cataract surgery (see Chapter 11). Therefore, a major objective of preoperative preparation and intraoperative management of the patient is to reduce the introduction of pathogenic organisms into the anterior chamber.

Before Surgery

Before the day of surgery, the surgeon should identify and reduce infectious risk factors as much as possible through preoperative treatment of coexisting eyelid disorders such as conjunctivitis, blepharitis, hordeolum, and chalazion. Systemic infections should also be identified and treated.

Cataract surgery is not considered to be an invasive procedure that induces transient bacteremia; thus, systemic antibiotic prophylaxis is not required. If questions arise about whether antibiotic prophylaxis is advisable in the perioperative period, the surgeon may wish to consult with the physicians involved in the patient's systemic care.

Although no studies have convincingly demonstrated their efficacy in reducing the risk of endophthalmitis in routine cataract surgery, there is some evidence supporting an association between the use of preoperative topical antibiotics and a reduction in ocular surface bacterial counts, as well as a lower incidence of positive aqueous cultures after surgery. Many cataract surgeons prescribe preoperative topical antibiotics.

For patients with a history of herpetic eye disease, a prescription of prophylactic antiviral medications can be considered. This topic is further discussed in Chapter 12.

During Surgery

In the operating room, fornix sterilization is important. A 5% povidone-iodine solution (not scrub or soap) placed in the conjunctival fornix before surgery has been associated with a reduction in bacterial colony counts in cultures from the ocular surface during surgery and a decreased risk of culture-proven endophthalmitis. In addition, skin preparation around the eye with a 10% povidone-iodine solution can reduce bacterial counts on the eyelid margins. Because eyelid margins may harbor pathogens, the eyelashes need to be draped out of the operative field (Fig 7-13). Povidone-iodine sensitivity should be verified. Caution should be used with chlorhexidine prep due to the potential for ocular toxicity.

Surgeons should limit the number of times that instruments are introduced into the eye and also check for signs of lint, cilia, and other debris on the tips of all instruments inserted. Meticulous wound closure is imperative. Despite surgeons' best efforts, however, cataract surgery can result in bacterial inoculation of the anterior chamber. The low incidence of endophthalmitis is a testament to the anterior chamber's ability to clear itself of a potentially pathologic inoculum. The risk of endophthalmitis increases with a torn posterior lens capsule, vitreous loss, and prolonged surgery.

The use of antibiotics injected into the anterior chamber (intracameral) at the end of the operation has increased rapidly in recent years. Some surgeons add antibiotics to the irrigating solution or inject them intravitreally. In the United States, preservative-free moxifloxacin is the predominant antibiotic used for intracameral administration. Care must be taken to

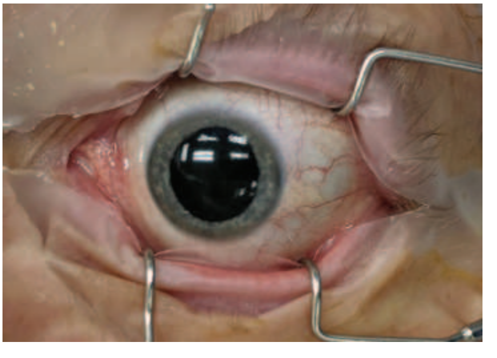


Figure 7-13 Sterile draping of the eye for surgery, with drape tucked around eyelashes to isolate them from the field. *(Courtesy of Karen Christopher, MD.)*

ensure that only a moxifloxacin formulation free from additives that can cause toxic anterior segment syndrome (TASS), such as xanthan gum, tyloxapol, or sorbitol, is used inside the eye. Proper dosage also ensures that the concentration delivered is high enough to decrease the risk of endophthalmitis while not so high as to cause TASS. The desired final concentration of moxifloxacin in the aqueous humor is between 0.1% and 0.15%; this dose typically corresponds to 0.5 mL of a 1-mg/ml (0.1%) solution or 0.1 mL of a 5-mg/ml (0.5%) solution but will vary based on anterior chamber volume. Thus far it has been safe and effective, although there have been reported cases of pigmentary dispersion and diffuse iris depigmentation after intracameral use as well as systemic use of moxifloxacin. Previously, intracameral vancomycin was commonly used; however, this antibiotic has been associated with a rare blinding hypersensitivity reaction that causes hemorrhagic occlusive retinal vasculitis (see Chapter 11). The Endophthalmitis Study Group reported a significant reduction in endophthalmitis with the use of intracameral cefuroxime, which has not been universally adopted in the United States because of the lack of commercially available cefuroxime for intracameral use.

Subconjunctival corticosteroids can be used with intracameral antibiotics. Another option is the injection of a bolus of antibiotic and corticosteroid medications at the end of surgery via transzonular or intravitreal injection so that the medications act over time, postoperatively. "Dropless" cataract surgery can refer to any of these methods in which medications are instilled during surgery and reduce or eliminate the need for postoperative eyedrops; this can be especially beneficial for patients with compliance difficulties or cost concerns.

Whether the risk of endophthalmitis is increased after cataract surgery performed using a sutureless clear corneal wound is controversial. Some have suggested that after tracking the flow of fluorescein into the anterior chamber, bacterial inflow from the ocular surface may be possible via a sutureless incision. For this reason, hydrating the corneal stroma to reapproximate the anterior and posterior aspects of the wound may reduce the risk of wound separation. Any possibility of leakage can be addressed with wound closure by suture.

Bowen RC, Zhou AX, Bondalapati S, et al. Comparative analysis of the safety and efficacy of intracameral cefuroxime, moxifloxacin, and vancomycin at the end of cataract surgery: a meta-analysis. *Br J Ophthalmol.* 2018;102(9):1268–1276.

Endophthalmitis Study Group, European Society of Cataract & Refractive Surgeons (ESCRS). Prophylaxis of postoperative endophthalmitis following cataract surgery: results of the ESCRS multicenter study and identification of risk factors. *J Cataract Refract Surg.* 2007;33(6):978–988.

Nentwich MM, Ta CN, Kreutzer TC, et al. Incidence of postoperative endophthalmitis from 1990 to 2009 using povidone-iodine but no intracameral antibiotics at a single academic institution. *J Cataract Refract Surg.* 2015;41(1):58–66.

Witkin AJ, Chang DF, Jumper JM, et al. Vancomycin-associated hemorrhagic occlusive retinal vasculitis: clinical characteristics of 36 eyes. *Ophthalmology.* 2017;124(5):583–595.

After Surgery

There is debate about the necessity for topical antibiotic eyedrops after routine cataract surgery when intracameral antibiotics are used. Although reduced bacterial counts have been documented with the administration of topical antibiotics, there is no definitive evidence that their use reduces the incidence of endophthalmitis.

Chang DF, Rhee DJ. Antibiotic prophylaxis of postoperative endophthalmitis after cataract surgery: results of the 2021 ASCRS member survey. *J Cataract Refract Surg.* 2022;48(1):3–7.

Ophthalmic Viscosurgical Devices

Ophthalmic viscosurgical devices (OVDs), also referred to as *viscoelastic agents,* are a class of clear gel-like materials that have been employed in anterior segment surgery since 1979. They play an important role in maintaining the anterior chamber and protecting the corneal endothelium during surgery, and their use has had a profound influence on the evolution of extracapsular and phacoemulsification surgery.

OVDs contain one or more of the following substances in varying concentrations:

- *Sodium hyaluronate*, a biopolymer that occurs in many connective tissues throughout the body, such as synovial (joint) fluid and vitreous. It was originally isolated from human umbilical cord and rooster combs. Sodium hyaluronate has a half-life of approximately 1 day in aqueous and 3 days in vitreous.
- *Chondroitin sulfate,* a sulfated glycosaminoglycan that is an important component of cartilage.
- *Hydroxypropyl methylcellulose (HPMC)*, which does not occur naturally in animal tissues; however, cellulose is widely distributed in plant fibers such as cotton and wood. The commercial product is a cellulose polymer modified by the addition of hydroxypropyl and methyl groups to increase the material's hydrophilic property. Methylcellulose is a nonphysiologic compound that does not appear to be metabolized intraocularly; it is eventually eliminated in the aqueous but can be easily irrigated from the eye.

Physical Properties of OVDs

The physical properties of OVDs are not necessarily due to their specific biopolymer composition; rather, they are the result of chain length and molecular interactions both within chains and between chains and ocular tissue. OVDs have 4 general physical properties:

- *Viscosity* describes resistance to flow and can be thought of as the "thickness" or "thinness" of a fluid. This characteristic is determined primarily by molecular weight and concentration, so that substances with high molecular weight and high concentration have the highest viscosity. The higher the viscosity, the better the OVD is at displacing tissue and staying in place.
- *Elasticity* refers to the ability of a material to return to its original shape after being stressed. It describes the OVD's ability to re-form after an external force is applied to the anterior chamber and then removed. A highly elastic substance is excellent for maintaining space.
- *Pseudoplasticity* refers to the ease with which a material can change from being highly viscous at rest to being watery at increasing rates of shear stress. This property is found in certain everyday substances such as toothpaste: when squeezed out of a tube, toothpaste flows easily, but it retains its shape at rest on a toothbrush. In clinical terms, at zero shear force, an OVD is a lubricant and coats tissues well, but when forced through a small-gauge cannula it functions like a liquid.

- *Surface tension* describes how the surface of a fluid tends to stick to another surface. This property is also referred to as coatability, which is inversely proportional to surface tension. Thus, an OVD with low surface tension is better at coating tissue but is harder to remove from the eye.

Given the different combinations of all of these properties, OVDs can be classified into 2 general categories:

- *Cohesive OVDs* are long-chain, high-molecular-weight, high-viscosity substances. These agents maintain space well at no or low shear rates, whereas at high shear rates, they are easily displaced. Cohesive OVDs are easier to remove from the eye because they stick together and are aspirated as long pieces (similar to spaghetti). However, they have minimal coating ability and therefore afford less tissue protection during surgery.
- *Dispersive OVDs* are short-chain, low-molecular-weight, low-viscosity substances with low surface tension. These agents provide excellent coating and protection at high shear rates; however, they are more difficult to remove from the eye, because they do not stick together and are aspirated in short fragments (similar to macaroni). Because of this, they are more likely to be retained in the eye after cataract surgery; this can cause angle obstruction with reduced outflow and subsequent intraocular pressure (IOP) elevation.

Cohesive agents include Amvisc, Amvisc Plus (Bausch + Lomb Surgical); Healon GV, Healon Pro (J&J Surgical); and ProVisc (Alcon). Dispersive agents include ClearVisc, OcuCoat (Bausch + Lomb Surgical); Healon EndoCoat (J&J Surgical); and Viscoat (Alcon). DisCoVisc (Alcon) combines qualities of dispersive and cohesive agents. Figure 7-14 shows the full spectrum of OVDs.

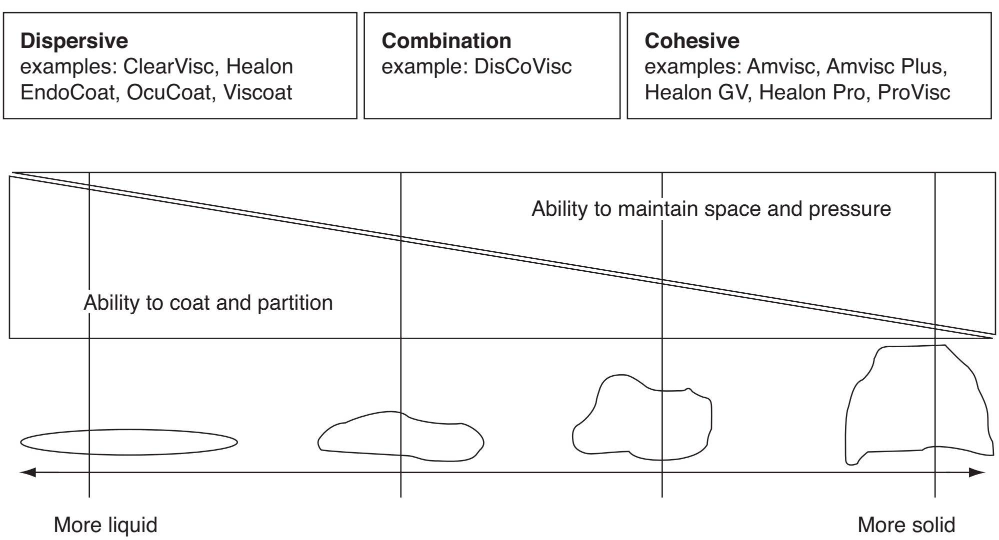


Figure 7-14 Behavior of ophthalmic viscosurgical devices (OVDs).

Some additional types of OVDs, such as the viscoadaptive agent Healon5 (J&J Surgical), may need separate classification. Healon5 is a long, fragile chain with a high molecular weight that changes its behavior at different flow rates. The lower the flow rate, the more viscous and cohesive the OVD is, and the higher the flow rate, the more the chains fracture. As a result, this OVD acts as a pseudodispersive agent. However, it must be carefully removed at the end of surgery because it can cause extremely elevated IOP if left in the eye.

Uses of OVDs

When OVDs are used during surgery, their space-maintenance ability keeps the anterior chamber formed despite the presence of one or more corneal incisions. With this chamber expansion, the surgeon can manipulate lens pieces away from the corneal endothelium and posterior lens capsule. A cohesive OVD can be used to enlarge a marginally dilated pupil (viscomydriasis). It can also be used to keep the anterior capsule plane flat to assist a controlled continuous curvilinear capsulorrhexis. Lens implantation is less traumatic to the zonular fibers and the posterior capsule when the capsular bag is inflated with an OVD.

The coatability of OVDs is useful to protect the corneal endothelium from phacoemulsification energy, particularly in dense cataracts or during long operations. The surgeon must take care to remove dispersive OVDs completely to reduce the risk of an ocular hypertensive period caused by angle outflow obstruction. In the presence of an open posterior lens capsule, a dispersive OVD can be injected over the tear to provide a vitreous tamponade and prevent prolapse of the vitreous anteriorly.

The optical clarity of OVDs has prompted some surgeons to use a layer of OVD on the corneal surface. When slightly moistened with a balanced salt solution, the agent coats the epithelium. This maneuver prevents drying and eliminates the need to irrigate the corneal surface. It also provides a slightly magnified view of anterior segment structures.

Ultimately, the choice of OVD varies depending on the clinical scenario and surgeon preference. A survey showed that 97% of surgeons vary their choice of OVD in complicated cases. For example, in pediatric cataract or cataract in adult patients with a low endothelial cell count, shallow anterior chamber, or IFIS, the choice of OVD can play a critical role in management. The preferred OVD for each surgical situation is a personal decision for each surgeon, guided by experience and product availability.

Riedel PJ. Ophthalmic viscosurgical devices. *Focal Points: Clinical Modules for Ophthalmologists.* American Academy of Ophthalmology; 2012, module 7.

Patient Preparation and Informed Consent

The surgeon must obtain informed consent preoperatively. Before deciding to proceed with cataract surgery, make sure that the patient has a clear understanding of the indications for surgery, the risks and benefits, the alternatives to surgery, the surgical technique, and IOL options. Discussion of supplemental technologies if available, such as intraoperative aberrometry, femtosecond laser, or pulse capsulotomy, can be considered (see Chapter 8 for additional discussion of these technologies). The surgeon should identify any risk factors for decreased visual outcome, including any preexisting ocular conditions that could adversely affect the result, and any medication use that could impact the surgical plan, and communicate those to the patient. The patient also needs to understand the anesthesia plan and be informed of what they are likely to experience during surgery. In addition, the surgeon and patient should discuss the anticipated postoperative refractive status, the limitations of pseudophakic correction, and the anticipated need for optical correction and at what point postoperatively it could be accurately provided. The surgeon should document these conversations in detail.

When planning cataract surgery, the surgeon must evaluate the patient's ability to adhere to the postoperative care regimen. The surgeon should inform the patient (and caregivers, if appropriate) of the importance of using prescribed medication, maintaining proper ocular hygiene, and keeping required appointments. It may be helpful to provide written instructions, along with appropriate illustrations or video presentations, and include a family member or friend in preoperative discussions to reinforce the patient's memory. The patient should be informed about any activity restrictions during the immediate postoperative period, although the advent of small-incision surgery has significantly minimized these limitations. The surgeon should consider the patient's ability to function with only the fellow eye in the event that visual rehabilitation of the surgical eye is prolonged.

Any costs associated with the surgery (eg, those related to medications or the use of premium IOL implants) should be clearly outlined preoperatively. In addition, if comanagement with an optometrist or another ophthalmologist is planned, the patient must be explicitly notified and must give consent in writing.

American Academy of Ophthalmology. Policy statement—an ophthalmologist's duties concerning postoperative care. 2022. Accessed November 30, 2023. aao.org/ethics-detail/policy-statement--ophthalmologists-duties-concerni

Miller KM, Oetting TM, Tweeten JP, et al. American Academy of Ophthalmology Preferred Practice Pattern Cataract/Anterior Segment Panel. Cataract in the Adult Eye Preferred Practice Pattern. *Ophthalmology.* 2022;129(1):P1–P126. doi.org/10.1016/j.ophtha.2021.10.006

Preventing Errors in Cataract Surgery Planning

During surgical planning, the patient name and cornea readings, as well as AL and other biometry measurements, should be confirmed and checked for irregularities. The IOL power and the manufacturer's model number are also specified. IOLs and their powers for placement in the capsular bag, sulcus, or anterior chamber angle are selected.

All this information, including the IOL calculations, should be double-checked by the surgeon on the day of surgery, and the implants verified and set aside preoperatively. In the operating room, a "time-out" is performed with the entire surgical team before the procedure begins to confirm the patient's identity; the operative eye, which should be marked unambiguously; the procedure; and the IOL to be implanted.

Some surgeons and surgical centers employ checklists as part of preoperative planning. A checklist enables a systematic review of the patient's general medical health, ocular concerns, and surgical planning to ensure that the correct IOL is ordered and that any special supplies needed are available. Checklist specifics will vary by location and surgeon.

CHAPTER 8

Phacoemulsification for Cataract Extraction

This chapter includes related videos. Go to aao.org/bcscvideo_section11 or scan the QR codes in the text to access this content.

Highlights

- Two main types of aspiration pumps are used in phacoemulsification machines: flow pumps (eg, a peristaltic pump) and vacuum pumps (eg, a Venturi pump). Flow pumps allow the surgeon to directly control aspiration flow rate and set a vacuum limit. Vacuum pumps allow direct control of the vacuum level only.
- Phacoemulsification uses ultrasound energy to emulsify a lens. Modes such as "pulse" and "burst" allow for intermittent rather than continuous delivery of phacoemulsification power, thereby decreasing the total amount of energy required for cataract extraction.
- Femtosecond laser platforms provide an alternative technology to assist in cataract extraction.
- Studies demonstrate that more than 90% of eyes having undergone phacoemulsification for cataract removal achieved a postoperative spherical equivalent within 1.00 diopters (D) of that predicted by preoperative biometry.

See BCSC Section 6, *Pediatric Ophthalmology and Strabismus,* for more detailed information regarding cataract extraction in the pediatric population.

Introduction

The modern era of cataract surgery began in 1967, when Charles Kelman invented phacoemulsification. In this procedure, an ultrasonically driven tip is used to emulsify the lens nucleus and remove the fragments with an automated aspiration system. This paradigm shift allowed cataract surgery to be performed via smaller corneal incisions, resulting in a lower incidence of wound- and vitreous-related complications and more rapid rehabilitation of vision. Although phacoemulsification was initially met with strong resistance, the procedure gained popularity by the 1990s, coinciding with the invention of ophthalmic viscosurgical devices (OVDs), the evolution of intraocular lens (IOL) design, and a change to performance of cataract surgery on an outpatient basis. Today, phacoemulsification is the most commonly performed method of cataract extraction in the United States and other higher-income regions.

In low- and middle-income parts of the world, however, the high cost of phacoemulsification technology and its associated disposable equipment have limited its adoption. Instead, extracapsular cataract extraction (ECCE) and manual small-incision cataract surgery (MSICS) are most commonly performed (see Chapter 9, Video 9-3). The use of historical techniques, such as intracapsular cataract extraction (ICCE) and couching, is rare. See the Introduction in this volume for further discussion of these techniques.

Instrumentation

Phacoemulsification (often referred to as *phaco*) makes use of ultrasound technology as well as *vacuum* (defined in the Glossary of Fluidics and Phacodynamics Terminology at the end of this chapter). Although there are several types of phaco machines, their major components are essentially the same: a handpiece, foot pedal, irrigation system, and aspiration pump.

The phaco handpiece (Fig 8-1) has been likened to a combination of a jackhammer, vacuum, and garden hose. The surgeon uses the handpiece to simultaneously emulsify and aspirate the crystalline lens while keeping the tip cool and maintaining anterior chamber depth. The mechanical energy of phacoemulsification is produced by the to-and-fro oscillation generated by *piezoelectric crystals* in the phaco handpiece. The amplitude of the movement, or *stroke length,* is variable and increases when the power is raised. As the phaco tip moves forward, compression of gas atoms in solution occurs; as the tip moves backward, expansion of gas atoms occurs, and bubbles of gas form (known as *cavitation*; see the Glossary of Ultrasonic Technology Terminology at the end of this chapter). The bubbles are also subject to compression and expansion; when the bubbles implode, they release heat and shock waves, which disassemble the nucleus at the phaco tip. Nonaxial vibrations generated by a torsional or elliptical motion of the tip can augment the primary oscillation and aid the mechanical breakdown of nuclear material. These mechanisms are specific to the type of phaco machine used.

Mastering use of the phaco foot pedal is critical to successful phacoemulsification technique. All current phaco machines have foot pedal controls with 3 positions. Position 1 activates irrigation, with the infusion pressure determined by irrigation bottle height or its

Figure 8-1 Phacoemulsification needle tip movements include longitudinal **(A),** torsional **(B),** and elliptical **(C).** *Reprinted with permission from Elsevier from Yang J, Xu T. A novel phacoemulsification needle with scissorlike motion end effector for reducing heat generation at cornea incision.* Sensors and Actuators A: Physical. *2019;288:92–100.*

equivalent. Position 2 engages the aspiration or vacuum mode at a fixed or variable rate. Position 3 adds ultrasound power at a fixed or variable level. In the fixed power mode, the level may be set from 0%–100%, and the chosen power level is delivered immediately when the foot pedal is depressed into position 3. With variable ultrasound, the surgeon controls the amount of phaco power delivered by varying the depth of depression of the foot pedal while it is in position 3.

Key Concepts and Advances in Phaco Power Delivery

The delivery of phaco power can have both favorable and unfavorable consequences. Cavitation, shock waves, shear forces, and heat buildup at the tip may facilitate disassembly of the lens nucleus. However, more power is not necessarily better; the longitudinal stroke of the phaco tip tends to push nuclear fragments away even as the aspiration attracts them, resulting in *chatter.* In addition, heat buildup from the delivery of phaco power may cause thermal injuries such as wound burns (also called corneal incision contracture [CIC]) or damage to the corneal endothelium.

Many parameters can be adjusted to deliver phaco power more efficiently and safely. The size and angle of the phaco tip can be altered to increase cutting efficiency. Intermittent, rather than continuous, phacoemulsification modes, such as "pulse" and "burst," can also be used. Various mechanical strategies, including torsional and elliptical movement of the phaco tip (rather than only longitudinal movement), may also minimize heat generation (see Fig 8-1).

Phaco Tip

Phaco tips vary by angle and size of the lumen. Phaco tips are available with bevels of 0°, 15°, 30°, 45°, and 60° (Fig 8-2A). The surgeon chooses the bevel angle of the phaco tip according to personal preference. A tip with a steeper bevel has an oval port with a larger surface area, which can generate more holding force and greater cutting efficiency. The disadvantage of steeper bevels is that the larger opening may be more difficult to occlude to achieve full vacuum. End configurations can be straight, curved (Kelman), flared, or balanced (Fig 8-2B).

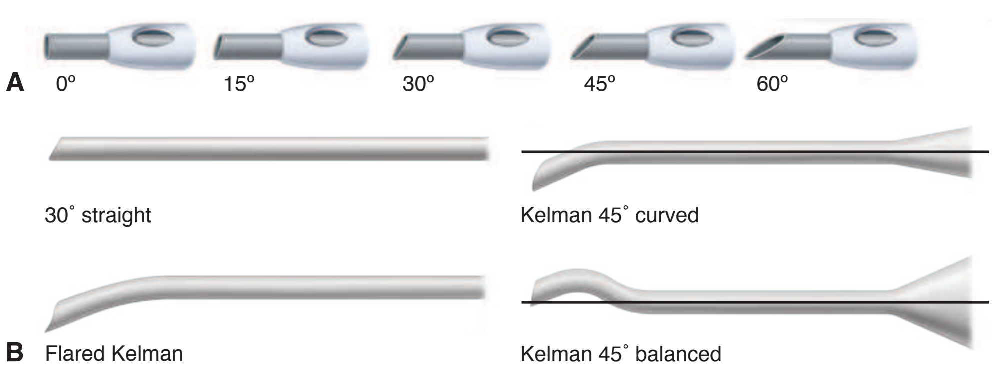


Figure 8-2 Phaco tip bevels **(A)** and end configurations **(B)**. *(Illustration by Mark Miller.)*

Pulse and Burst Modes

To reduce the total energy delivered into the eye, the surgeon can use an intermittent rather than a continuous mode of phacoemulsification (Fig 8-3). The delivery of phaco power for only a portion of the cycle also reduces repulsion of material by the vibrating tip (ie, reduces chatter) and improves *followability*. This method of breaking up the delivery of ultrasonic power into smaller packets of pulses and bursts is called *phaco power modulation*.

Pulse-mode phacoemulsification involves setting the number of pulses per second (ie, the number of intervals during which phaco power is turned on) while the foot pedal is in position 3. These intervals alternate with "rest" intervals, during which phaco power is off. The phaco power of each pulse increases as the foot pedal is depressed farther in position 3. When the foot pedal is fully depressed in position 3, each pulse has the preset maximum power.

Burst-mode phacoemulsification involves delivery of preset power (0%–100%) in single bursts that are separated by decreasing intervals as the foot pedal is depressed through position 3. When the foot pedal is fully depressed in position 3, the power is no longer delivered in bursts but is continuous. Burst mode allows the tip of the phaco needle to be buried into the lens, an essential step for chopping techniques.

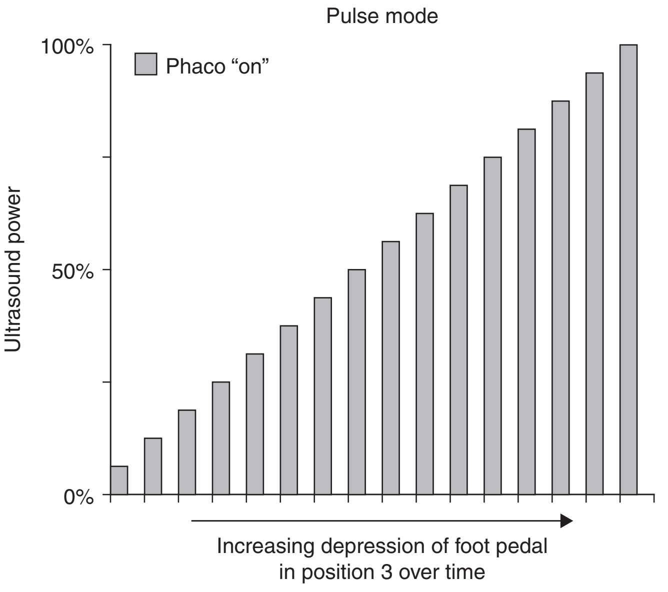
The ratio of "power-on" time to total time is referred to as the *duty cycle*. The traditional pulse mode has a default duty cycle of 50%, with the phaco energy on and then off for equal periods (50 : 50). Modern pulse modes allow detailed control of the duty cycle and the number of pulses per second. As mentioned previously, during burst-mode phacoemulsification, foot pedal position 3 allows linear control between minimum and maximum set duty cycles, with the maximum usually being continuous.

Torsional and Elliptical Phacoemulsification

Other advances in phacoemulsification technology can also reduce chatter and the total amount of phaco energy used. For example, in torsional phacoemulsification, the piezoelectric crystals of the phaco handpiece produce an oscillatory (torsional) movement, which is amplified by use of a curved phaco tip (eg, a curved Kelman-style phaco tip). The greater side-to-side movement at the tip may allow for greater shearing forces to assist in nucleus disassembly. Another system utilizes a combination of transverse and longitudinal modalities; the resulting elliptical cutting pattern may enhance nucleus emulsification.

Irrigation

The fluid dynamics of phacoemulsification require constant irrigation through the sleeve around the ultrasound tip and minimal egress of fluid through the incisions. Coaxial irrigation with balanced salt solution (BSS) cools the phaco tip, preventing heat buildup and consequent damage to adjacent tissue.



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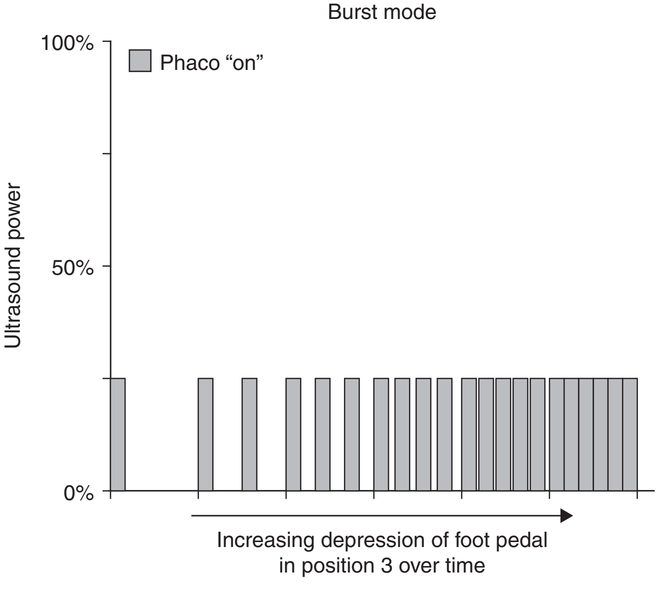


B

Figure 8-3 Pulse- versus burst-mode phacoemulsification. **A,** In pulse mode, foot pedal excursion provides linear control of ultrasound power, with a fixed duty cycle (50% in this case) and number of pulses per second. **B,** In burst mode, foot pedal excursion provides linear control of number of bursts per second, with a fixed ultrasound power (25% in this case) and burst duration. *(Data modified from Seibel BS.* Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery; *4th ed. Slack; 2005:121, Fig 1-55.)*

Another important purpose of irrigation is maintenance of a stable anterior chamber during surgery. The surgeon can adjust intraocular pressure and anterior chamber depth by changing the infusion pressure. In some phaco machines, infusion pressure is controlled by the height of the irrigation bottle, with gravity providing the force necessary to increase the level of irrigation. Air infusion can also be used to pressurize the irrigation bottle. In other phaco machines, infusion pressure is controlled by a collapsible bag that is compressed by pressure plates that provide continuous feedback to maintain a stable anterior chamber. Some surgeons put additives, such as phenylephrine, epinephrine, and ketorolac, in the irrigation bottle to maintain pupillary dilation. Others add antibiotics to the bottle as prophylaxis against endophthalmitis (see Chapter 7).

Donnenfeld ED, Whitaker JS, Jackson MA, Wittpenn J. Intracameral ketorolac and phenylephrine effect on intraoperative pupil diameter and postoperative pain in cataract surgery. *J Cataract Refract Surg*. 2017;43(5):597–605.

Aspiration Pumps

The aspiration system of the phaco machine is a critical element in the performance of various maneuvers. Thus, an understanding of this system can greatly improve the efficiency of the surgeon's phacoemulsification technique. Ideally, the surgeon is able to utilize fluidics to maximize phacoemulsification efficiency and to grasp nuclear fragments without inadvertently damaging the iris, capsule, or other intraocular tissues. For example, adjusting the aspiration flow rate can help attract nuclear or cortical material into the aspiration port of the phaco tip or irrigation/aspiration handpiece. Adjusting the vacuum determines how tightly particulate material that has occluded the aspiration port is grasped.

Two main types of aspiration pumps are used in phaco machines: *flow pumps* (of which peristaltic pumps are the most common example) and *vacuum pumps* (of which Venturi pumps are the most common example). In general, both peristaltic and Venturi pumps are effective, although the vacuum rise time varies between the different pump designs. The latest generation of machines features continuous feedback sensors that measure flow and vacuum and make immediate adjustments and in some cases use both flow and vacuum functions.

Peristaltic (or Flow) Pumps

A *peristaltic pump* (Fig 8-4) directly creates flow by moving a set of rollers along flexible tubing, pushing fluid through the tubing. The pressure differential between the lower-pressure aspiration tubing and the higher-pressure anterior chamber creates a relative vacuum at the aspiration port of the phaco tip. Direct linear control of the aspiration flow rate can be achieved by depressing the foot pedal farther down into position 2, thereby increasing the speed of the pump rollers. Higher aspiration flow rates will cause the nuclear fragments to more quickly approach the phaco tip. If the anterior chamber collapses while there is steady flow, the irrigation bottle height can be increased, or the aspiration flow rate can be decreased.

Figure 8-4 Illustration of the peristaltic pump. *(Redrawn with permission from* Practical Phacoemulsification: Proceedings of the Third Annual Workshop. *Medicopea International; 1991:43–48.)*

Although a *vacuum limit* is set on the machine, a peristaltic pump does not directly produce this level of vacuum. Rather, the peristaltic pump directly controls the aspiration flow rate, which indirectly controls the vacuum level produced. The vacuum level depends on the resistance in the fluidic circuit. Vacuum (grip) builds upon occlusion of the aspiration port. When the aspiration port is not occluded, a higher aspiration flow rate will attract material to the aspiration port more quickly. With complete occlusion, the vacuum level will build up to (but not exceed) the preset vacuum limit and will determine how tightly a nuclear fragment is held onto the aspiration port. The vacuum *rise time* (the amount of time required to reach a given level of vacuum) is related to the aspiration flow rate: during occlusion, a higher aspiration flow rate will cause a faster vacuum rise time.

During complete occlusion, modern peristaltic phaco machines *do* allow for linear control of the vacuum because there is no flow. For example, if the vacuum limit has been reached during full occlusion, lifting the foot pedal up while still remaining in position 2 will decrease the amount of applied vacuum (by a slight reversal of the pump rollers), even though the aspiration port is still completely occluded.

Venturi (or Vacuum) Pumps

Vacuum pumps directly control only the level of vacuum in the aspiration tubing; they indirectly control the aspiration flow rate as the level of vacuum is increased or decreased. A *Venturi pump* (Fig 8-5) directly creates vacuum based on the Venturi effect: a flow of gas across a port creates vacuum proportional to the rate of flow of the gas. This direct control of the vacuum level in the pump cassette then indirectly produces flow (while the aspiration port is not occluded) by "pulling" on the fluid in the aspiration tubing. The actual aspiration flow rate that is produced depends on the resistance in the fluidic circuit. In the absence of significant occlusion, higher vacuum levels will produce a faster aspiration flow rate, attracting material to the aspiration port more quickly.

With occlusion, the surgeon can attenuate the inherently rapid rise time of a vacuum pump via a programmed time delay or by controlling the speed at which the foot pedal is depressed through position 2. That is, direct linear control of vacuum is achieved by varying the foot pedal's excursion through position 2. During complete occlusion, the effect produced by a Venturi pump's linear control of vacuum is clinically equivalent to that produced by a modern peristaltic pump's linear control.

Seibel BS. *Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery.* 4th ed. Slack; 2005.

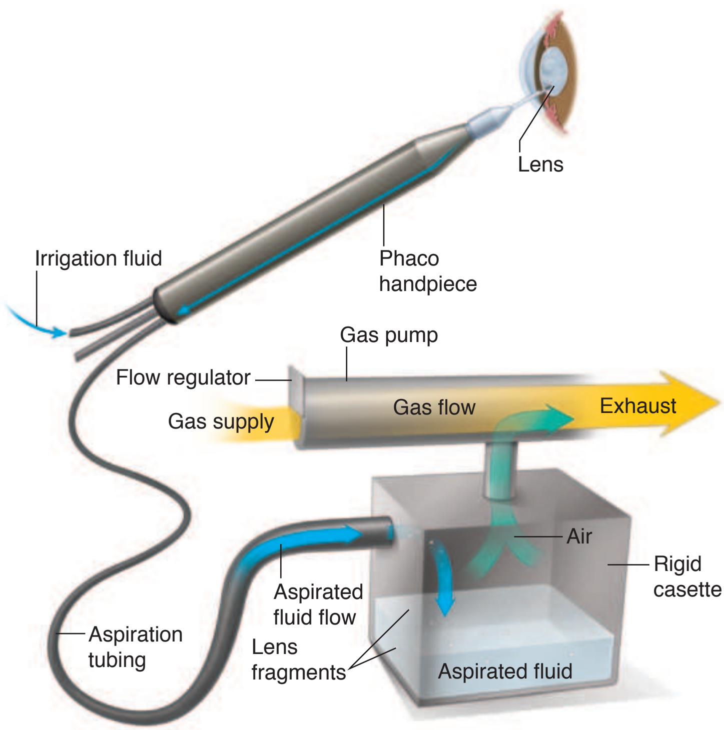


Figure 8-5 Illustration of the Venturi pump. The volume of gas flowing through the pump dictates the amount of air pulled from the rigid cassette, which in turn creates a vacuum that pulls fluid through the aspiration tubing. *(Illustration by Mark Miller.)*

Outline of the Phacoemulsification Procedure

Eye Marking and Time-Out

As discussed previously, the eye is marked and a time-out performed (see Chapter 7.)

Exposure of the Globe

After anesthesia has been administered and the eye has been prepared and draped in sterile fashion (see the section Antimicrobial Therapy in Chapter 7 and Figure 7-13), the eyelids are held apart with an eyelid speculum. When the speculum is selected, it is important to ensure that it will accommodate the phaco handpiece and other instruments.

The surgeon may choose to be seated superiorly or temporally. This preference may be dictated by the prominence of the patient's brow, the presence of a large pterygium or filtering bleb, or patient history of ocular surgery. Another factor to consider is the axis of astigmatism, as mild flattening will be induced at the site of a clear corneal wound.

Paracentesis

The paracentesis incisions are used for multiple purposes, including insertion of a second instrument, introduction of intracameral additives, and placement of iris hooks. A small, sharp blade, such as a 15° blade or microvitreoretinal (MVR) blade, is used to create 1 or 2 paracentesis incisions approximately 2–3 clock-hours away from the site where an incision will be made for the phaco handpiece. A straight entry plane is made parallel to the iris or at a slight downward angle. Alternatively, these incisions may be made by femtosecond laser (see the section Alternative Technologies for Cataract Extraction later in this chapter). Once the paracentesis is complete, intracameral anesthetic and/or mydriatic is often instilled (see Chapter 7). An OVD is then frequently used to protect intraocular structures and to give the surgeon more control during creation of the phaco incision.

Clinical Pearl The operating microscope's light reflecting off the paracentesis blade can be used to ensure that the blade is parallel to the iris plane.

Clear Corneal Incision

During phacoemulsification, most surgeons use a clear corneal approach for the main incision (Fig 8-6). These small incisions are typically 1.8–3.2 mm wide, just large enough to accommodate the phaco handpiece and allow insertion of the IOL. However, larger clear corneal incisions placed on the steep axis can reduce small but clinically significant amounts of astigmatism. Globe stabilization is important in clear corneal incisions, especially when the procedure is performed with topical anesthesia. Fixation rings, 0.12-mm toothed forceps, or instruments supplying counterpressure can be used to stabilize the globe as the incisions are made.

Various types of corneal phacoemulsification incisions have been described, including biplanar and multiplanar incisions. Regardless of which type of clear corneal incision is used, an important objective is to create a stable, watertight incision to minimize the risk of wound leak and endophthalmitis. In the multiplanar technique, a diamond or metal blade is used to create a 0.3-mm-deep groove perpendicular to the corneal surface. The blade is inserted into the groove, and its tip is then directed tangentially to the corneal surface, creating a tunnel through clear cornea into the anterior chamber.

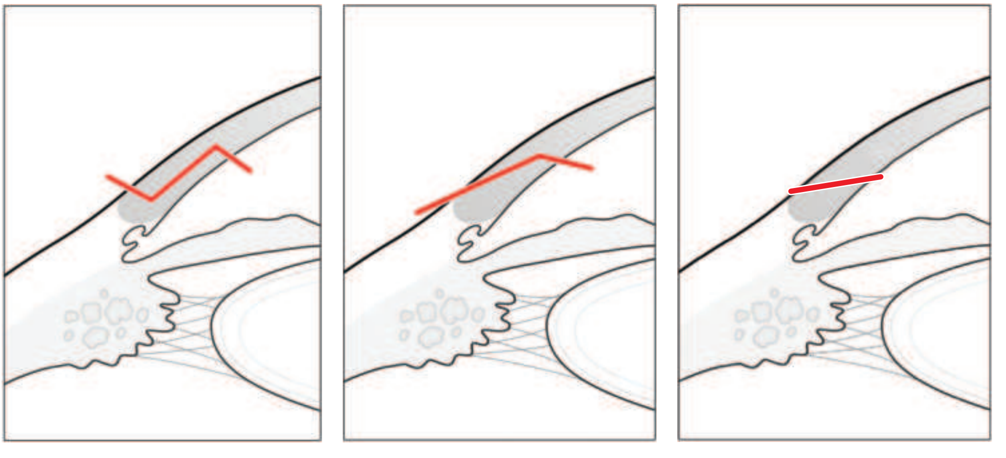


Figure 8-6 Illustration of the architecture of clear corneal incisions: triplanar *(left)*, biplanar *(center)*, and uniplanar *(right)*. *(Illustration developed by Lisa Park, MD, and rendered by Christine Gralapp.)*

Another approach is the beveled, self-sealing biplanar incision. A beveled blade is flattened against the eye, and the tip is used to enter the cornea just anterior to the vascular arcade. The blade is advanced tangentially to the corneal surface until the shoulders of the blade are fully buried in the stroma. The point of the blade is then redirected posteriorly so that the point and the rest of the blade enter the anterior chamber parallel to the iris.

Self-sealing uniplanar clear corneal incisions can be created with beveled, trapezoidal diamond blades. Such blades can be advanced in one motion and in one plane, from the clear cornea into the anterior chamber. The blade is oriented parallel to the iris, and the tip is placed at the start of the clear cornea, just anterior to the vascular arcade. The blade is tilted up and the heel down so that the blade is angled 10° from the iris plane; it is then advanced into the anterior chamber in one smooth, continuous motion.

Another type of incision uses the "near-clear" approach, in which the incision begins within the vascular arcade. Proponents of this approach cite better wound closure and a reduced incidence of induced astigmatism. However, there may be slight bleeding during surgery, and conjunctival ballooning may occur. In addition, a subconjunctival hemorrhage may be present postoperatively.

Clear corneal incisions may also be made using a femtosecond laser; see the section Alternative Technologies for Cataract Extraction for further discussion.

Regardless of which type of clear corneal incision is used, the length of the wound should permit optimal visualization and instrument manipulation during phacoemulsification. If the corneal incision is too long, the surgeon may have problems manipulating the phaco tip within the anterior chamber, and corneal striae may reduce visibility as the surgeon manipulates the handpiece. If the tunnel is too short, the incision may not seal postoperatively. The phaco tip may also abrade the iris, possibly causing atrophy and pupil distortion.

Scleral Tunnel Incision

An alternative to the clear corneal incision is a scleral tunnel incision (Fig 8-7). One advantage of this incision is that it may reduce the incidence of both early and late surgically induced astigmatism. It can also provide safety by avoiding the possibility of transecting prior cornea surgery incisions (as in prior high-cut radial keratotomy) or in circumstances of peripheral corneal thinning. Another advantage may be more-controlled conversion to ECCE, if this becomes necessary.

For this incision, a limited conjunctival peritomy is created over the intended incision site. The surgeon then clears the overlying Tenon capsule from the sclera and may apply light bipolar cautery to achieve hemostasis. Excessive cautery should be avoided because it can cause scleral shrinkage and postoperative astigmatism.

The scleral incision is usually linear, but it may be either curvilinear (smile shaped, following the limbus, or frown shaped, following the curve opposite the limbus) or chevron shaped. After making the incision, the surgeon uses a blade to enter the scleral groove at a depth of half the scleral thickness, dissecting anteriorly into clear cornea just anterior to the vascular arcade, creating a partial-thickness scleral tunnel. If the scleral groove is entered too deeply, the scleral flap will be very thick, and the blade may penetrate the anterior chamber earlier than anticipated, closer to the vascular iris root. If the scleral groove is entered too

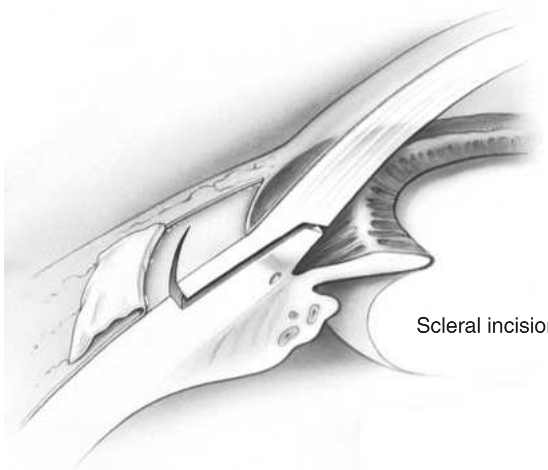


Figure 8-7 Illustration showing scleral tunnel incision, side view: The initial groove is one-third to one-half of the scleral depth. The incision is traditionally 2–3 mm posterior to the limbus. The tunnel is traditionally dissected past the vascular arcade. A short third plane is made by changing the angle of the blade before it enters the anterior chamber. *(Reproduced with permission from Johnson SH. Phacoemulsification.* Focal Points: Clinical Modules for Ophthalmologists. *American Academy of Ophthalmology; 1994, module 6. Illustration by Christine Gralapp.)*

superficially, the scleral flap will be very thin and prone to tears at the edges of the flap as well central tears ("buttonholes").

To enter the anterior chamber from beneath the scleral flap, the surgeon uses a keratome sized to match the width of the phaco tip. The keratome is inserted into the corneal stroma until the tip reaches the clear cornea beyond the vascular arcade. The heel of the keratome is elevated, and the tip of the keratome is pointed posteriorly and aimed toward the center of the lens; this creates a dimple in the peripheral cornea. The keratome is then slowly advanced in this posterior direction to create an internal corneal lip as it enters the anterior chamber.

Continuous Curvilinear Capsulorrhexis

After the main incision has been made, the next step is to open the lens capsule. Opening the capsule with a continuous curvilinear capsulorrhexis (CCC; Fig 8-8) offers a number of advantages; it

- allows the surgeon to choose from a wide range of phacoemulsification techniques
- resists radial anterior capsule tears that could extend around and open the posterior capsule
- stabilizes the lens nucleus, allowing maneuvers to disassemble it within the capsular bag (thereby reducing trauma to the corneal endothelium)
- transfers haptic forces circumferentially and helps stabilize and center the lens implant

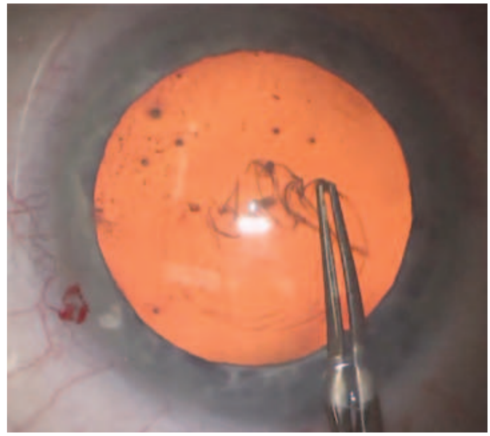


Figure 8-8 A capsulorrhexis is initiated with a puncture into the anterior capsule, which is then extended radially, and a flap turned over. A cystotome or forceps is then used to grasp this flap and tear circumferentially. *(Courtesy of Nathan Hesemann, MD.)*

In addition, a CCC sized just smaller than the IOL optic may allow for tighter contact between the posterior surface of the posterior chamber IOL (PCIOL) and the posterior capsule, possibly reducing the incidence of posterior capsule opacification. Trypan blue dye can be used to stain the anterior capsule to improve visualization and facilitate creation of the CCC.

The surgeon begins a CCC with a central, radial cut in the anterior capsule using a cystotome needle or capsulorrhexis forceps with special tips for grasping and tearing. At the end of the radial cut, the needle or forceps is either pushed or pulled in the direction of the desired tear, allowing the anterior capsule to fold over on itself. The surgeon then engages the free edge with either forceps or the cystotome needle, and the flap is carried around in a circular manner (Video 8-1). For maximum control of the size of the CCC, frequent regrasping of the flap near the tear is helpful. An OVD may be added to keep the lens surface flat and reduce the likelihood of peripheral extension.

VIDEO 8-1 Continuous curvilinear capsulorrhexis.
Courtesy of Nathan Hesemann, MD.
Available at: aao.org/bcscvideo_section11

If the capsulorrhexis tear is allowed to turn too far inward, it can result in a central opening that is too small. If the tear turns too far outward, it can result in an opening that is too large or in extension of the tear to the posterior capsule. An opening that is too small complicates most nucleus disassembly techniques and may contract postoperatively (capsular phimosis). A capsulorrhexis that is too large may allow the IOL optic or haptic to become decentered or dislocate anteriorly. For these reasons, many surgeons advocate a size that just allows the capsular rim to cover the optic edge for 360°. This technique has become increasingly important with the use of premium IOLs, which require a stable position within the eye for optimal refractive results. An impending capsulorrhexis runout toward the equator can be rescued by the Little maneuver, which involves the surgeon pulling backward on the free edge of the rhexis (see Chapter 10, Video 10-7).

If a CCC cannot be completed, conversion to a can-opener capsulotomy is an acceptable strategy (see Chapter 9). A can-opener capsulotomy is performed by using a cystotome or bent 27-gauge needle to create multiple small tears or punctures in the anterior capsule: these are circumferential to the equator and pulled centrally in a clockwise or counterclockwise direction to create a complete opening. However, this type of anterior capsulotomy makes hydrodissection, hydrodelineation, and endocapsular phacoemulsification more challenging because of the increased likelihood of an anterior capsule tear extending around to the posterior capsule.

Alternatively, a circular capsulotomy may be made by a handheld electronic capsulotomy device or by a femtosecond laser (see the section Alternative Technologies for Cataract Extraction later in this chapter). Creation of a capsulotomy in the pediatric population can be much more difficult (see BCSC Section 6, *Pediatric Ophthalmology and Strabismus*).

Little BC, Smith JH, Packer M. Little capsulorhexis tear-out rescue. *J Cataract Refract Surg.* 2006;32(9):1420–1422.

Hydrodissection

Hydrodissection is performed to separate the peripheral and posterior cortex from the underlying posterior lens capsule. In addition to loosening the lens–cortex complex, this procedure facilitates nucleus rotation during phacoemulsification and hydrates the peripheral cortex, making it easier to aspirate after nucleus removal.

In this procedure, the surgeon uses a bent, blunt-tipped 25- to 30-gauge cannula or flattened hydrodissection cannula attached to a 3- to 5-mL syringe to inject BSS carefully under the capsular flap in a radial direction. Exerting gentle posterior pressure on the nucleus will express posterior fluid and prevent fluid pressure from rupturing the posterior capsule. Gentle irrigation continues until the surgeon sees a wave of fluid moving under the nucleus and across the red reflex (Video 8-2). Careful hydrodissection continues until nucleus rotation can be performed. Irrigation in the subincisional area may require a right-angled or J-shaped hydrodissection cannula or use of a paracentesis to access the area directly.

VIDEO 8-2 Hydrodissection.
Courtesy of Nathan Hesemann, MD.
Available at: aao.org/bcscvideo_section11

If the nucleus is displaced into the anterior chamber, it can be reposited into the posterior chamber with injection of OVD and application of slight posterior pressure. Alternatively, a supracapsular phacoemulsification technique may be selected in this situation. Hydrodissection is riskier after a can-opener capsulotomy has been performed, with weakened zonular fibers, or with a posterior polar cataract (see Chapter 12 for further discussion of posterior polar cataracts).

Hydrodelineation

Some surgeons also inject BSS into the substance of the nucleus for *hydrodelineation,* or separation, of the various layers of the nucleus. This separates the harder endonucleus from the softer epinucleus, which can be left to cushion the underlying posterior capsule. In less brunescent cataracts, a fluid wave can be seen separating the endonucleus from the epinucleus and producing the "golden ring" sign. In cataracts with a white or densely brunescent nucleus, the epinucleus layer may not be present, making hydrodelineation ineffective.

Nucleus Rotation

If hydrodissection has succeeded in breaking the attachments between the peripheral and posterior cortex and the posterior capsule, the surgeon should be able to rotate the nucleus within the capsular bag. Phacoemulsification techniques are easier to perform when the lens rotates freely. Difficulty in rotation may suggest inadequate hydrodissection, loose zonular fibers, or posterior capsule rupture. Attempting to rotate the nucleus in patients with loose zonular fibers can weaken the stability of the capsular bag.

Nucleus Disassembly and Removal

Most methods of nucleus disassembly and removal consist of several distinct steps: sculpting, cracking, chopping, grasping, and emulsifying. With modern phaco machines, all parameters (power levels and intervals of delivery, aspiration flow rate, and vacuum) can be adjusted for each step of the procedure as well as for the density of the cataract, giving the surgeon maximum control of the process.

Clinical Pearl Immediately before initiating phacoemulsification, the surgeon can use the phaco handpiece to aspirate some of the dispersive OVD above the anterior lens surface to create a "working space," thereby decreasing the risk of thermal wound burn (see Chapter 10 for a discussion of intraoperative thermal injury to the cornea).

Two main modes, or settings, are used during phacoemulsification: (1) sculpt (if a "divide and conquer" technique is used) or chop (if a chopping technique is used; see the section Techniques of Nucleus Disassembly) and (2) segment removal. Although exact settings will depend on the machine and can be optimized for a surgeon's technique, preliminary relative settings for the major steps of nucleus removal are shown in Table 8-1.

With the *sculpt* setting, the central nucleus is debulked. This process involves a shaving maneuver in which the phaco tip is never fully occluded in order to generate minimal vacuum. Thus, the portion of the phaco needle that is in contact with the lens passes through

Table 8-1 Preliminary Relative Settings for the Steps of Nucleus Removal

	Vacuum Limit	Aspiration Flow Rate	Ultrasound Mode
Sculpting	Low	Low	Continuous mode, or pulse mode (with high duty cycle and high pulses per second)
Chopping	High	Low/moderate	Burst mode (with longitudinal ultrasound)
Segment Removal	Moderate/high	Moderate/high	Pulse mode

it without grabbing, and the lens material can be emulsified and aspirated in a controlled fashion. Because of the scaphoid shape of the posterior lens, the sculpted groove should be deeper centrally and shallower peripherally to avoid sculpting through the peripheral posterior capsule. Sculpting is usually performed with low vacuum, low aspiration flow rate, and linear continuous or pulsed ultrasound mode (with high duty cycle and high pulses per second), with a relatively high maximum power setting.

The *chop* setting is used to impale and hold the nucleus with the fully occluded phaco tip, allowing for mechanical chopping of the nucleus with a second instrument. This can be effectively performed with burst-mode longitudinal phacoemulsification, high vacuum, and a 0°, 15°, or 30° bevel phaco tip (which is easier to occlude to achieve full vacuum than is a 45° or 60° bevel phaco tip).

The *segment removal* setting is employed once the nucleus has been divided (using one of the techniques described later in this chapter); the resulting fragments are grasped using moderately high vacuum and pulled centrally for emulsification. Full occlusion of the phaco tip is required for vacuum to build to the desired level. Once this level has been reached, ultrasound power may be applied. After the nucleus has been emulsified, the epinuclear material may be removed with a lower aspiration flow rate setting with either the phaco handpiece or the irrigation/aspiration instrument (discussed in the section Irrigation and Aspiration later in this chapter).

Alternatively, nonphaco mechanisms for nuclear disassembly include fracturing the lens mechanically with a nitinol loop or prechopper or segmenting and softening the nucleus with a femtosecond laser (see the section Alternative Technologies for Cataract Extraction later in this chapter).

Location of Emulsification

The nucleus may be emulsified at various locations within the eye, including the posterior chamber, iris plane, and anterior chamber. The location determines which techniques are used to emulsify the nucleus.

Posterior chamber

The posterior chamber is a common location for nucleus disassembly and emulsification. Removal of the nucleus at this location is facilitated by hydrodissection and nucleus rotation. The advantages of posterior chamber phacoemulsification include a reduced risk of corneal endothelial trauma and the ability to minimize the size of the capsulorrhexis opening, which is helpful with suboptimal pupil dilation. Disadvantages include increased risk of complications because emulsification takes place closer to the posterior capsule, greater stress placed on the capsule and zonular fibers when the nucleus is being manipulated, and the need for sophisticated methods of nucleus splitting.

Iris plane

When phacoemulsification is performed at the iris plane, one piece (or pole) of the nucleus is prolapsed anteriorly. Once prolapsed, the nucleus can be manipulated with less stress on the posterior capsule and zonular fibers. Emulsification occurs between the corneal endothelium and the posterior capsule, thereby reducing the risk of damage to either structure.

This location is often suitable for the beginning phacoemulsification surgeon and advantageous in patients who have compromised capsular or zonular integrity. In patients with small pupils, this technique permits good visualization and enables safe emulsification. The disadvantages of working at the iris plane include possible difficulty prolapsing the nucleus and risk of damage to the corneal endothelium if the surgeon emulsifies the nucleus too close to the cornea.

Anterior chamber

This supracapsular approach involves prolapsing the nucleus through the capsulorrhexis during hydrodissection, which requires a medium to large capsulorrhexis and a relatively soft nucleus. This technique theoretically reduces the stress on the zonular fibers during manipulation of the nucleus. The risks include a greater chance of aspirating the iris in the phaco tip as well as damaging the corneal endothelium. Nevertheless, phacoemulsification in a supracapsular location is useful in situations such as the presence of posterior capsule rupture. Using an OVD to protect the endothelium and minimizing phaco energy are recommended.

Techniques of Nucleus Disassembly

Phaco fracture "divide and conquer" technique

The most widely used 2-handed technique, referred to as "divide and conquer nucleofractis," can be effectively applied to all but very soft cataracts.

After adequate hydrodissection (and hydrodelineation if desired), continuous ultrasound is used to sculpt a deep central linear groove or trough in the nucleus that is 1–1.5 times the width of the phaco tip. Signs of adequate groove depth include smoothing of the striations in the groove, brightening of the red reflex in the groove, and sculpting to a central depth of 2 or 3 phaco tip diameters (Fig 8-9).

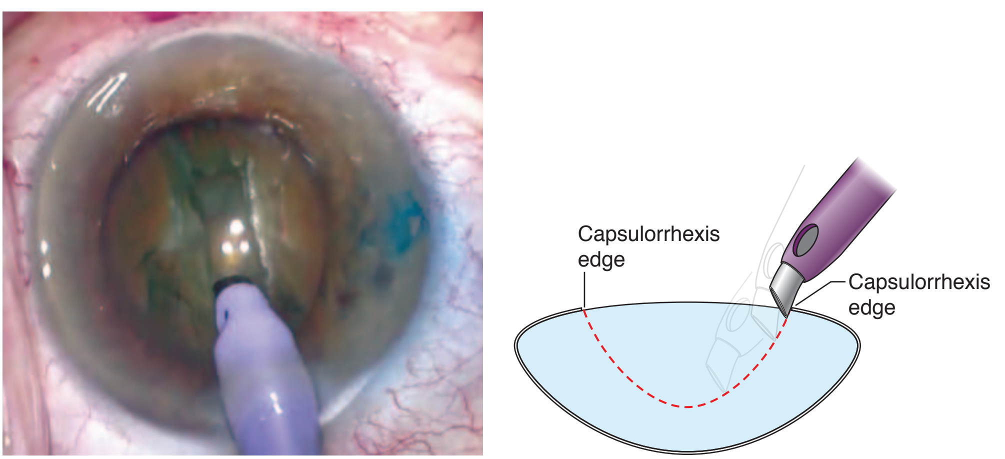


Figure 8-9 A central groove is sculpted under conditions of low vacuum *(left)*. The ideal groove is deeper centrally than peripherally to allow for effective cracking of the lens *(right)*. *(Photo courtesy of Lisa Park, MD. Illustration by Mark Miller.)*

Clinical Pearl Because of the scaphoid shape of the posterior lens, the sculpted groove should be deeper centrally and progressively shallower toward the periphery of the nucleus to avoid sculpting through the peripheral posterior capsule.

At this point, the surgeon can either separate the nucleus into 2 pieces (nucleus cracking) or rotate the nucleus 90° and sculpt a perpendicular groove (Video 8-3). The phaco tip and second instrument are then inserted into each groove and spread apart, thereby achieving complete separation/cracking of the pieces.

VIDEO 8-3 Nucleus cracking.
Courtesy of Lisa Park, MD.
Available at: aao.org/bcscvideo_section11

The surgeon can then engage a quadrant using the phaco tip and a segment removal setting. After adequate vacuum has been attained, the nuclear quadrant is pulled toward the center of the capsular bag and emulsified. Each quadrant is sequentially removed in the same manner (Video 8-4).

VIDEO 8-4 Divide and conquer technique.
Courtesy of Kevin M. Miller, MD.
Available at: aao.org/bcscvideo_section11

Chopping techniques

The *horizontal phaco chop* technique does not entail creation of a central groove but instead uses the natural fault lines in the lens nucleus to create a fracture plane. After burying the phaco tip in the center of the nucleus while using high vacuum, the surgeon inserts a chopping instrument (Fig 8-10A) under the anterior capsule flap, deeply engages the endonucleus in the periphery, and draws it toward the phaco tip, thereby cracking the nucleus into 2 pieces (Videos 8-5 and 8-6). This technique requires the surgeon to place the chopper under the capsular rim and around the equatorial nucleus. The phaco tip is then buried in one of the nuclear halves, and the surgeon uses the chopping instrument in the same fashion to create multiple small wedges of nucleus for emulsification.

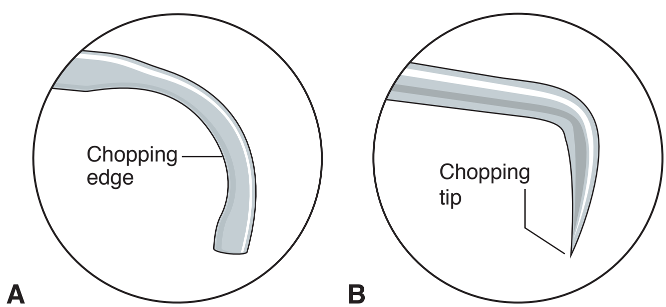


Figure 8-10 An example of a horizontal chopper tip **(A)** and vertical chopper tip **(B).** *(Illustration by Mark Miller.)*

VIDEO 8-5 Horizontal phaco chop technique.
Courtesy of Lisa Park, MD.
Available at: aao.org/bcscvideo_section11

VIDEO 8-6 Horizontal phaco chop technique using Connor wand.
Courtesy of Kevin M. Miller, MD.
Available at: aao.org/bcscvideo_section11

A modification of this procedure entails sculpting a central groove and then cracking the nucleus into 2 pieces. The resulting heminuclei are then chopped into smaller pieces. This technique, known as *stop and chop,* affords the surgeon more room to manipulate the nuclear pieces in the capsular bag.

Vertical chopping techniques are also used. After the center of the nucleus is impaled with the phaco tip, using high vacuum, the surgeon buries a chopper with a sharp tip within the nucleus, just adjacent to the phaco tip (Fig 8-10B). The phaco tip lifts while the chopper depresses, and the surgeon separates the instruments to complete the chop, which occurs along natural fault lines in the nucleus (Video 8-7).

VIDEO 8-7 Vertical phaco chop technique.
Courtesy of Alex W. Cohen, MD, PhD.
Available at: aao.org/bcscvideo_section11

In practice, either the vertical or the horizontal chopping technique can be used with almost any other strategy for disassembly of the nucleus. Chopping may be difficult in soft nuclei, for example, as with pure posterior subcapsular cataracts. Other techniques, such as hydrodelineation and aspiration with minimal phaco power, may be more appropriate in these cases.

Chang DF. *Phaco Chop and Advanced Phaco Techniques: Strategies for Complicated Cataracts.* 2nd ed. Slack; 2013.
Garg SD, Koch DD. *Steinert's Cataract Surgery.* 4th ed. Elsevier; 2023.

Irrigation and Aspiration

Once phacoemulsification of the nucleus has been completed, a plate of soft epinucleus or transitional cortex may rest on the posterior capsule. The surgeon can use irrigation and aspiration (I/A) alone or the phaco needle with reduced vacuum and flow settings, without ultrasound energy, to aspirate this material from the capsular fornix or posterior capsule.

In the coaxial cortical removal technique, the port is rotated toward the equator of the lens capsule, and the cortical material is engaged under low vacuum and stripped to the center of the inflated capsular bag. The surgeon rotates the port so that it is fully visible, and the cortex can be aspirated under greater vacuum. This procedure is repeated until all of the cortex is removed. If the surgeon finds it difficult to reach the subincisional cortex, a 45°, right-angled (90°), or U-shaped (180°) aspiration cannula may be useful (Video 8-8).

VIDEO 8-8 Coaxial irrigation and aspiration of cortex.
Courtesy of Nathan Hesemann, MD.
Available at: aao.org/bcscvideo_section11

The I/A functions may also be separated using a bimanual technique in which the aspiration port is introduced through the paracentesis incision while irrigation through a second paracentesis maintains the anterior chamber. The instruments may be interchanged as needed (Video 8-9). An advantage of this technique is that it allows the surgeon to more easily reach the subincisional cortex. A disadvantage is the need for an additional paracentesis.

VIDEO 8-9 Bimanual irrigation and aspiration of cortex.
Courtesy of Lisa Park, MD.
Available at: aao.org/bcscvideo_section11

Cortex resistant to aspiration can be separated from the capsular bag with an OVD (ie, viscodissection) to allow easier access with the I/A handpiece. Another strategy is to postpone removal of residual cortex until after IOL implantation. The implant can be rotated within the capsular bag so that the haptics further loosen the cortex. The surgeon must weigh the benefits of attempting to remove small amounts of residual cortex against the risk of damaging the posterior capsule. Very small amounts of retained fine cortical strands may be resorbed postoperatively.

The surgeon may then polish the posterior capsule and/or posterior surface of the anterior lens capsule to remove residual lens epithelial cells, which contribute to development of postoperative capsular opacification and capsular phimosis. Polishing can be accomplished either with a mechanical polishing instrument or with gentle aspiration, using an I/A tip. The surgeon must take care to avoid posterior capsule rupture during this maneuver.

Insertion of the Intraocular Lens

For a discussion of the history of IOL design and development, see the Introduction in this volume. IOLs are also discussed in BCSC Section 3, *Clinical Optics and Vision Rehabilitation*, and Section 13, *Refractive Surgery*. For a more detailed discussion of currently available IOLs, including toric, accommodating, extended depth of focus, and multifocal IOLs, see Chapter 7.

In uncomplicated cataract surgery, the surgeon's goal is generally to place an IOL into the capsular bag. The surgeon must determine whether the support structures within the eye are adequate to maintain IOL centration and stability. With posterior capsule rupture, sufficient anterior capsule support may allow a 3-piece PCIOL to be safely placed in the ciliary sulcus. Complete lack of capsular support warrants placement of an anterior chamber IOL (ACIOL) or a scleral- or iris-fixated posterior chamber lens.

In all cases, an OVD is used to fill the capsular bag or expand the ciliary sulcus, stabilize the anterior chamber during IOL insertion, and protect the corneal endothelium from contact with the IOL. The phacoemulsification incision must be large enough to accommodate the IOL and inserter; if necessary, the incision may be enlarged after removal of the cataract.

Some surgeons choose to utilize intraoperative aberrometry to confirm lens power selection prior to lens insertion to reduce refractive error, which can be of particular benefit in patients who have had prior refractive surgery and those in need of astigmatism correction (see Chapters 7 and 12 for details).

Foldable single-piece IOLs

Foldable single-piece and 3-piece IOLs are the most commonly used IOL styles. A foldable single-piece IOL (Fig 8-11A) is loaded into an injector cartridge that has been prefilled with an OVD (Video 8-10). The cartridge is then inserted into a handpiece, which is operated with a manual plunger or screw mechanism. Preloaded IOL injector systems are increasingly common, and automated inserters are also available. The tip of the injector is then introduced into the corneal wound and the IOL inserted, with the first haptic placed carefully into the capsular bag under direct visualization. The trailing haptic is flexed and placed into position, or "dialed in," by being rotated clockwise with slight posterior pressure and utilization of either the tip of the injector or a second instrument, such as a hook, so that the second haptic slides under the anterior capsule (Video 8-11). A "Z" orientation of the IOL haptics ensures that the lens is placed right-side-up in the bag. A foldable single-piece IOL should never be placed in the ciliary sulcus or anterior chamber because of the risk of iris chafing and uveitis-glaucoma-hyphema (UGH) syndrome (see Chapter 11).

VIDEO 8-10 One-piece lens loading technique.
Courtesy of Nathan Hesemann, MD.
Available at: aao.org/bcscvideo_section11

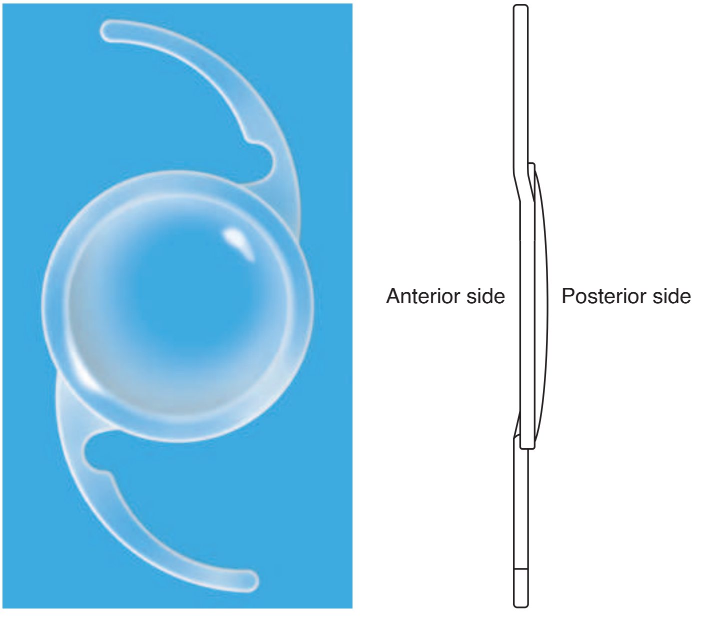
VIDEO 8-11 Injection of a single-piece intraocular lens.
Courtesy of Nathan Hesemann, MD.
Available at: aao.org/bcscvideo_section11

Foldable 3-piece IOLs

Foldable 3-piece IOLs are generally made of either an acrylic or a silicone optic with polypropylene haptics (Fig 8-11B), though haptics made of polyvinylidene fluoride, which are less fragile, are also available. These lenses can be placed into either the capsular bag or the ciliary sulcus using an injector, or they can be folded in half and placed through the incision using implant forceps. Three-piece IOL insertion usually requires incision enlargement. The optic and trailing haptic are positioned using forceps or by dialing in the lens, as described in the preceding section.

Polymethyl methacrylate IOLs

Polymethyl methacrylate (PMMA) IOLs are not foldable and may be safely inserted with standard, fine-tip, smooth forceps. The phacoemulsification incision must be widened to accommodate the size of the lens, and the IOL is advanced by first placing the leading haptic into position and then rotating the optic and trailing haptic into place.



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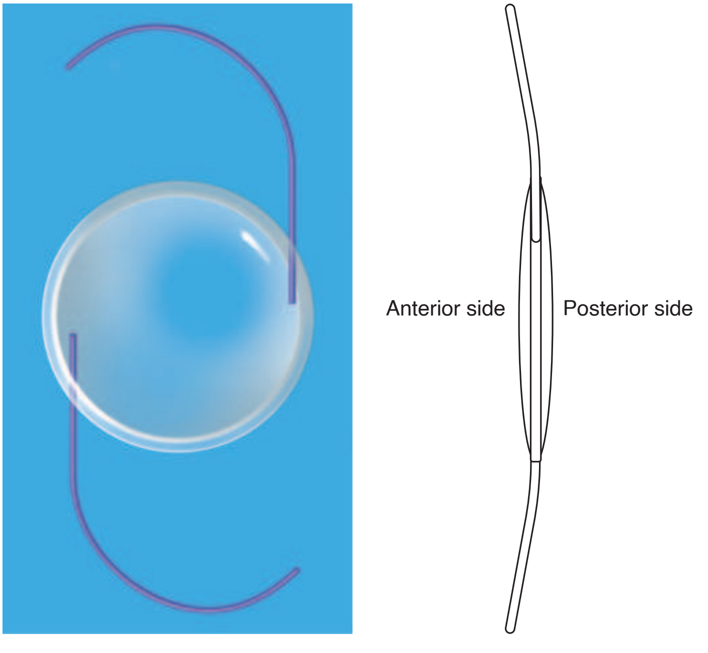


B

Figure 8-11 Illustrations of a modern foldable single-piece posterior chamber intraocular lens **(A)** and a modern foldable 3-piece posterior chamber intraocular lens **(B).** Note the "Z-configuration" of the haptics and the posterior displacement of the optic relative to the haptics, which denote that the IOL is right-side-up. *(Illustration by Mark Miller.)*

Scleral- or iris-fixated posterior chamber IOLs

Several techniques have been described for securing a PCIOL behind the iris when capsular support is inadequate. If the lens is to be sutured to the sclera, polypropylene sutures or Gore-Tex sutures (W. L. Gore & Associates) are typically used instead of nylon sutures, because nylon degrades over time and lens dislocation may result. Transscleral polypropylene or Gore-Tex sutures may be used to secure the IOL haptics in the ciliary sulcus, or the haptics may be sutured to the overlying iris with polypropylene sutures. Note that the Gore-Tex suture packaging explicitly states that the product is not for ophthalmic use. Alternative techniques have been described whereby the PCIOL haptics are secured via a scleral tunnel, with or without the use of surgical glue (see Chapter 11 for a detailed discussion of these techniques).

A scleral-fixated PCIOL is a valuable alternative to an ACIOL in situations when an angle-supported lens may be problematic, such as when peripheral anterior synechiae are present or there is significant corneal endothelial compromise. Scleral-fixation techniques are more difficult than those used in standard implantation and are associated with a greater risk of complications, such as vitreous hemorrhage, lens dislocation, lens tilt, and late endophthalmitis (see Chapters 10 and 11).

Agarwal A, Jacob S, Kumar DA, Agarwal A, Narasimhan S, Agarwal A. Handshake technique for glued intrascleral haptic fixation of a posterior chamber intraocular lens. *J Cataract Refract Surg.* 2013;39(3):317–322.

Yamane S, Sato S, Maruyama-Inoue M, Kadonosono K. Flanged intrascleral intraocular lens fixation with double-needle technique. *Ophthalmology.* 2017;124(8):1136–1142.

Anterior chamber IOLs

Modern, flexible, open-loop ACIOLs with 4-point fixation are supported by the anterior chamber angle and considered acceptable for use when implantation in the posterior chamber is not feasible (Fig 8-12). The appropriate length of the ACIOL is commonly determined using the horizontal diameter of the limbus, as measured externally with a caliper ("white to white"), plus 1 mm.

If an ACIOL is being implanted during the initial phacoemulsification procedure, it is generally advisable that the primary clear corneal phacoemulsification incision be sutured and abandoned in favor of a wider scleral tunnel incision at a secondary site. Otherwise, the corneal phacoemulsification incision will have to be enlarged with the keratome or with corneal scissors to enable insertion of an ACIOL, and this could lead to inadequate wound integrity. The pupil is generally constricted pharmacologically before IOL implantation, and any vitreous in the anterior chamber is removed. At least one peripheral iridectomy is performed to avoid pupillary block. The anterior chamber depth is stabilized, and the corneal endothelium is protected with an OVD. A lens glide may be inserted across the anterior chamber into the distal angle to isolate the iris from the advancing IOL haptic. The IOL is then inserted with the optic vaulted anteriorly (ensuring that the IOL is placed right-side-up) into the angle while the iris is observed for any indication of distortion. If a glide has been used, it is removed as the IOL is stabilized with forceps. The posterior lip of the incision is gently retracted to allow placement of the trailing haptic in the angle (Video 8-12).

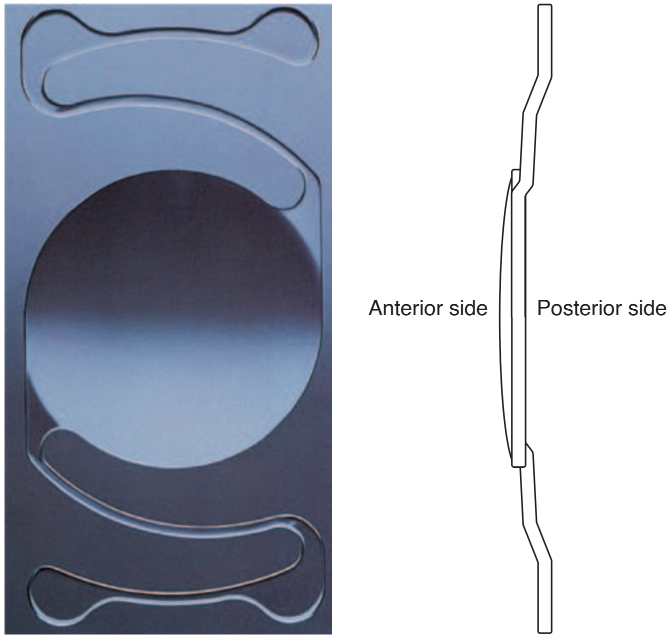


Figure 8-12 Kelman-style open-loop anterior chamber IOL with flexible 4-point fixation. Note the anterior displacement of the optic relative to the haptics. *(Photograph courtesy of Robert C. Drews, MD. Illustration by Mark Miller.)*

VIDEO 8-12 Placement of an anterior chamber intraocular lens.
Courtesy of Lisa Park, MD.
Available at: aao.org/bcscvideo_section11

Careful inspection confirms proper insertion. The pupil will peak toward any area of iris "tuck," in which case the IOL can be repositioned until the pupil is round and the optic is centered. The surgeon can adjust the position of the ACIOL by using a hook to flex the optic toward either angle.

After IOL Insertion

After removing the cataractous lens and inserting the IOL, the surgeon removes the OVD from the anterior segment to minimize the risk of increased postoperative intraocular pressure (IOP). In an uncomplicated case, once the IOL is in the capsular bag, the OVD may be removed by inserting the I/A tip behind the optic or pushing the optic posteriorly to prolapse the OVD and allow its aspiration from the anterior chamber; OVD is also aspirated from the angle and corneal endothelium. In the setting of capsular rupture or sulcus IOL placement, removal of the OVD is performed with minimal manipulation of the IOL to avoid destabilization.

To reproduce physiologic IOP, BSS is instilled via the paracentesis incision to reform the anterior chamber. The main incision is then examined for adequate closure. If the incision leaks, both sides and/or the roof of the corneal tunnel incision can be hydrated with BSS injected via a syringe with a blunt 25- to 30-gauge irrigating tip. Hydration of the corneal incision causes temporary stromal swelling and increases the wound apposition between the roof and the floor of the tunnel. This anterior–posterior reapproximation, rather than apposition of the external corneal edges, is the critical anatomical feature that determines good wound closure.

With the continuing evolution of techniques for self-sealing incisions and the use of foldable IOLs, many surgeons elect not to suture the incision at the conclusion of a routine case. Long-term results have shown that the small incisions used in modern cataract surgery heal quickly, are relatively stable, and induce minimal astigmatism.

When there is wound leakage, however, the surgeon must be ready to use additional means of closure, such as placement of a 10-0 nylon suture that can be removed postoperatively at the slit lamp. Incisions may also be closed with corneal sealants such as fibrin glue or cyanoacrylate-based adhesive.

Intracameral antibiotics are often instilled prior to case completion (see Chapter 7).

Dewey S, Beiko G, Braga-Mele R, Nixon DR, Raviv T, Rosenthal K; ASCRS Cataract Clinical Committee, Instrumentation and IOLs Subcommittee. Microincisions in cataract surgery. *J Cataract Refract Surg.* 2014;40(9):1549–1557.

Alternative Technologies for Cataract Extraction

Femtosecond Laser–Assisted Cataract Surgery

In 2010, the US FDA approved femtosecond lasers for cataract extraction. Well known to refractive surgeons, these Nd:glass lasers generate focused, ultrashort pulses (10^{-15} s) at a wavelength of 1053 nm (in the near-infrared region), creating cavitation bubbles within the tissues by photodisruption. Because femtosecond laser technology virtually eliminates collateral damage, it can be used to dissect tissue on a microscopic scale, enabling creation of a capsulotomy, lens fragmentation patterns, corneal relaxing incisions, and clear corneal incisions, if desired (Video 8-13).

VIDEO 8-13 Femtosecond laser treatment before cataract extraction.
Courtesy of Eric D. Snyder, MD.
Available at: aao.org/bcscvideo_section11

Before femtosecond laser–assisted surgery commences, the treatment plan is entered into the system's computer. For a capsulotomy, the size of the intended opening and IOL-centration method are selected. For lens fragmentation, the pattern used to segment and soften the lens is chosen (available patterns vary by machine). For corneal relaxing incisions, the optical zone, arc length, axis, and depth are selected. The laser can create either anteriorly penetrating corneal relaxing incisions or intrastromal (nonpenetrating) corneal relaxing incisions (see Chapter 9). For clear corneal incisions, the location, size, and wound architecture are selected.

After the eye has been dilated, the patient assumes a supine position. A patient interface docks the patient's eye to the laser unit. The system measures and maps the dimensions of the anterior segment with 3-dimensional spectral-domain optical coherence tomography (SD-OCT) or Scheimpflug imaging. The surgeon confirms the intended treatment protocol and ocular landmarks, including the proper axis orientation of any intended astigmatic treatment, and then activates the femtosecond laser by depressing the foot pedal. During lens fragmentation, gas released from the cavitation bubbles can accumulate between the nucleus and the capsule, creating a pneumodissection effect, which may reduce the need for subsequent hydrodissection. When the laser portion of the procedure is finished, the patient is undocked; some surgeons instill additional eyedrops at this point to address possible laser-induced miosis.

In the operating room, the eye is then prepared and draped for cataract surgery in the typical fashion and positioned beneath the operating microscope for cataract extraction using phacoemulsification (Video 8-14). If clear corneal incisions were created as part of the laser treatment, the surgeon dissects them open. The surgeon verifies that the capsulotomy is complete, carefully removes the anterior capsule with forceps, and may perform gentle hydrodissection and nucleus rotation before proceeding with nucleus removal. To titrate any anteriorly penetrating corneal relaxing incisions and increase their astigmatic effect, the surgeon may gently open them, either during surgery or in the postoperative period at the slit lamp. Methods of marking the intended axis of toric IOL alignment, including small astigmatically neutral corneal incisions or small tabs on the capsulotomy pattern, vary by laser platform.

VIDEO 8-14 Cataract extraction after femtosecond laser treatment.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

Potential complications related to femtosecond laser–assisted cataract surgery include subconjunctival hemorrhage from the patient interface; incomplete capsulotomy, which may lead to a radial capsular tear; and buildup of gas bubbles within the capsular bag, which can lead to posterior capsule rupture with aggressive hydrodissection.

Since the femtosecond laser was introduced into cataract surgery, its utility has been intensely debated within the ophthalmological community. Proponents of this approach extol its advantages, including more precise and predictable incisional astigmatism management, improved capsulotomy centration, reduced phaco energy, and reduced posterior capsular rupture. Others have raised concerns about the higher costs involved and point out that similar visual outcomes can be achieved by small-incision phacoemulsification as it is currently practiced, particularly for basic monofocal nontoric IOLs.

Outcomes of Cataract Surgery

Modern cataract surgery usually improves visual acuity and enhances subjective visual function. More than 90% of otherwise healthy eyes achieve a best-corrected visual acuity of 20/40 or better after surgery. When eyes with comorbid conditions such as diabetic retinopathy, glaucoma, and age-related macular degeneration are included, these rates are reported to be 85%–89%. A study of a large multicenter European database reported that approximately 93% of eyes achieved a postoperative spherical equivalent within 1.00 D of that predicted by preoperative biometry.

However, visual acuity is only one measure of the functional success of cataract surgery. Research tools have also been developed to assess how cataract progression and cataract surgery affect visual function (see Chapter 6). Prospective studies using these tools have shown that patients who undergo cataract surgery have substantial improvement in many quality-of-life parameters, including performance of activities in the community and the home, number of falls, mental health, driving ability, and life satisfaction.

Jaycock P, Johnston RL, Taylor H, et al. The Cataract National Dataset electronic multi-centre audit of 55,567 operations: updating benchmark standards of care in the United Kingdom and internationally. *Eye (Lond).* 2009;23(1):38–49.

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(4):447–452.

Melles RB, Holladay JT, Chang WJ. Accuracy of intraocular lens calculation formulas. *Ophthalmology.* 2018;125(2):169–178.

Sustainable Cataract Surgery

Enhancing patient safety and the effectiveness of cataract surgery are the surgeon's primary concerns. Consideration of economic costs to a national health budget, unnecessary waste production, landfill capacity, and the high energy input and carbon footprint of current cataract surgery practices deserve additional scrutiny. For example, one cataract surgery in the United Kingdom generates 30 times more surgical waste than a similar procedure at Aravind Eye Hospital in Madurai, India, which has a similarly low rate of endophthalmitis to that in the United States. Learning about best sustainability practices in other facilities may stimulate surgeons to make changes at their own centers, including using smaller surgical drapes, requesting reusable surgical instruments rather than disposable ones, and working with industry for more sustainable packaging for ophthalmic devices, including IOLs.

Waste of multidose ophthalmic medications is another example of poor economic and ecological sustainability. Some surgery centers prohibit reuse of topical medications because of concerns about contamination, despite evidence that proper reuse of eyedrop bottles doesn't lead to an increased risk of postoperative endophthalmitis. Discarding multiuse bottles of eyedrop medication after use in a single patient may waste hundreds of thousands of dollars per year and annually may generate up to 105,000 metric tons of carbon dioxide equivalent per surgical site. In 2022, a task force of the American Academy of Ophthalmology, American Society of Cataract and Refractive Surgery, American Glaucoma Society, and Outpatient Ophthalmic Surgery Society recommended that (1) topical medications can be used safely for multiple patients when proper protocol is followed; (2) topical medications can be used until the manufacturer's expiration date; and (3) patients should be allowed to take their partially used medications home with them after surgery. Despite support from the USFDA and the Joint Commission, some facilities still do not permit medication reuse.

Palmer DJ, Robin AL, McCabe CM, Chang DF. Ophthalmic Instrument Cleaning and Sterilization Task Force. Reducing topical drug waste in ophthalmic surgery: multisociety position paper. *J Cataract Refract Surg.* 2022;48(9):1073–1077.

Schehlein E, Farazdaghi M, Pettey J. "Sustainable Operating Room Practices" in Allen RC, ed. *Basic Principles of Ophthalmic Surgery.* 5th ed. American Academy of Ophthalmology. 2024:221–227.

Glossary of Fluidics and Phacodynamics Terminology

The following terms are commonly used in the discussion of fluidics and phacodynamics in phacoemulsification.

Aspiration flow rate (or flow rate) The rate of removal of fluid and lens material from the eye through the tubing, measured in milliliters per minute (mL/min); produced by depressing the foot pedal to position 2 and continuing in position 3. Flow occurs when the aspiration port is not completely occluded; the rate of flow helps determine how quickly fragments approach the aspiration port.

Aspiration port The opening at the end of an instrument (eg, phaco tip or irrigation/aspiration handpiece) through which fluid and lens material are removed from the eye.

Compliance A measure of how easily aspiration tubing is deformed by vacuum forces. Compared with low-compliance tubing, high-compliance tubing collapses more easily as vacuum builds, leading to a greater surge once occlusion has been broken and the tubing rebounds to an uncollapsed state.

Followability A qualitative descriptor for how quickly and easily fragments are attracted to and held at the aspiration port. Distal followability (how quickly fragments are attracted to the aspiration port) is improved by increasing the aspiration flow rate. Proximal followability (how easily fragments are held at the aspiration port) is improved by increasing both aspiration flow rate (in the case of partial occlusion) and vacuum (in cases of partial and complete occlusion).

Infusion pressure The pressure of the fluid coming through the irrigation tubing. It is controlled either by the irrigation bottle height (on a gravity-based machine) or by the IOP setting (on a bag compression–based machine).

Irrigation The influx of fluid into the eye, which is related to the infusion pressure.

Occlusion An obstruction of the aspiration port or aspiration tubing that causes vacuum to build until it reaches the machine's preset value or until the material is evacuated.

Rise time The time it takes for vacuum to build to a given level once the aspiration port has been occluded.

Surge (or postocclusion surge) An undesirable phenomenon that occurs when vacuum has built up because of an occlusion and the occlusion is suddenly broken, causing the fluid in the higher-pressure (positive) anterior chamber to rush into the lower-pressure (negative) aspiration tubing. When the sudden egress of fluid exceeds the influx capability of the irrigation line, sudden shallowing of the anterior chamber may occur, and the iris or posterior capsule may be drawn into the aspiration port. Surge can be minimized by increased infusion pressure (ie, increased irrigation), lower vacuum, low-compliance tubing of smaller diameter, a smaller aspiration port, coiled aspiration tubing, and occlusion-mode software (including automatic modification of irrigation and aspiration flow rate).

Vacuum The magnitude of negative pressure created in the aspiration tubing, measured in millimeters of mercury (mm Hg). Vacuum builds when the aspiration port is occluded, providing a gripping force; its strength determines how strongly particulate material will be held.

Vacuum limit The maximum level of vacuum that a pump can produce upon complete occlusion of the aspiration port.

Glossary of Ultrasonic Technology Terminology

The following terms are commonly used in reference to the ultrasonic technology of phacoemulsification.

Cavitation The formation of gas bubbles that arise from the aqueous in response to pressure changes at the phaco tip. The bubbles expand and contract; implosion of the bubbles causes localized intense heat and pressure liberation at the tip, resulting in emulsification of lens material. Continuous cavitation, which is produced by continuous ultrasound delivery, is less efficient than transient cavitation, which is produced by intermittent ultrasound delivery.

Chatter This undesirable phenomenon occurs when the repulsive force of the ultrasonic stroke overcomes the vacuum, or "holding power." This process causes the nuclear fragments to be repelled by the ultrasonic tip until the vacuum reaches a level sufficient to neutralize this repulsive energy and once again hold the material. This back-and-forth movement of lens material from the tip impairs followability (see the Glossary of Fluidics and Phacodynamics Terminology). Chatter can be diminished by reducing the phaco power (ie, by decreasing the stroke length of the tip), thereby reducing the forces that push a fragment away from the tip.

Duty Cycle The ratio of power-on time to total power-on plus power-off time. For example, a 10 millisecond pulse of phaco power followed by a 30 millisecond rest interval would have a duty cycle of 25%.

Energy Power multiplied by time. Surgeons can reduce the amount of energy released inside the eye by decreasing either the phaco power or the length of time that the phaco power is on. Thus, energy and power are not the same.

Frequency The speed at which the phaco needle moves back and forth. The term *ultrasonic* is used for frequencies above the range of human hearing or greater than 20,000 Hz. The frequency of phaco handpieces is between 27,000 and 60,000 Hz.

Piezoelectric crystal A type of transducer used in ultrasonic handpieces that transforms electrical energy into mechanical energy. Linear motion is generated when a tuned, highly refined crystal is deformed by the electrical energy supplied by the console.

Power The ability of the phaco needle to vibrate and cavitate the adjacent lens material. Power is noted as a linear percentage of the maximum stroke length of the phaco needle. Phaco power is produced when the foot pedal is in position 3.

Stroke length The linear distance that the tip traverses to impact the lens material. Among phaco devices, the stroke length varies from 0.05 to 0.10 mm (or 0.002 to 0.004 inch).

CHAPTER 9

Nonphacoemulsification Cataract Surgery Techniques

This chapter includes related videos. Go to aao.org/bcscvideo_section11 or scan the QR codes in the text to access this content.

Highlights

- Nonphacoemulsification techniques may be the procedure of choice for certain cases.
- Extracapsular cataract extraction (ECCE) is a large-incision technique that allows for removal of the intact lens nucleus.
- Manual small-incision cataract surgery (MSICS) is a variation of ECCE that allows for smaller, often sutureless, incisions.
- MSICS can typically be performed at a fraction of the cost and with comparable safety and visual outcomes to phacoemulsification.

Intracapsular Cataract Extraction

Traditional intracapsular cataract extraction (ICCE; Video 9-1) is a historical technique that is rarely performed today. ICCE surgery removed the entire lens, capsule, and zonule complex through a large incision. It is worthwhile to understand how an ICCE is performed and its role in the evolution of contemporary cataract extraction techniques.

VIDEO 9-1 Intracapsular cataract surgery.
Courtesy of John A. Hovanesian, MD.
Available at: aao.org/bcscvideo_section11

ICCE used a very large limbal incision to gain access to the lens-capsular complex. Manual intervention or chemical means, such as alpha-chymotrypsin, was used to disrupt the zonular fibers that attach the lens to the ciliary body. The limbal incision was stretched or folded open, and the entire lens-capsular complex was then removed in one piece with forceps, a suction cup, or a cryoprobe (Fig 9-1). There was a higher likelihood of vitreous prolapse, retinal detachment, and cystoid macular edema with this technique, compared to newer surgical approaches. Multiple sutures were required to close the large incision. The

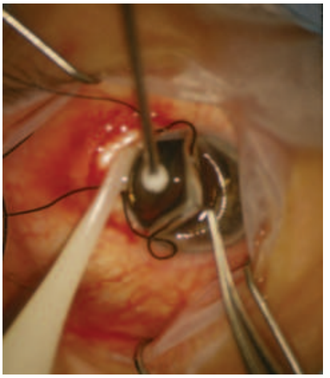


Figure 9-1 Cryoextraction of cataract (intracapsular cataract extraction). The probe is frozen to the cataract, which is then lifted out of the eye. *(Courtesy of Lisa F. Rosenberg, MD.)*

patient was either left aphakic or required an anterior chamber intraocular lens (ACIOL), an iris-fixated lens, or a scleral-fixated lens implant due to the lack of capsular support.

Standard Extracapsular Cataract Extraction

Some patients present with cataracts judged to be too dense to safely employ phacoemulsification. Other patients have damaged corneas that may not permit adequate visualization for the more frequently used cataract surgery techniques. For such patients, standard extracapsular surgery (Video 9-2) may be the best option, depending on the surgeon's preference.

VIDEO 9-2 Standard extracapsular cataract surgery.
Courtesy of Yen Cheng Hsia, MD, and Cynthia S. Chiu, MD.
Available at: aao.org/bcscvideo_section11

Some patients may have ocular findings or history that would make ECCE or MSICS a more challenging technique. Patients with small pupils, scleral scarring from previous surgical procedures (such as pars plana vitrectomy), diseases that cause scleral thinning, and who have had or may need glaucoma filtering surgery may not be good candidates for ECCE or MSICS.

Patient preparation

The patient is prepared for intraocular surgery in routine fashion: informed consent is obtained, the surgical site is unambiguously marked, the pupil is dilated, and a time-out is performed. Anesthesia is begun; this usually consists of conscious sedation with a retrobulbar block. The eye is then prepared and draped in the usual sterile fashion, and an eyelid speculum is placed. Detailed descriptions of surgical preparation can be found in Chapter 7.

Incision

A bridle suture, a 6-0 silk suture placed transconjunctivally beneath the superior rectus tendon, may help infraduct the eye and improve exposure of the superior sclera after it is secured to the surgical drape. A fornix-based conjunctival flap is made superiorly, followed by cauterization of the scleral bed.

An 8–12 mm, partial-thickness groove of approximately 50% depth is made in the sclera approximately 1 mm posterior to the limbus; this is done curvilinearly, parallel to the limbal curvature. A round-tipped steel blade is then used to create a shelved incision, or scleral tunnel, along the entire length of the groove; this typically extends to the limbus. A small paracentesis incision is created through the clear cornea, with care taken not to intersect with the scleral tunnel, and the anterior chamber is filled with an ophthalmic viscosurgical device (OVD). Next, a keratome blade is used to enter the anterior chamber through this scleral tunnel, but the incision is not yet extended along the entire length of the scleral tunnel in order to maintain the stability of the anterior chamber for creation of the capsulotomy.

Anterior capsulotomy

ECCE can be performed with either a large continuous curvilinear capsulorrhexis (CCC) or a noncontinuous capsulorrhexis, such as a can-opener capsulotomy (Fig 9-2) or a triangular capsulotomy. Both can-opener capsulotomies and CCCs are performed with the same technique as described in chapter 8, but the diameter of the capsular opening should be larger (>6 mm) than for routine phacoemulsifcation, due to the expression of an intact nucleus through it. Expression of a large or dense nucleus through a small CCC may cause uncontrolled traumatic tears in the capsulorrhexis, which can lead to rupture of the posterior

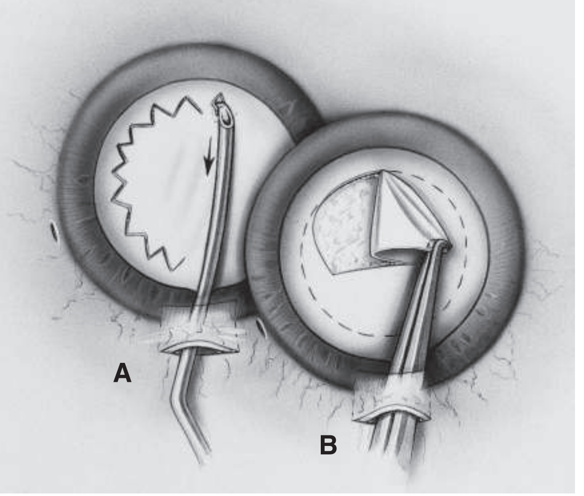


Figure 9-2 Anterior capsulotomy techniques. **A,** In a can-opener incision, punctures are made peripherally and pulled centrally so that the torn edges connect. Each puncture site has the potential for a radial tear if stressed. **B,** In a capsulorrhexis, tearing is begun within the area to be excised and finished from the outside in. When stress lines in the free flap appear between forceps and the tear site, best control is maintained by regrasping the flap near the tear site. "Positive vitreous pressure" makes the tear travel peripherally; filling the anterior chamber with an ophthalmic viscosurgical device will counteract the posterior vitreous pressure and make it easier to complete the capsulorrhexis tear. *(Reproduced from Johnson SH. Phacoemulsification.* Focal Points: Clinical Modules for Ophthalmologists. *American Academy of Ophthalmology; 1994, module 6. Illustration by Christine Gralapp.)*

capsule. After the capsulotomy is completed, the initial scleral tunnel incision is opened along its entire length to allow safe passage of the nucleus through the incision.

Nucleus removal

The surgeon first loosens the nucleus and elevates it out of the capsular bag. This can be accomplished using a hooked instrument to rock and rotate the nucleus or by using an irrigating cannula to prolapse the lens anteriorly. Some surgeons skip this step if a large can-opener capsulotomy was made. A lens loop, spoon, or vectis (irrigating looped cannula) is placed through the scleral incision, under the superior pole of the nucleus, and used to carefully depresses the posterior lip of the incision. A second instrument, such as a muscle hook, is used to apply gentle pressure on the outside of the globe, 180° away from the incision. This creates a pressure gradient that is used to sweep the nucleus through the incision and out of the eye.

The incision is partially sutured to allow deepening of the anterior chamber with irrigation. Using irrigation/aspiration equipment or a Simcoe cannula (Fig 9-3), the surgeon then aspirates the lens cortex.

Intraocular lens insertion

Prior to posterior chamber intraocular lens (PCIOL) insertion, the anterior chamber and capsular bag are filled with an OVD. One or more of the sutures may need to be cut, depending on the technique for inserting the PCIOL. An appropriate PCIOL may be inserted into the ciliary sulcus or the capsular bag. The type and size of capsulotomy usually determines what type of PCIOL is placed. The larger capsulotomy size may make it harder to determine if the haptics are within the capsular bag, especially if the pupil size has decreased during the case. If the surgeon cannot see the anterior capsular edge during surgery and wants to place a 1-piece foldable PCIOL in the capsular bag, then confirmation of the haptic's position underneath the anterior capsule must be performed with an instrument that can push the iris edge back to allow for exposure of the capsule, such as a Kuglan hook. If the capsulotomy is very large or cannot be visualized, a 3-piece lens may be the preferred intraocular lens (IOL), as it can safely be placed in the sulcus or the capsular bag.

Figure 9-3 Simcoe irrigating/aspirating cannula. *(Courtesy of Carol Everhart Roper.)*

Closure

The ECCE incision is then fully closed with multiple interrupted 10-0 nylon sutures. Residual OVD is removed from the eye with the irrigation/aspiration equipment or with a Simcoe cannula through a properly sized gap in the interrupted sutures. The conjunctiva is closed with cautery or with an 8-0 vicryl suture.

Proper suturing technique, which consists of radial sutures at the correct tension, helps reduce postoperative astigmatism: loose sutures induce corneal flattening, whereas tight sutures cause corneal steepening in the axis of the suture. The refraction is typically stable by the fourth to sixth postoperative week. If a significant amount of postoperative astigmatism is present in the axis of tight sutures, the clinician may selectively remove the sutures as guided by wound stability, keratometry readings, or corneal topography measurements.

Manual Small-Incision Cataract Surgery

MSICS (Video 9-3) is a variation of ECCE. Both ECCE and MSICS utilize a binocular operating microscope but otherwise do not require access to electronic instrumentation, which makes these techniques especially useful in areas of the world that require low-cost and high-volume cataract extraction.

VIDEO 9-3 Manual small-incision cataract surgery.
Courtesy of Charles Cole, MD; video by Grace Sun, MD.
Available at: aao.org/bcscvideo_section11

Incision

A patient undergoing MSICS is prepared for surgery, a bridle suture is sometimes placed, a fornix-based conjunctival flap is made, and hemostasis is achieved with cautery in the scleral bed in the same manner as traditional ECCE. A partial-thickness scleral incision of approximately 50% depth is made 1.5–2.0 mm posterior to the limbus in the form of a straight or frown-shaped groove 6–7 mm in length, oriented away from the limbus. Using a round-tipped blade, the surgeon tunnels this incision forward into clear cornea. The tunnel is shaped like a trapezoid or a fan, such that the internal corneal incision is wider than the external scleral incision. This construction allows for delivery of the nucleus while a self-sealing external incision is generally maintained. A small stab paracentesis is made with care to avoid the main incision, and the anterior chamber is filled with OVD. Similar to a traditional ECCE, a keratome blade is used to enter the anterior chamber through the scleral tunnel, but the incision is not extended at this time in order to maintain the stability of the anterior chamber for creation of the capsulotomy.

Anterior capsulotomy

Like a traditional ECCE, MSICS can be performed with either a large CCC or a noncontinuous capsulotomy. After the capsulotomy is completed, the initial scleral tunnel incision is opened along its entire length to allow passage of the nucleus through the incision.

Nucleus removal

The nucleus is loosened and then prolapsed completely into the anterior chamber with an irrigating cannula or hook. A small or soft nucleus may be expressed by placing an irrigating vectis anterior to the capsule and underneath the nucleus. The intraocular pressure is then increased by irrigating through the vectis, and the nucleus is delivered intact through the scleral incision. A large or dense nucleus may be expressed intact as above, or it may require manual fragmentation prior to delivery. Aspiration of cortex is performed using the Simcoe cannula. If necessary, the MSICS incision may be converted to a traditional ECCE incision for nucleus removal.

IOL insertion

The anterior chamber and capsular bag are filled with OVD. Traditionally, a rigid 6-mm polymethyl methacrylate (PMMA) lens is then placed into the capsular bag, although 3-piece acrylic lenses and even 1-piece foldable acrylic lenses have been used successfully by some surgeons in MSICS cases. As noted above, if a 1-piece acrylic lens is inserted, it needs to be situated securely within the capsular bag to assure that the thicker haptics do not chafe the iris or ciliary body.

Closure

A properly constructed wound should be self-sealing. If necessary, the wound may be closed with 10-0 nylon sutures to prevent wound leakage. The conjunctiva is closed at the limbus with cautery or an 8-0 vicryl suture.

Studies have shown that, in comparison to ECCE, MSICS allows a higher volume of surgical procedures as well as faster vision recovery, less postoperative astigmatism, and better uncorrected visual acuity. Multiple studies have shown that vision outcomes and complication rates for MSICS are comparable to those for phacoemulsification, although better early uncorrected visual acuity may favor phacoemulsification. At least one study has shown that phacoemulsification is about 4 times more expensive than MSICS.

Haripriya A, Chang DF, Reena M, Shekhar M. Complication rates of phacoemulsification and manual small-incision cataract surgery at Aravind Eye Hospital. *J Cataract Refract Surg.* 2012;38(8):1360–1369.

Riaz Y, de Silva SR, Evans JR. Manual small incision cataract surgery (MSICS) with posterior chamber intraocular lens versus phacoemulsification with posterior chamber intraocular lens for age-related cataract. *Cochrane Database Syst Rev*. 2013;10.

Ruit S, Tabin G, Chang D, et al. A prospective randomized clinical trial of phacoemulsification vs manual sutureless small-incision cataract surgery in Nepal. *Am J Ophthalmol.* 2007;143(1):32–38.

Tabin G, Chen M, Espandar L. Cataract surgery for the developing world. *Curr Opin Ophthalmol.* 2008;19(1):55–59.

CHAPTER 10

Intraoperative Challenges in Cataract Surgery

This chapter includes related videos. Go to aao.org/bcscvideo_section11 or scan the QR codes in the text to access this content.

Highlights

- Posterior capsule rupture is the most common significant intraoperative complication of phacoemulsification.
- Patients with intraoperative floppy iris syndrome have an increased risk of surgical complications.
- Because a continuous curvilinear capsulorrhexis (CCC) resists radial anterior capsule tears and helps stabilize the nucleus and the intraocular lens (IOL), any discontinuity of the CCC can complicate the remainder of the cataract extraction and IOL placement.
- In cases of posterior capsule rupture, vitreous loss can be minimized by reducing fluid inflow and stabilizing the anterior chamber with an ophthalmic viscosurgical device (OVD) prior to removing instruments from the main incision.
- Vitreous loss should be managed with bimanual vitrectomy if possible, not with pulling and external cutting.

Introduction

Complications of cataract surgery that result in permanent loss of vision are rare, thanks to the advent of modern surgical techniques and technology used by experienced cataract surgeons. Posterior capsule rupture (PCR) is the most common significant *intraoperative* complication of phacoemulsification (reported in 0.6%–1.65% of cases, a range that has decreased in recent years). There are multiple reports of the rate of PCR having increased (up to 3.5%) for a short time, immediately after temporary shutdowns related to COVID. The incidence of severe adverse events after cataract surgery, including endophthalmitis, suprachoroidal hemorrhage, and retinal detachment, has declined over the past several decades. *Postoperative* complications are discussed in Chapter 11.

Minimizing intraoperative complications begins with surgical planning and preparation. As discussed in Chapters 7 and 12, it is critical to make sure that the patient is comfortable to avoid complications due to excessive patient movement. The proper functioning of instruments to be used in the eye should always be checked prior to surgery. A loose cannula can become a projectile in the anterior chamber (Video 10-1); a retracted irrigation sleeve can slip external to the incision; a detached irrigation tube from the phacoemulsification handpiece can cause a sudden collapse of the anterior chamber. Some complications are mild and self-limited; others are severe and vision-threatening (Table 10-1).

VIDEO 10-1 Projectile in anterior chamber.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

American Academy of Ophthalmology Cataract/Anterior Segment Panel, Hoskins Center for Quality Eye Care. Preferred Practice Pattern® Guidelines. *Cataract in the Adult Eye—2022.* American Academy of Ophthalmology; 2022. aao.org/ppp

Segers MHM, Behndig A, van den Biggelarr FJHM, et al. Risk factors for posterior capsule rupture in cataract surgery as reflected in the European Registry of Quality Outcomes for Cataract and Refractive Surgery. *J Cataract Refract Surg.* 2022;48(1):51–55.

Theodoraki K, Naderi K, Lam CFJ, et al. Impact of cessation of regular cataract surgery during the COVID pandemic on the rates of posterior capsular rupture and post-operative cystoid macular oedema. *Eye (Lond).* 2023;37(3):440–445.

Corneal and Conjunctival Complications

Self-Limited Intraoperative Complications

Subconjunctival hemorrhages may occur due to conjunctival contact with stabilization instruments used in the process of making clear corneal incisions, or from incidental conjunctival contact during other maneuvers. Conjunctival chemosis can result from balanced salt solution (BSS) exiting the wounds underneath the conjunctiva, especially when a limbal or near-clear corneal incision has been made. Excessive subconjunctival fluid may cause liquid to pool over the cornea, inhibiting visualization. A small conjunctival peritomy can be created so that the fluid does not continue to accumulate. Intraoperative corneal abrasions can result from instruments during draping or surgery. Sloughing of epithelium due to use of topical anesthetic agents or from conditions such as epithelial basement membrane dystrophy may occur.

Incision and Wound Complications

Proper incision construction and closure are critical in reducing surgical complications. An incision that is too large may result in fluid efflux and intraoperative shallowing of the anterior chamber. An incision that is too tight may restrict fluid influx during phacoemulsification, increasing the risk of a corneal burn. Scleral, limbal, and corneal wound strength are only 10% of normal tissue strength at 1 week, increasing to just 40% by 8 weeks and 75%–80% of their original strength by 2 years. Some early studies suggest that sutureless clear corneal incisions may be responsible for an increased incidence of postoperative wound leakage and subsequent greater risk of endophthalmitis.

Table 10-1 High-Risk Characteristics for Intraoperative Challenges and Complications

Preoperative Condition	Surgical Challenge	Complication
Dense brunescent nuclear cataract	Minimal cortex and epinucleus protecting capsule	PCR, VL
	Poor visualization due to intraoperative miosis	RLF
	Zonular laxity	Zonular dehiscence, IOL dislocation
	Increased ultrasound time	Corneal edema
	Increased risk of thermal and mechanical injury to cornea/iris	Incision/wound complications
High hyperopia (short axial length)	Shallow anterior chamber/higher risk of endothelial trauma	Corneal edema
	Iris trauma and prolapse	Iris defects
	Intraoperative suprachoroidal effusion (nanophthalmic eyes)	PCR, VL, RLF
High myopia	Deep anterior chamber	Lens–iris diaphragm retropulsion syndrome
Miotic pupil	Poor visualization	Iris damage, PCR, VL, RLF
Posterior polar cataract	Defective posterior capsule	PCR, VL, RLF
Posterior synechiae	Intraoperative miosis and decreased visualization	PCR, VL, RLF
	Iris bleeding	Hyphema
Prior intravitreal injections	Weakened or open posterior capsule	PCR, VL, RLF
Prior glaucoma surgery	Increased filtration through bleb during surgery with shallow anterior chamber	PCR, VL, RLF, corneal edema
	Zonular laxity	Zonular dehiscence, IOL dislocation
Prior keratorefractive surgery	Dehiscence of RK incision	Wound leakage, irregular astigmatism
Prior pars plana vitrectomy	Intraoperative anterior chamber depth fluctuations	PCR, VL, RLF
	Miosis	Iris damage
	Weakened lens capsule or zonule	IOL dislocation
Prior keratoplasty	Poor visualization	RLF
	Prior full-thickness corneal incisions	Wound leak, graft failure/rejection
Pseudoexfoliation	Zonular laxity	Zonular dehiscence, IOL dislocation
	Miosis	PCR, VL, RLF
	Decreased trabecular outflow	Elevated IOP
Use of tamsulosin and other α_{1a}-adrenergic antagonists	IFIS	PCR, VL, RLF
	Iris prolapse	Iris trauma/defects
White cataract	Difficulty visualizing and performing CCC	IOL dislocation
	Lens intumescence	Radial anterior capsule tear with extension to posterior capsule, VL, RLF

(Continued)

Table 10-1 *(continued)*

Preoperative Condition	Surgical Challenge	Complication
Zonular laxity or dehiscence	Phacodonesis	Vitreous prolapse around equator of lens, dropped nucleus
	Difficulty performing capsulorrhexis	IOL dislocation or decentration, capsule contraction/phimosis

CCC = continuous curvilinear capsulorrhexis; IFIS = intraoperative floppy iris syndrome; IOL = intraocular lens; IOP = intraocular pressure; PCR = posterior capsule rupture; RK = radial keratotomy; RLF = retained lens fragments; VL = vitreous loss.

Data from American Academy of Ophthalmology Cataract/Anterior Segment Panel, Hoskins Center for Quality Eye Care. Preferred Practice Pattern® Guidelines. *Cataract in the Adult Eye—2016.* American Academy of Ophthalmology; 2016. aao.org/ppp

All incisions should be checked to ensure closure at the end of the surgery. When gentle pressure is applied with cellulose sponges to the eye and incision, the incision should maintain integrity without leakage, and the eye should maintain a physiologic pressure. Low postoperative intraocular pressure (IOP) may induce bacterial ingress into the anterior chamber and inhibit adequate valve closure by the corneal incision, resulting in leaks. If the incision leaks, additional stromal hydration can be performed, or the incision can be sutured.

Prior corneal trauma or existing corneal incisions from laser in situ keratomileusis (LASIK), radial keratotomy (RK), or keratoplasty may become unstable during cataract surgery. When new corneal incisions for cataract surgery are made, prior incisions from LASIK, RK, or corneal trauma should be avoided, if possible. Any wound dehiscence can be secured with sutures.

Endophthalmitis Study Group, European Society of Cataract & Refractive Surgeons. Prophylaxis of postoperative endophthalmitis following cataract surgery: results of the ESCRS multicenter study and identification of risk factors. *J Cataract Refract Surg.* 2007;33(6):978–988.

Thermal wound burn

Thermal injury to the incision may result in whitening of the corneal tissue, contraction, and wound gape (Fig 10-1A). During phacoemulsification, heat may be transferred from the needle to the cornea because of inadequate cooling of the phaco tip. This can result from an insufficient inflow of coaxial irrigation fluid or from occlusion of outflow at the phaco tip or aspiration line by an ophthalmic viscosurgical device (OVD) or lens material. This complication is more common with a dispersive OVD, increased lens density, and use of continuous, rather than intermittent, ultrasound energy. Bimanual small-incision surgery raises the risk, because the phaco needle is without an irrigating jacket and so in direct contact with the cornea.

The collagen at the corneal wound contracts at a temperature of 60°C or higher, which distorts the incision. If the distortion is significant, wound gape and associated leakage may occur. Although the overall incidence of wound burns is low (0.037%–0.10%), their repercussions are significant: these incisions are not self-sealing and will require suturing (interrupted, mattress, or rhomboid sutures), a sliding scleral flap, tissue adhesive, or

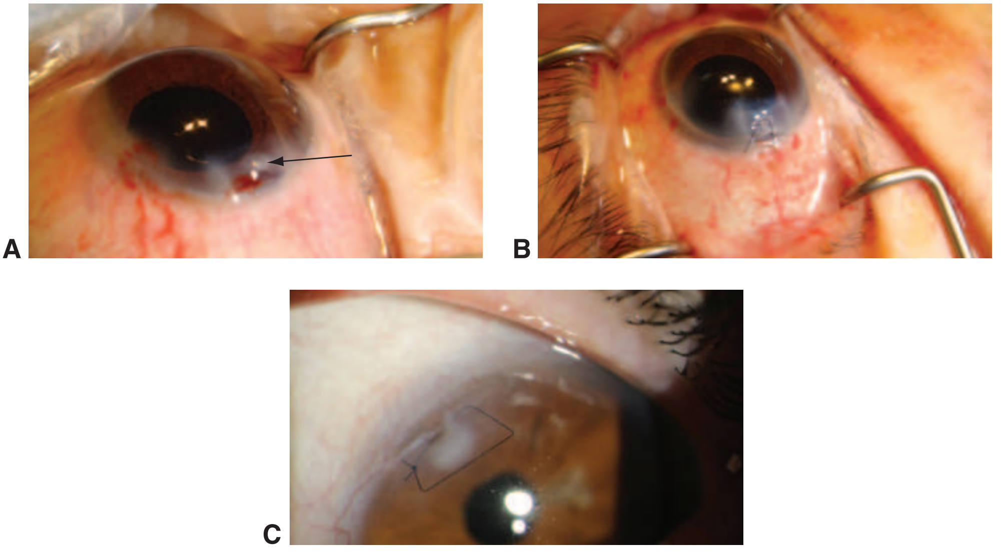


Figure 10-1 Thermal wound burn. **A,** Contraction and whitening of anterior corneal tissue *(arrow)* cause wound gape. **B,** Multiple sutures are required for closure. **C,** Rhomboid suture as alternative for closure. *(Parts A and B courtesy of Uday Devgan, MD; part C courtesy of Bruno L. Cançado Trindade, MD.)*

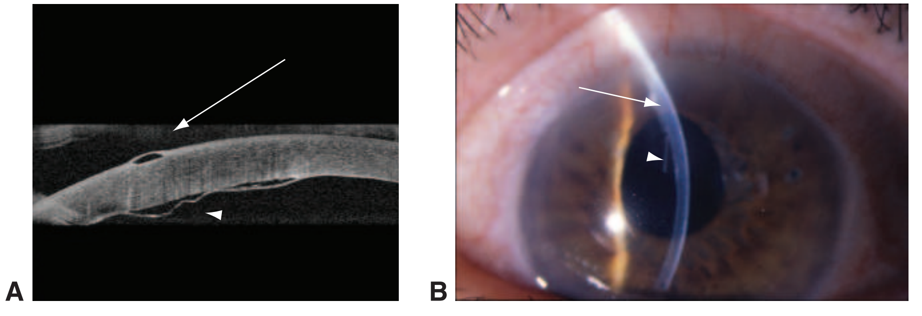


Figure 10-2 Descemet membrane detachment. **A,** Optical coherence tomography of the anterior segment. Note the epithelial bullae *(arrow)* anterior to detachment *(arrowhead).* **B,** Slit-lamp photograph of corneal edema superiorly *(arrow).* The detached membrane is reflected inferiorly *(arrowhead). (Part A courtesy of Benjamin Currie, MD; part B courtesy of Thomas L. Steinemann, MD.)*

patch grafts for adequate closure (Fig 10-1B, C). Postoperatively, induced astigmatism can be problematic.

Descemet Membrane Detachment

Descemet membrane detachment can occur when an instrument or IOL is introduced through a corneal incision. This complication results in stromal swelling and localized epithelial bullae (Fig 10-2). It is important to evacuate any OVD from the interface prior to attempting reattachment. Small detachments may resolve spontaneously; otherwise, the membrane may be reattached with air or an expansile gas (eg, sulfur hexafluoride [SF_6]) tamponade in the anterior chamber. Larger detachments can be sutured back into place under gas or an OVD. Intraoperative optical coherence tomography, if available, can assist in visualizing the reattachment.

Anterior Segment Complications

Intraoperative Floppy Iris Syndrome

Intraoperative floppy iris syndrome (IFIS) refers to the intraoperative triad of iris billowing and floppiness, iris prolapse into incisions, and progressive pupillary miosis. Especially when unexpected, IFIS results in a higher rate of surgical complications, including iris trauma, posterior capsule rupture, and vitreous loss. IFIS was originally associated solely with the use of tamsulosin, a selective α_{1a}-adrenergic antagonist, but now has been reported with the use of other selective and nonselective α-adrenergic antagonists, such as doxazosin, terazosin, alfuzosin, and silodosin. IFIS may also occur following the use of some antipsychotic agents, such as chlorpromazine, or other drugs and supplements with α-adrenergic antagonist activity (Table 10-2). Drugs that are selective α_{1a}-adrenergic antagonists, such as tamsulosin, seem to have a greater effect on the iris dilator muscle than do nonselective drugs.

Tamsulosin is most commonly used to treat lower urinary tract symptoms associated with benign prostatic hypertrophy but is also prescribed for patients with renal stones and women with urinary retention. Doxazosin, terazosin, prazosin, and labetalol (the last of which is both an α-adrenergic antagonist and a β-adrenergic antagonist) are used to treat hypertension. IFIS may occur in patients who have had no apparent exposure to α-adrenergic antagonists, and it has been reported more commonly in patients with hypertension but not diabetes mellitus. There is no correlation with adrenergic antagonist dosage or duration of therapy, and discontinuing the medication preoperatively has no effect on the degree of IFIS.

Table 10-2 Medications Commonly Associated With Intraoperative Floppy Iris Syndrome

Selective α_{1a}-adrenergic antagonists	Nonselective α_1-adrenergic antagonists	Other drugs with α-adrenergic antagonist activity
Tamsulosin (Flomax)	Alfuzosin (Uroxatral)	Chlorpromazine (Thorazine)
Silodosin (Rapaflo)	Doxazosin (Cardura)	Donepezil (Aricept)
Tamsulosin and dutasteride (Jalyn)	Prazosin (Minipress)	Finasteride
	Terazosin (Hytrin)	Labetalol (Normodyne, Trandate)
		Mianserin
		Naftopidil
		Rispiridone (Risperdal)
		Zuclopenthixol
		Saw palmetto

It is important to question all preoperative patients about their use of α-adrenergic antagonists. Since 2005, the US Food and Drug Administration (FDA) has required that these medications be labeled with a precautionary statement about IFIS and cataract surgery.

Many surgeons employ intracameral irrigation with 0.5–1.0 mL of buffered, preservative-free lidocaine 0.75% solution mixed with preservative-free epinephrine 1:4000 or phenylephrine 1.5%. Because these solutions must be compounded, mixing errors and subsequent toxic anterior segment syndrome (TASS) may occur. Preservative-free and bisulfite-free epinephrine is available in the United States (through 503B compounding pharmacies); epinephrine stabilized with bisulfite has been used successfully when diluted in a ratio of at least 1:4 with BSS. Also available in the United States is a commercial solution of unpreserved ketorolac and phenylephrine used as an additive to the irrigation solution. Despite these interventions, significant miosis and/or iris prolapse still occurs intraoperatively in some patients (Video 10-2). See the section Small Pupil in Chapter 12 for further discussion and management options.

VIDEO 10-2 Intraoperative floppy iris syndrome (IFIS).
Courtesy of Tom Oetting, MD; The University of Iowa.
Available at: aao.org/bcscvideo_section11

PROPOSED INTERVENTIONS TO REDUCE THE INTRAOPERATIVE EFFECTS OF IFIS

- use of preoperative atropine
- intracameral injection of α-adrenergic agonists, such as phenylephrine or epinephrine
- addition of phenylephrine and ketorolac to the BSS infusion bottle
- avoidance of incisions that are too short, too posterior, or too wide
- use of iris hooks or pupil expansion rings for stabilization
- use of bimanual microincision surgical techniques
- employment of highly retentive OVDs to “viscodilate” the pupil and maintain a concave iris near the incisions
- discontinuation of fluid inflow prior to withdrawal of instruments to prevent fluid and iris egress
- use of low-flow settings to minimize anterior chamber turbulence and eliminate a higher pressure gradient posterior to the iris

Femtosecond Laser–Associated Miosis

The use of a femtosecond laser for lens fragmentation and creation of incisions prior to phacoemulsification can result in pupillary miosis by a different mechanism than IFIS. Compared to levels measured in control cataract surgery patients, aqueous humor concentrations of cytokines and prostaglandin E_2 (PGE_2) are elevated following femtosecond laser treatment.

Preoperative use of topical nonsteroidal anti-inflammatory drugs (NSAIDs) mitigates the rise in PGE_2 levels after femtosecond laser treatment and reduces, but does not eliminate, the associated miosis. Femtosecond laser–induced pupillary miosis may be managed by the same strategies listed for IFIS (see sidebar above).

Christou CD, Esagian S, Ziakas N, Prousali E, Tzamalis, A. Factors predisposing to intraoperative floppy-iris syndrome: an up-to-date meta-analysis. *J Cataract Refract Surg.* 2022;48(11): 1335–1341.

Jun JH, Hwang KY, Chang SD, Joo CK. Pupil-size alterations induced by photodisruption during femtosecond laser–assisted cataract surgery. *J Cataract Refract Surg.* 2015;41(2): 278–285.

Jun JH, Yoo YS, Lim SA, Joo CK. Effects of topical ketorolac tromethamine 0.45% on intraoperative miosis and prostaglandin E_2 release during femtosecond laser–assisted cataract surgery. *J Cataract Refract Surg.* 2017;43(4):492–497.

Lens–Iris Diaphragm Retropulsion Syndrome

Lens–iris diaphragm retropulsion syndrome (LIDRS) is characterized by posterior displacement of the lens–iris diaphragm with a marked deepening of the anterior chamber, posterior iris bowing, and pupil dilation. It occurs more commonly in highly myopic eyes and in eyes that have undergone previous vitrectomy. LIDRS results from a high level of infusion pressure in the anterior chamber with a reverse pupillary block; it may cause stress on the zonular apparatus and considerable discomfort for patients under topical anesthesia. Surgery may be more difficult in eyes with LIDRS due to their excessively deep anterior chambers. Lifting the iris off the anterior capsule is usually sufficient to break the pupillary block and restore normal anterior chamber depth. LIDRS is also discussed in Chapter 12 in the section Conditions Associated With Extremes in Axial Length.

Iridodialysis and Iris Trauma

Iridodialysis, the tearing of the iris at its root or insertion, may occur at the time of insertion of the phaco tip or IOL or already be present from prior trauma. Traction on the iris root during phacoemulsification or irrigation/aspiration (I/A) can cause a tear and subsequent hyphema. If the iridodialysis is small or insignificant, it can be left alone. More extensive iridodialysis, which could cause optical problems or be cosmetically significant, may require surgical reattachment by suturing the iris to the sclera (Fig 10-3).

Chronic mydriasis or iris damage from surgery or trauma may cause the patient to experience excessive glare, particularly if the pupillary light response is inadequate or if the edge of the IOL is not covered. An iris defect may be repaired by a variety of intraocular techniques, including

- a McCannel suture technique with a Siepser sliding knot (see Chapter 11 for a discussion of dislocated IOLs)
- a single-pass 4-throw pupilloplasty (Video 10-3)
- pupillary cerclage (Video 10-4) or the implantation of artificial iris devices (Video 10-5) to alleviate symptoms or address a patient's cosmetic concerns

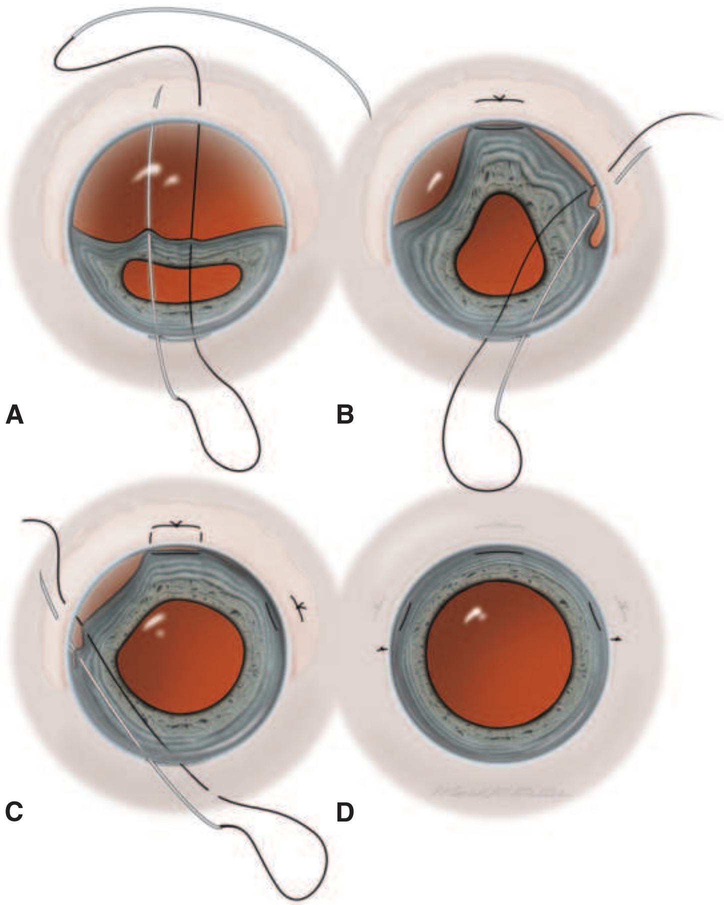


Figure 10-3 Iridodialysis repair. *(Figure developed by Natalie Afshari, MD, and illustrated by Mark Miller.)*

Other strategies may be useful, as well, including

- postoperative use of an iris-colored contact lens as a nonsurgical alternative
- cornea tattooing (keratopigmentation)

VIDEO 10-3 Iris repair with single-pass 4-throw pupilloplasty.
Courtesy of Jason Leng, MD.
Available at: aao.org/bcscvideo_section11

VIDEO 10-4 Iris repair with pupillary cerclage.
Courtesy of Jason Leng, MD.
Available at: aao.org/bcscvideo_section11

VIDEO 10-5 Artificial iris implantation.
Courtesy of Winston D. Chamberlain, MD, PhD.
Available at: aao.org/bcscvideo_section11

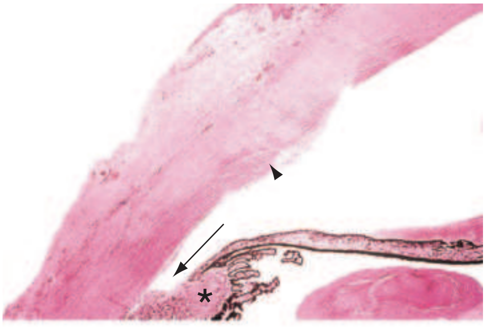


Figure 10-4 Pathology of cyclodialysis. Detachment of ciliary body muscle *(asterisk)* from the scleral spur *(arrowhead),* resulting in a cyclodialysis cleft *(arrow). (© 2019 American Academy of Ophthalmology.)*

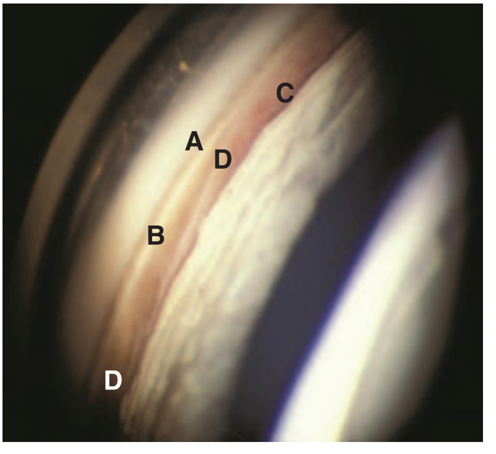


Figure 10-5 Goniophotograph of cyclodialysis. **A,** Trabecular meshwork. **B,** Scleral spur. **C,** Ciliary body band. **D,** Area of separation of ciliary band from sclera. *(Courtesy of Hans E. Grossniklaus, MD. © 2019 American Academy of Ophthalmology.)*

Cyclodialysis

Cyclodialysis, the separation of the ciliary body from its insertion at the scleral spur, may occur as a result of trauma or surgical manipulation of intraocular tissue (Fig 10-4). Gonioscopic examination shows a deep-angle recess with a gap between the sclera and the ciliary body (Fig 10-5). Repair of a cyclodialysis cleft is indicated if hypotony results. Closure may be achieved with laser photocoagulation at the site of cyclodialysis; if this is ineffective, it may be necessary to reattach the ciliary body with sutures (Video 10-6). A significant and sudden elevation in IOP may occur as a result of cyclodialysis closure. For further discussion of cyclodialysis, see BCSC Section 10, *Glaucoma.*

VIDEO 10-6 Closure of a cyclodialysis cleft.
Courtesy of Arsham Sheybani, MD.
Available at: aao.org/bcscvideo_section11

Intraoperative Shallow or Flat Anterior Chamber

During extracapsular cataract extraction (ECCE) or phacoemulsification, the anterior chamber may become shallow because of inadequate infusion, leakage through an oversized incision, external pressure on the globe, "positive vitreous pressure," fluid misdirection syndrome, suprachoroidal effusion, or suprachoroidal hemorrhage. If the reason for loss of normal chamber depth is not apparent, the surgeon first reduces aspiration, then raises the infusion pressure and checks the incision. If the incision is too large, the surgeon may partially suture it in order to keep the chamber formed. External pressure on the globe can be relieved by readjusting the surgical drapes or the eyelid speculum. "Positive vitreous pressure," or forward displacement of the lens–iris diaphragm, occurs more commonly in patients who are obese or who have thick necks, in patients with pulmonary disease such as chronic obstructive pulmonary disease (COPD), and in patients experiencing a level of anxiety or discomfort that may lead them to squeeze their eyelids or perform a Valsalva maneuver. Placing patients in a reverse Trendelenburg position may alleviate the pressure. Intravenous mannitol can be used to reduce the vitreous volume and deepen the anterior chamber in selected cases.

If the reason for the loss of anterior chamber depth or the elevated IOP is unknown, it is important to check the red reflex to evaluate for the possibility of a suprachoroidal hemorrhage or effusion. In these situations, the eye typically becomes very firm, and the patient becomes agitated and reports experiencing pain. The surgeon should immediately close the incisions and confirm the diagnosis by examining the fundus with an indirect ophthalmoscope or fundus lens. If the hemorrhage or effusion is significant, the operation should be postponed until the pressure has decreased. (See the section Suprachoroidal Effusion or Hemorrhage later in this chapter and BCSC Section 12, *Retina and Vitreous.*)

In *posterior fluid misdirection syndrome,* irrigation fluid infused into the anterior chamber may be misdirected into the vitreous cavity through intact zonular fibers or through a zonular or capsular tear, causing an increase in the vitreous volume with subsequent forward displacement of the lens and shallowing of the anterior chamber. The fluid may accumulate in the retrolental space or dissect posteriorly along the vitreoretinal interface. If gentle posterior pressure on the lens or reinflation of the capsular bag with OVD does not alleviate the fluid accumulation, an intravenous infusion of mannitol and waiting at least 20 minutes may allow the anterior chamber to deepen. If suprachoroidal effusion or hemorrhage has been ruled out, the surgeon can insert a 20- to 23-gauge needle through the pars plana into the vitreous by direct visualization, gently aspirate fluid vitreous, and deepen the anterior chamber with irrigation fluid or OVD. Alternatively, vitreous aspiration may be performed with a cutting/aspirating pars plana vitrectomy tip inserted through a sclerotomy 3.5 mm behind the limbus, combined with infusion of BSS or injection of additional OVD into the anterior chamber.

A shallow or flat anterior chamber can also occur postoperatively; see Chapter 11 for further discussion.

Anterior Capsule Tears

Performance of a continuous curvilinear capsulorrhexis (CCC) is an integral step in phacoemulsification surgery (see Chapter 8). Any discontinuity in the CCC can complicate the remainder of the phacoemulsification procedure. Occasionally during a CCC, the capsulorrhexis may extend toward the periphery (ie, the diameter becomes larger than intended); the "Little maneuver" can be used to rescue an errant anterior capsulorrhexis in such cases (see Video 10-7 and sidebar).

VIDEO 10-7 Little capsulorrhexis rescue maneuver.
Courtesy of Tom Oetting, MD; The University of Iowa.
Available at: aao.org/bcscvideo_section11

HOW TO PERFORM A LITTLE CAPSULORREXIS RESCUE MANEUVER

1. Completely fill the anterior chamber with OVD.
2. Using an instrument or OVD, unfold the anterior capsule flap and lay it flat against the lens cortex.
3. Using capsulorrhexis forceps, grasp the edge of the flap as close to the root of the tear as possible.
4. Pull the flap back circumferentially in the direction from which it came while applying traction in the horizontal plane of the capsule to maintain tension.
5. Apply inward traction to pull the flap centrally.
6. Refold the flap forward and safely complete the capsulorrhexis.

Little BC, Smith JH, Packer M. Little capsulorhexis tear-out rescue. *J Cataract Refract Surg.* 2006;32(9):1420–1422.

If it is not possible to complete the CCC, several options are available; these maneuvers can be facilitated with intraocular scissors, microforceps, and the generous use of OVDs to maintain a fully deep anterior chamber. One option is to create a second tear with a cystotome, near the origin of the first tear, and extend it in the opposite direction until it "meets up" with the original tear. Another option is to convert to a *"can-opener" capsulotomy* (see chapter 9).

There are also other causes of anterior capsule tears that may occur during surgery. In eyes with white intumescent cataracts, the anterior capsule may suddenly split as the capsule is punctured centrally with a cystitome at the start of the CCC, creating an "Argentinian flag sign" in capsules that have been stained with trypan blue (Video 10-8). During a femtosecond laser capsulotomy, a radial tear may occur if a complete capsulotomy is not created before the surgeon removes the capsule remnant. During phacoemulsification, contact of the phaco tip with the anterior capsule may result in a tear in the capsule. In eyes with a discontinuous capsulorrhexis, care must be taken during each subsequent step of the surgery to make sure that the anterior capsule tear is not extended to the posterior capsule, because of the higher risk of vitreous loss and retained lens fragments (see the sidebar Interventions for a Discontinuous Capsulorrhexis). If extension past the equator to the posterior capsule does occur, it should be managed as a capsule rupture (see the sidebar Management of Posterior Capsule Rupture later in this chapter).

VIDEO 10-8 Argentinian flag sign.
Courtesy of Kamran M. Riaz, MD.
Available at: aao.org/bcscvideo_section11

INTERVENTIONS FOR A DISCONTINUOUS CAPSULORRHEXIS

- use of a push-pull instrument (eg, a Kuglen hook) to retract the iris and check the extent of a radial tear
- hydrodissection and hydrodelineation, performed gently and without excessive pressure
- use of "low-flow" phacoemulsification settings (ie, lower infusion pressure, vacuum, and aspiration flow rate) to minimize fluctuations of anterior chamber depth
- liberal use of OVD to prevent anterior chamber collapse
- avoidance of aspirating "tags" of anterior capsule, which can cause extension of the tear, during aspiration of the cortex. Consider use of a manual dry-aspiration technique (with a Simcoe cannula) to reduce irrigation.
- prior to IOL insertion and after OVD is injected, checking again the extent of the anterior capsule tear with a push-pull instrument
- if a 1-piece acrylic IOL is used, placement of the haptics so that they are not located in the area of the anterior capsule tear, to avoid uveitis-glaucoma-hyphema (UGH) syndrome (see Chapter 11)
- placement of a monofocal IOL to avoid potential postoperative complications. If the haptics will not be in the position of the tear, it may be possible to place a toric or presbyopia-correcting IOL within the capsule, but rotation and centration, and so intended visual correction, may be affected.
- placement of a 3-piece IOL into the ciliary sulcus, unless there is concomitant zonular compromise

Posterior Capsular Rupture

If posterior capsule rupture occurs during surgery, it is important to reduce fluid inflow and stabilize the anterior segment with OVD prior to withdrawing any instrument from the main incision in order to minimize the risk of vitreous prolapse.

Causes of posterior capsule rupture include

- *extension of an anterior capsule radial tear* (see discussion in previous section)
- *intraoperative capsular block syndrome,* in which excessive pressure within the capsule causes blowout of the posterior capsule. This occurs during hydrodissection and may be more likely with
  - posterior polar cataract
  - preexisting capsule defects, such as those resulting from intravitreal injections, trauma, or prior vitrectomy
  - dense cataracts with a small capsulorrhexis
  - femtosecond laser treatment in which gas bubbles build up behind the nucleus
- *contact with the phacoemulsification or I/A tip.* Risk of this increases with
  - higher flow settings
  - poor visualization, for example in eyes with IFIS or miotic pupil
  - dense nucleus with minimal epinuclear shell

    - anterior chamber fluctuations and postocclusion surge (see Chapter 8)
    - "posterior pressure," for example with choroidal effusion or Valsalva maneuver
- *contact with an intraocular instrument,* such as a cannula, chopper, or manipulator
- *rapid insertion and unfolding of an IOL*

After a posterior capsule rupture, lens material may enter the posterior segment, and vitreous may prolapse into the anterior segment. The location and size of the tear determine the appropriate response. A small rupture in the posterior capsule during emulsification of the nucleus can be managed by alteration of the surgical technique. The surgeon can compartmentalize the vitreous with a dispersive OVD and use low-flow, low-vacuum settings to remove the remaining nuclear and cortical material. Full occlusion of the aspiration port and use of minimal phaco power reduce the risk of aspiration of vitreous or further damage to the capsule.

If a small tear appears in the posterior capsule during aspiration of the cortex and the vitreous face remains intact, the surgeon can attempt to remove the residual cortex without expanding the tear. Using low-flow I/A and compartmentalizing the vitreous with an OVD help avoid disruption of the vitreous face. Some surgeons prefer a manual dry-aspiration technique, which involves using a cannula attached to a handheld syringe to remove the residual cortex after a capsular rupture, thereby avoiding any pressure from irrigation. After the anterior chamber is stabilized with the use of an OVD, capsulorrhexis forceps may be employed to convert the posterior capsule tear into a round posterior capsulorrhexis that will resist extending equatorially.

If most of the nucleus remains and the capsular tear is large, further attempts at phacoemulsification should be abandoned. To extract the remaining nuclear fragments mechanically, the surgeon can enlarge the incision and remove the nucleus with a lens loop in a manner that minimizes vitreous traction and further damage to the capsule. Insertion of a second instrument or lens glide behind the nuclear remnant may help prevent the remnant from being dislocated into the vitreous. Alternatively, an OVD can be introduced posterior to the fragment in an effort to float it anteriorly, or the nucleus can be elevated into the anterior chamber with an instrument. Retrieval of nuclear fragments from the deep vitreous is not recommended.

If vitreous prolapse occurs, it is best to remove all vitreous from the anterior chamber during the initial surgery. Doing so will facilitate the removal of residual cortex and the subsequent placement of an IOL. In addition, a vitrectomy can reduce the chance of vitreoretinal traction or vitreous adherence to the IOL, the iris, or the incision. Vitreous loss during cataract surgery is associated with an increased risk of retinal detachment, cystoid macular edema, and endophthalmitis.

The vitreous may be stained with unpreserved or washed triamcinolone for better visualization. It is important to avoid manually externalizing and cutting vitreous through the incision, because this increases vitreoretinal traction, which elevates the risk of retinal tears and retinal detachment. A 2-port bimanual anterior vitrectomy can be performed with separate infusion and aspirating/cutting instruments inserted through new, properly sized limbal incisions (Fig 10-6A and B; Video 10-9). Alternatively, the aspiration/cutting instrument may be placed through a pars plana incision while irrigation is continued through the limbus (Fig 10-6C; Video 10-10), reducing the amount of vitreous that migrates into the anterior segment, thereby decreasing vitreoretinal traction.

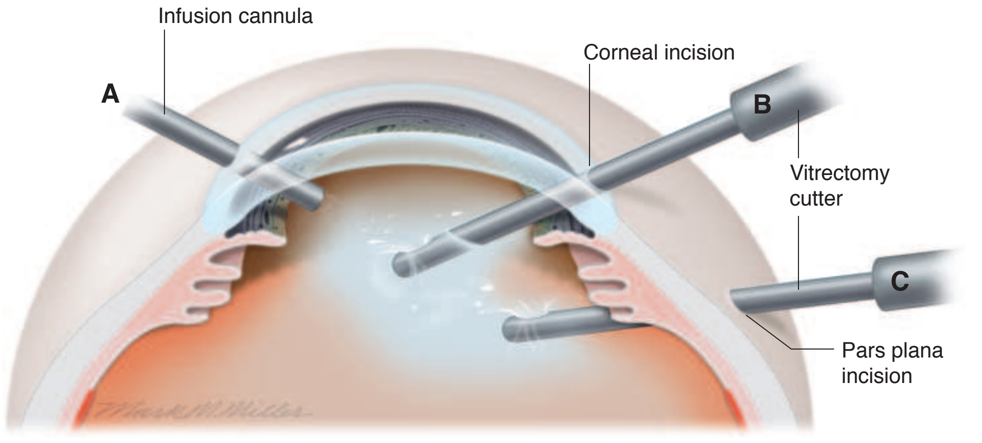


Figure 10-6 Bimanual anterior vitrectomy. Infusion cannula **(A)** through corneal incision. A corneal incision may be used for a vitrectomy cutter **(B).** Alternatively, a pars plana incision may be used for the vitrectomy cutter **(C).** *(Figure developed by Natalie Afshari, MD, and illustrated by Mark Miller.)*

VIDEO 10-9 Bimanual anterior vitrectomy.
Courtesy of Winston D. Chamberlain, MD, PhD.
Available at: aao.org/bcscvideo_section11

VIDEO 10-10 Bimanual anterior vitrectomy with pars plana incision.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

MANAGEMENT OF POSTERIOR CAPSULE RUPTURE

- Maintain a normotensive globe and prevent anterior chamber collapse.
- Avoid intraoperative vitreous traction.
- Compartmentalize the lens and vitreous with an OVD.
- Attempt removal of lens fragments only if they are visible and easily accessible.
- Using either a bimanual limbal or pars plana approach, perform an anterior vitrectomy until no vitreous is seen anterior to the capsule.
- Insert an IOL only when safe and indicated—preferably a posterior chamber lens placed in the ciliary sulcus or fixated to iris or sclera, or an anterior chamber lens with prophylactic peripheral iridectomy.
- Adjust the lens power appropriately for the position and type of IOL used.
- Perform a watertight incision closure and remove the OVD.
- If posteriorly dislocated lens fragments are present, arrange a prompt referral to a vitreoretinal surgeon for removal.
- Disclose and discuss all surgical complications with the patient.

IOL Placement with Posterior Capsule Rupture

If posterior capsule support for intracapsular placement of the IOL is inadequate, the surgeon should attempt to preserve the anterior capsule and capsulorrhexis to enable placement of the IOL optic in the capsular bag with the haptics placed in the ciliary sulcus ("optic capture"; Fig 10-7A). Generally, a 3-piece IOL with a total diameter greater than 12.5 mm may be inserted into the ciliary sulcus with or without optic capture. In

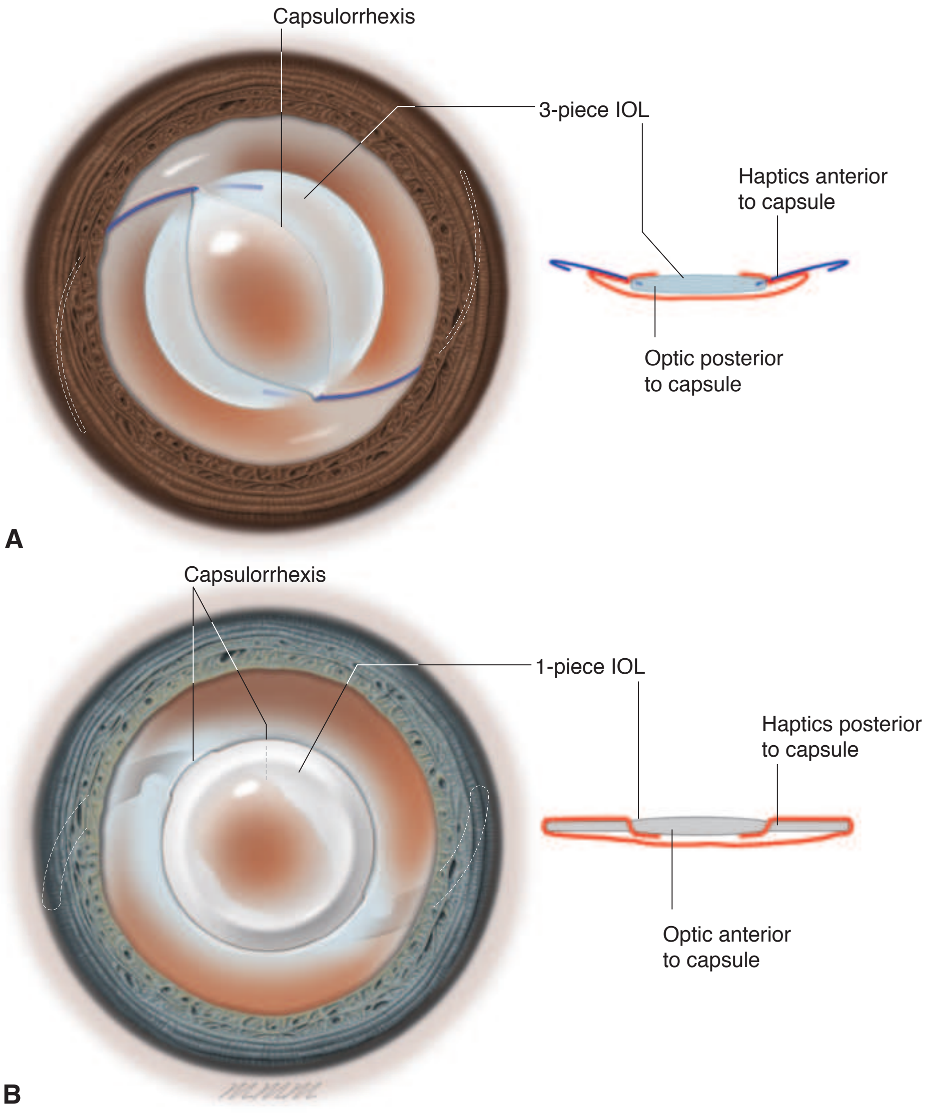


Figure 10-7 Intraocular lens (IOL) capture. **A,** IOL optic capture. A 3-piece IOL with haptics in the sulcus. The optic is "captured" within the capsule so that the anterior capsule edge is anterior to the optic. **B,** IOL reverse optic capture. A 1-piece IOL with the optic in the sulcus. The optic is "captured" by capsulorrhexis so that the anterior capsule edge is anterior to the haptics. *(Figure developed by Natalie Afshari, MD, and illustrated by Mark Miller.)*

certain situations, a single-piece acrylic IOL may be safely placed in the ciliary sulcus by *reverse optic capture* (Fig 10-7B). In reverse optic capture, the haptics of the IOL are placed within the capsule, while the optic is captured through the anterior capsule into the sulcus. To reduce the possibility of UGH syndrome, the haptics of the single-piece acrylic IOL must be fully contained within the capsule; otherwise, a 3-piece lens is recommended.

If capsular integrity is insufficient, the surgeon may substitute an anterior chamber lens. A posterior chamber IOL (PCIOL) may also be used in the absence of capsular support: the haptics are either sutured to the iris or fixed to the sclera through the ciliary sulcus. Several techniques for IOL fixation are discussed in detail in Chapter 11. If significant lens material remains in the posterior chamber, it can be approached via a pars plana vitrectomy performed by a vitreoretinal surgeon.

Hemorrhage

Retrobulbar Hemorrhage

Retrobulbar hemorrhages vary in intensity and are more common with retrobulbar anesthetic injections than with peribulbar injections, with an incidence of 0.44%–0.74% following retrobulbar injection.

Venous retrobulbar hemorrhages are usually self-limited and tend to spread slowly. *Arterial retrobulbar hemorrhages* occur more rapidly and are associated with taut orbital swelling, marked proptosis, elevated IOP, reduced mobility of the globe, inability to separate the eyelids, and massive ecchymosis of the eyelids and conjunctiva. This type of retrobulbar hemorrhage causes an increase in orbital volume and associated orbital pressure, which can restrict the vascular supply to the globe. Large orbital vessels may be occluded. Tamponade of the smaller vessels in the optic nerve may occur, resulting in severe vision loss from anterior ischemic optic neuropathy and subsequent optic atrophy, despite the absence of obvious retinal vascular occlusion.

Ophthalmologists can often make the diagnosis of retrobulbar hemorrhage by observing the rapid onset of eyelid and conjunctival ecchymosis and tightening of the orbit. The diagnosis can be confirmed by tonometry revealing elevated IOP. Ophthalmoscopy may reveal pulsation or occlusion of the central retinal artery in severe cases.

Treatment of acute retrobulbar hemorrhage consists of maneuvers to lower the intraocular and orbital pressure as quickly as possible, such as the following:

- digital massage
- intravenous osmotic agents
- aqueous suppressants
- lateral canthotomy and cantholysis
- localized conjunctival peritomy (to allow egress of blood)

The planned surgery should be postponed until the IOP and mobility of the globe and eyelids are normal. To reduce the risk of a recurrent retrobulbar hemorrhage, it may be advisable to use another form of anesthesia for the second attempt at surgery.

In addition to retrobulbar hemorrhage, potential complications of retrobulbar injections include central retinal artery occlusion, ischemic optic neuropathy, toxic neuropathy or myopathy, diplopia, ptosis, globe penetration or perforation and inadvertent subdural injections with possible central nervous system depression, and apnea. Ischemic complications are more common if epinephrine is used in the anesthetic. (See BCSC Section 1, *Update on General Medicine,* and Section 6, *Pediatric Ophthalmology and Strabismus.*)

Intraoperative Hemorrhage

Iris manipulation, such as lysis of posterior synechiae, sphincterotomies, or pupil expansion or stretching may result in intraoperative hemorrhage and early postoperative hyphema. Surgical trauma to the iris, iris root, and ciliary body can cause significant bleeding. Hemorrhage may also originate from the angle structures when cataract surgery is combined with microinvasive glaucoma surgery (MIGS; see also BCSC Section 10, *Glaucoma*). Resolution of hemorrhage may take longer if vitreous is mixed with the blood. (See the section Hyphema in Chapter 11.)

Suprachoroidal Effusion or Hemorrhage

Suprachoroidal effusion with or without suprachoroidal hemorrhage usually occurs intraoperatively but may also occur later, especially in cases with prolonged postoperative hypotony. Suprachoroidal effusion typically presents as a forward prolapse of ocular structures, including iris, lens diaphragm, and vitreous, generally accompanied by a change in the red reflex. Clinically, suprachoroidal effusion may be difficult to differentiate from suprachoroidal hemorrhage. Patient agitation and pain followed by an extremely firm globe suggest suprachoroidal hemorrhage. Suprachoroidal effusion and suprachoroidal hemorrhage have been associated with

- hypertension
- arteriosclerotic cardiovascular disease
- tachycardia
- obesity
- high myopia
- glaucoma
- advanced age
- nanophthalmos
- choroidal hemangioma associated with encephalotrigeminal angiomatosis (Sturge-Weber syndrome)
- chronic ocular inflammation

Fortunately, both suprachoroidal effusion and suprachoroidal hemorrhage are much less likely with small-incision phacoemulsification than with larger-incision surgery because of the relatively closed system formed by the small, self-sealing incisions. The relatively tight fit of the phaco tip in the incision prevents prolonged hypotony and reduces intraoperative fluctuations in IOP.

Suprachoroidal effusion may be a precursor to suprachoroidal hemorrhage. Exudation of fluid from choroidal vasculature ultimately stretches veins and arteries that supply the choroid after coursing through the sclera. If suprachoroidal hemorrhage occurs in this situation, it is presumably a result of disruption of one or more of these taut blood vessels (see also BCSC Section 12, *Retina and Vitreous*).

Expulsive Suprachoroidal Hemorrhage

Expulsive suprachoroidal hemorrhage, a rare but serious condition, generally occurs intraoperatively in eyes with hypotony. The hemorrhage usually presents as a sudden increase in IOP accompanied by acute onset of pain and the following:

- darkening of the red reflex
- incision gape
- iris prolapse
- expulsion of the lens, vitreous, and bright red blood

The instant any suprachoroidal effusion or hemorrhage is recognized, the surgeon must close the incision with sutures or digital pressure. Prolapsed vitreous is excised and uveal tissue reposited, if possible. After the wound is securely closed, the surgeon may consider posterior sclerotomies to allow the escape of suprachoroidal blood to decompress the globe, enable repositioning of prolapsed intraocular tissue, and facilitate permanent closure of the cataract incision. Drainage of suprachoroidal blood may be achieved by performing sclerotomies in one or more quadrants, 5–7 mm posterior to the limbus (Video 10-11). Sclerotomies for choroidal hemorrhage are also discussed in BCSC Section 12, *Retina and Vitreous*. Elevated IOP serves both to stop bleeding and to expel suprachoroidal blood. Once there is optimal clearance of blood from the suprachoroidal space, the sclerotomies may be left open to allow further drainage postoperatively. It may be necessary to repeat the drainage procedure 7 days or more after an expulsive hemorrhage in cases of residual suprachoroidal blood that threatens ocular integrity or vision. These procedures may lower dangerously elevated IOPs and restore appropriate anatomical relationships within the eye, but they carry some risk that bleeding will recur.

VIDEO 10-11 Drainage of suprachoroidal hemorrhage.
Courtesy of Christina Weng, MD.
Available at: aao.org/bcscvideo_section11

If the incision can be closed without posterior sclerotomies, more rapid tamponade of the bleeding vessel can be achieved. Most surgeons would then terminate the operation and observe the patient for 7–14 days to allow clotting and liquefaction of the hemorrhage, while managing elevated IOP medically. Referral to a vitreoretinal surgeon for management and subsequent drainage of choroidal hemorrhage may be considered. It is important to inform the patient of the guarded prognosis for restoration of vision.

CHAPTER 11

Postoperative Surgical Course and Complications

This chapter includes related videos. Go to aao.org/bcscvideo_section11 or scan the QR codes in the text to access this content.

Highlights

- Treatment of a retained lens fragment depends on the fragment's location, the presence of corneal edema, the degree of inflammation, and the fragment's effect on intraocular pressure.
- Posterior capsule opacification occurs frequently after cataract surgery; it can appear months to years after cataract surgery and is commonly treated with Nd:YAG capsulotomy.
- Toxic anterior segment syndrome is a sterile inflammation caused by toxic substances such as instrument residue and may mimic endophthalmitis.
- Despite numerous studies showing a reduced incidence of endophthalmitis with the use of intracameral antibiotics after cataract surgery, no antibiotics are currently approved by the US Food and Drug Administration for this indication.
- Cystoid macular edema is a common cause of decreased vision that occurs weeks to months following cataract extraction. It is associated with increased perifoveal capillary permeability and fluid accumulation in the retina's inner nuclear and outer plexiform layers.

Introduction

After uncomplicated phacoemulsification, the postoperative course generally allows for rapid vision rehabilitation over several weeks:

- *Symptoms:* Foreign-body sensation and photosensitivity are common immediately after surgery. Fluctuations in vision may occur. Topical lubrication may alleviate these symptoms.
- *Signs:* The corneal incisions are typically leak-free. Irregular epithelium or small epithelial defects may be seen at the incisions. Corneal edema is variable and may have a marked effect visual acuity. Normally, the anterior chamber is deep, with

mild to moderate cellular reaction. The surgeon should ensure that the intraocular lens (IOL) is well positioned and stable. If present, ptosis is generally minimal (unless a retrobulbar or peribulbar block was used, when ptosis may be complete for several hours).

- *Course:* Typically, the patient's vision stabilizes, and pain and photosensitivity decrease over several days to weeks. Although further refractive changes may occur later, most patients are prescribed postoperative spectacles, if needed, by 2–6 weeks after uncomplicated cataract surgery.

Although the ophthalmologist strives to attain excellent results during both cataract surgery and the postoperative course, complications do occur, even in the best of hands. Recognizing and appropriately treating any complications are critical to a successful outcome.

Postoperative complications of cataract surgery include the following (listed from most common to least):

- posterior capsule opacification (common; increases with time after surgery)
- corneal wound leak (10%–31% of cases)
- corneal edema (0.03%–5.18% of cases)
- clinically apparent cystoid macular edema (CME) (1.2%–3.5% of cases)
- retained lens fragments (0.45%–1.70% of cases)
- IOL dislocation (0.19%–1.10% of cases)
- retinal detachment (about 0.7% of cases in the first postoperative year)
- endophthalmitis (0.04%–0.20% of cases)
- toric IOL rotation (rare; occurs early in postoperative course)

Corneal Complications

Corneal Edema

Stromal and/or epithelial edema due to multiple etiologies may occur throughout the postoperative period (Table 11-1). Edema due to surgical trauma, acute endothelial decompensation from underlying dystrophy, and epithelial edema due to elevated intraocular pressure (IOP) may be seen early. Toxic substances inadvertently introduced into the anterior chamber can also cause acute endothelial dysfunction as well as early diffuse corneal edema, referred to as *toxic anterior segment syndrome* (*TASS;* discussed later in this chapter). Late postoperative inferior corneal edema may occur because of small nuclear fragments retained in the anterior chamber angle. These fragments may be noticed on initial postoperative examinations or identified up to years later if they migrate into the anterior chamber from a secluded location in the posterior chamber. Vitreocorneal touch or adherence may contribute to persistent corneal edema after cataract surgery complicated by vitreous prolapse. Significant chronic corneal edema from loss of endothelial cells results in bullous keratopathy (discussed later in this chapter), which is associated with reduced vision, ocular irritation, foreign-body sensation, epiphora, and occasionally infectious keratitis.

Table 11-1 Principal Causes of Corneal Edema After Cataract Surgery

Causes of Early Postoperative Corneal Edema
Surgical effects
Mechanical energy from phacoemulsification
Instruments
IOL
Irrigating solutions
Lens fragments
Prior or prolonged intraocular surgery
Corneal endothelial diseases
Fuchs dystrophy
Low endothelial cell density
Descemet membrane detachment
Chemical or toxic effects
Toxic anterior segment syndrome
Preservatives in intraocular solutions
Residual toxic chemicals on instruments (eg, detergents, dried solutions)
Improper concentrations of intraocular solutions (eg, antibiotics, anesthetics, irrigating solutions)
Osmotic damage
Direct toxicity
Elevated intraocular pressure
Inflammation
Causes of Early or Late Postoperative Corneal Edema
IOL-related factors
IOL–endothelial touch
Uveitis-glaucoma-hyphema syndrome
Rigid anterior chamber IOL
Endothelial contact
Flat chamber centrally
Wound leak
Ciliary block (aqueous misdirection)
Suprachoroidal effusion or hemorrhage
Flat chamber peripherally
Pupillary block
Iris bombé
Vitreous touch
Retained material
Nuclear fragments
Particulate foreign matter
Membranous ingrowth
Epithelial or fibrous ingrowth
Endothelial proliferation

IOL = intraocular lens. Adapted with permission from Steinert RF. *Cataract Surgery.* 3rd ed. Saunders; 2010:596.

In its early stages, corneal edema after cataract surgery can be managed with topical hypertonic eyedrops, corticosteroids, and/or aqueous suppressants. Edema from surgical trauma generally resolves completely within 4–6 weeks. When epithelial edema is due to elevated IOP, lowering the pressure medically or via aqueous release from the paracentesis site often results in rapid resolution.

Removing all vitreous from the anterior chamber during complicated cataract surgery decreases the risks of corneal edema as well as CME and retinal detachment. When vitreous prolapse with corneal touch or incarceration in the wound is recognized postoperatively and corneal edema or CME develops, an anterior vitrectomy with removal of vitreous from the incision or Nd:YAG laser vitreolysis may be indicated. In more advanced cases with prolonged corneal edema, keratoplasty combined with vitrectomy may be indicated (discussed later in this chapter).

Incision and wound complications

Intraoperative incision complications are discussed in Chapter 10 of this volume. Signs of *postoperative* wound leak include decreased vision, hypotony, corneal striae, shallow anterior chamber, hyphema, choroidal folds, choroidal effusion, macular edema, and optic nerve edema. A Seidel test (performed by touching a fluorescein test strip to the incision and observing for fluid egress under cobalt blue light), ultrasound biomicroscopy, or anterior segment optical coherence tomography (OCT) may help diagnose or confirm subtle cases. Small leaks in the early postoperative period may be asymptomatic and self-limited.

Medical treatment may include prophylactic topical antibiotics, cycloplegia, aqueous inhibitors, patching, decreased or discontinued corticosteroid therapy, or a collagen shield or bandage contact lens. Surgical repair is indicated in more serious cases with persistent anterior chamber shallowing, iris prolapse, prolonged hypotony, choroidal effusion, or macular edema. Wound suturing is usually sufficient, but an amniotic membrane graft or tissue adhesive such as cyanoacrylate may be used.

A wound leak under a conjunctival flap may lead to an inadvertent filtering bleb, which may require surgical intervention. Techniques that may be used to promote wound healing and bleb cicatrization include cryotherapy, diathermy, chemical cauterization with trichloroacetic acid, and injection of an autologous blood patch. In chronic cases, it may be necessary to excise the bleb/conjunctiva and search for a fistula, which can be scraped free of invading epithelium or excised and covered with a scleral patch graft if necessary, followed by resuturing of the wound.

Late postoperative wound dehiscence may be spontaneous or secondary to trauma. Smaller incisions have decreased the occurrence of wound dehiscence. Traumatic wound rupture is often accompanied by extrusion of intraocular contents and almost always requires urgent surgical repair.

Corneal Melt

Keratolysis, or sterile corneal melting (Fig 11-1), may occur after cataract extraction. It is most frequently associated with preexisting tear film abnormalities resulting from keratoconjunctivitis sicca and autoimmune diseases such as Sjögren syndrome, rheumatoid arthritis, or graft-vs-host disease. Keratitis may be exacerbated by the chemical or mechanical stress of surgery or by the topical medications used perioperatively.

Stromal melting has been reported with the postoperative use of topical nonsteroidal anti-inflammatory drugs (NSAIDs), due in part to the epithelial toxicity and hypoesthesia that these drugs can induce. NSAID-associated stromal melting is more likely to occur in

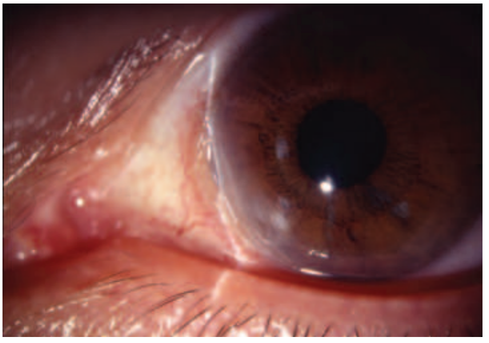


Figure 11-1 Corneal melt. *(Courtesy of Thomas L. Steinemann, MD.)*

patients with keratoconjunctivitis sicca, systemic autoimmune disease, or collagen vascular disease.

Frequent perioperative use of nonpreserved topical lubricants, punctal plug placement, or lateral tarsorrhaphy may lessen morbidity in eyes with preexisting tear film abnormalities. Persistent epithelial defects accompanied by stromal dissolution require intensive treatment with nonpreserved topical lubricants and, if needed, platelet-derived growth factor (PDGF). Corneal sensitivity should be assessed; if there is evidence of a neurotrophic cornea, it may respond to cenegermin (recombinant human nerve growth factor). It is important to minimize the use of preserved topical medications to reduce their toxic effect on the corneal epithelium. Additional treatments to encourage epithelialization and arrest stromal melting include punctal occlusion, bandage contact lenses, autologous serum eyedrops, collagenase inhibitors such as acetylcysteine 10% or hydroxyprogesterone 1%, and systemic matrix metalloproteinase inhibitors such as doxycycline.

If the disease continues to progress despite medical therapy, a commercially available temporary amniotic membrane graft may be considered. In advanced recalcitrant cases, lamellar or penetrating keratoplasty may be necessary. Corneal melting may recur even with grafted tissue. For the treatment of any underlying autoimmune disease, systemic immunosuppressive therapy may be necessary.

Induced Astigmatism

Localized change in corneal curvature may result from corneal burns produced by the phaco tip or, more commonly, from surgical incisions. Most well-constructed peripheral corneal, limbal, or scleral incisions that are less than 3 mm wide will induce less than 1.00 diopter (D) of astigmatism, usually flattening in the incision meridian. Larger incisions closer to the corneal apex or those that require suture closure are more likely to induce astigmatism. Tight radial sutures may steepen corneal curvature in the suture meridian.

Astigmatism induced by larger sutured incisions, such as those used in intracapsular cataract extraction (ICCE), extracapsular cataract extraction (ECCE), and secondary IOL implantation, may decrease by several diopters over time as the sutures dissolve or relax. When suture removal is needed to modulate astigmatism, waiting 6–8 weeks postoperatively is preferred. When more than one suture must be removed, cutting adjacent sutures in a series of visits is preferable to cutting them all at once. Removal of too many sutures too early in the postoperative period may result in either significant corneal flattening in the incision meridian or wound dehiscence.

Other Anterior Segment Complications

Epithelial or Fibrous Ingrowth

Epithelial ingrowth (or *downgrowth*) is a rare complication of intraocular surgery (Fig 11-2) or trauma. It is characterized by the growth of epithelium, rather than fibrovascular tissue, intraocularly with proliferation over the corneal endothelium, trabecular meshwork, and/or iris surfaces. Epithelial cells introduced into the anterior chamber during surgery may adhere to intraocular structures and proliferate as a cellular mass or membrane. Alternatively, a sheet of epithelium from the ocular surface may grow through a wound or incision. Epithelial ingrowth progresses faster than fibrous ingrowth. Signs of epithelial ingrowth include elevated IOP, clumps of cells floating in the anterior chamber, a grayish retrocorneal membrane (often with overlying corneal edema), an abnormal iris surface, and pupillary distortion. Green laser burns applied to the membrane on the iris surface will appear white if epithelial cells are present, which helps confirm the diagnosis.

Fibrous ingrowth (Fig 11-3) is more prevalent than epithelial ingrowth. In this complication, fibrovascular tissue proliferates from a penetrating wound. Fibrous ingrowth progresses more slowly than epithelial ingrowth and may be self-limited. It is a common cause of corneal graft failure and may result in the formation of peripheral anterior synechiae (PAS) and secondary angle-closure glaucoma.

Risk factors for both fibrous and epithelial ingrowth include trauma, prolonged inflammation, wound dehiscence, delayed wound closure, vitreous incarceration, prior filtering surgery, and Descemet membrane tears. Many surgical treatments, including membrane excision and fistula repair, have been suggested, but none has been uniformly successful. Local application of cryotherapy or intracameral injection of 5-fluorouracil or mitomycin-C has been effective. Elevated IOP is often difficult to control with medical therapy, and filtering procedures or tube shunt surgery may be necessary, as discussed in BCSC Section 10, *Glaucoma.*

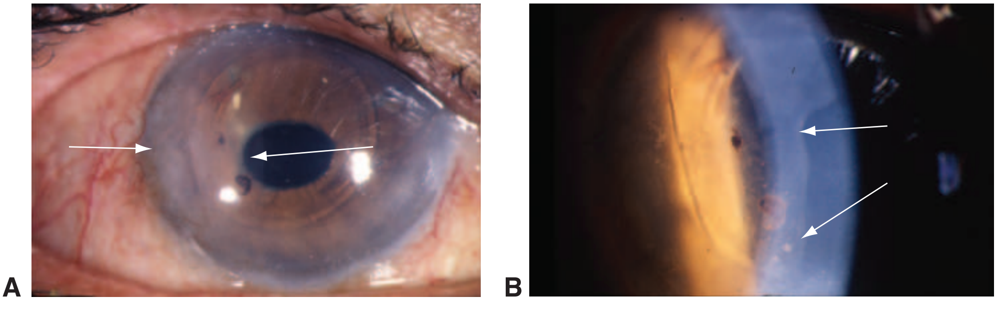


Figure 11-2 Epithelial ingrowth. **A,** Clinical photograph shows extent of epithelial ingrowth *(arrows)*. **B,** Slit-lamp photograph shows anterior extent of epithelial ingrowth *(arrows)*. *(Courtesy of Thomas L. Steinemann, MD.)*

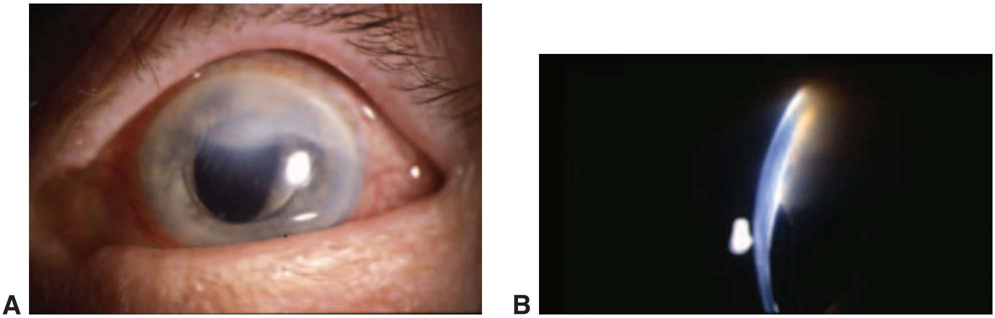


Figure 11-3 Fibrous ingrowth. **A,** Clinical photograph. **B,** Slit-lamp photograph. *(Courtesy of Thomas L. Steinemann, MD.)*

Shallow or Flat Anterior Chamber

Intraoperative anterior chamber shallowing is discussed in Chapter 10.

During the postoperative period, a flat anterior chamber may permanently damage ocular structures. Prolonged apposition of the iris to angle structures can result in PAS formation and chronic angle-closure glaucoma. Corneal contact with vitreous or an IOL can result in endothelial cell loss and chronic corneal edema. Postoperative shallow or flat anterior chambers can be classified according to their etiology and level of IOP (Table 11-2).

Patients with ocular hypotension (IOP less than 10 mm Hg) and a shallow chamber may be asymptomatic, especially when a leaking incision is plugged by iris incarceration, allowing re-formation of the anterior chamber. Slow or intermittent leaks may still allow a formed anterior chamber. Performing a Seidel test and carefully comparing the chamber depth in the surgical eye with that of the fellow eye may help the surgeon identify subtle cases of incisional leaks. Surgical exploration with re-formation of the anterior chamber and incision repair is indicated if no improvement occurs within 24–48 hours, if an obvious wound gape is present, if the iris is prolapsed out of the incision, or if intraocular structures such as the IOL are in contact with the corneal endothelium.

Pupillary block with a shallow anterior chamber and normal to high IOP may occur from various causes. Early, it may follow a resolved incision leak. Later, postoperative uveitis with iridovitreal or iridocapsular synechiae may be the cause. Failure to perform a peripheral iridectomy after placement of an anterior chamber IOL (ACIOL) may also be associated with early or late postoperative pupillary block. When initial attempts at pupillary dilation fail to deepen the anterior chamber and lower the pressure, a laser peripheral iridotomy is usually effective.

Elevated IOP

A mild, self-limited rise in IOP is common after cataract surgery. However, a significant and sustained elevation may require timely management.

Ophthalmic viscosurgical device (OVD) material retained in the eye after cataract surgery is frequently responsible for early postoperative IOP elevation, which peaks 4–6 hours after surgery. The large molecules of the OVD material can impair aqueous outflow through the trabecular meshwork. Even when all apparent OVD has been removed from

Table 11-2 Causes of Postoperative Flat or Shallow Anterior Chamber According to IOP Level

Associated With Low IOP in the Early Postoperative Period
Incision leak
Choroidal detachment
Ciliary body detachment
Associated With Low IOP in the Late Postoperative Period
Cyclodialysis
Retinal detachment
Filtering bleb formation
Uveitis
Associated With Normal or Elevated IOP
Anterior chamber IOL without patent peripheral iridectomy
Pupillary block
Aqueous misdirection
Capsular block syndrome
Suprachoroidal hemorrhage

IOP = intraocular pressure.

the anterior chamber, residual OVD can lodge in the posterior chamber or behind the lens implant (see Chapter 7). In general, IOP elevation usually does not last more than a few days and is amenable to medical treatment.

Marked IOP elevation in the early postoperative period may be temporarily managed by releasing fluid from the anterior chamber. The surgeon may consider instilling povidone-iodine 5% solution or a topical antibiotic before applying gentle pressure on the posterior lip of a preexisting paracentesis incision to release a small amount of aqueous humor. It is important to check wound integrity after the release. Caution is advised when performing this procedure in the setting of capsule rupture or zonular dialysis, because vitreous strands may become incarcerated in the paracentesis. Topical and/or systemic pressure-lowering agents should also be administered, as IOP reduction after aqueous release is short-lived, with the IOP likely to rise again within 1–2 hours of decompression.

After cataract surgery, elevated IOP without angle closure may also be caused by hyphema, TASS, endophthalmitis, retained lens material (phacolytic or phacoantigenic reactions), uveitis, iris pigment release, pigment dispersion syndrome, pseudoexfoliation, preexisting glaucoma, corticosteroid use, vitreous in the anterior chamber, or ghost cell glaucoma. Angle-closure glaucoma may be due to pupillary block, aqueous misdirection, epithelial ingrowth, neovascular glaucoma, or PAS. Treatment of the underlying cause of IOP elevation is indicated.

Aqueous misdirection

Aqueous misdirection (also known as *ciliary block glaucoma, malignant glaucoma,* or *vitreous block*) has been described as a ciliolenticular block induced by anterior movement of the lens–iris interface, poor vitreous fluid conductivity (increased resistance to fluid movement through the vitreous), and choroidal expansion. These factors cause the central and peripheral portions of the anterior chamber to become very shallow and lead to a secondary elevation of IOP due to angle obstruction. Aqueous misdirection occurs most commonly after intraocular surgery in eyes with prior angle-closure glaucoma, but it can also occur in small eyes with open angles.

Aqueous misdirection must be differentiated from pupillary block glaucoma, capsular block, suprachoroidal hemorrhage, and choroidal detachment. Unlike pupillary block, aqueous misdirection is not relieved by iridotomy but requires either intense medical therapy or surgery.

Medical treatment consists of cycloplegia and aqueous suppression, as well as hyperosmotic agents (eg, oral glycerin or intravenous mannitol). Use of miotics is not recommended, because they can worsen aqueous misdirection by exacerbating the anterior displacement of the lens–iris interface.

Surgical intervention consists of Nd:YAG laser irido-zonulo-hyaloidotomy or vitrectomy to disrupt the anterior vitreous face and vitreous–ciliary body interface. This procedure in effect establishes a unicameral eye with an open channel for aqueous to circulate into the anterior chamber. (See also BCSC Section 10, *Glaucoma.*)

Kaplowitz K, Yung E, Flynn R, Tsai JC. Current concepts in the treatment of vitreous block, also known as aqueous misdirection. *Surv Ophthalmol.* 2015;60(3):229–241.

Varma DK, Belovay GW, Tam DY, Ahmed II. Malignant glaucoma after cataract surgery. *J Cataract Refract Surg.* 2014;40(11):1843–1849.

Hyphema

Hyphema in the immediate postoperative period usually originates from the incision or the iris. The risk of hyphema is greater in patients with pseudoexfoliation syndrome, anterior segment neovascularization, Fuchs uveitis syndrome (Fuchs heterochromic uveitis), or vascular tufts at the pupillary margin. Combined microinvasive glaucoma procedures may cause hyphema postoperatively.

Hyphema is commonly mild and resolves spontaneously. When it is prolonged, the major complications are elevated IOP and corneal blood staining. IOP should be monitored closely and if elevated should be initially treated medically, although it may be difficult to control if the blood is mixed with the OVD used during the procedure or if the patient has sickle cell disease. Resolution may take longer if the blood has mixed with vitreous. Surgical evacuation is occasionally necessary; however, there is a risk of rebleeding with surgical intervention, which should be considered in the decision to proceed with surgery. See also Section 6, *Pediatric Ophthalmology and Strabismus.*

Hyphema occurring months to years after surgery is usually the result of incision vascularization or erosion of vascular tissue in the iris or ciliary body by an IOL haptic or optic edge. Laser photocoagulation of the bleeding vessel, often performed through a goniolens, may stop the bleeding or prevent rebleeding. To reduce the risk of continued or recurrent bleeding, antiplatelet or anticoagulation therapy may be withheld, if medically possible, until the hyphema resolves. Occasionally, an IOL that comes in contact with the angle, iris, or ciliary sulcus structures and causes recurrent intraocular hemorrhage (uveitis-glaucoma-hyphema [UGH] syndrome, discussed later in this chapter) must be repositioned or exchanged.

Retained Lens Fragments

During cataract extraction, lens fragments may remain in the anterior chamber angle or the posterior chamber behind the iris, or they may migrate into the vitreous cavity when zonular dehiscence or posterior capsule rupture occurs. Retained lens fragments are thought to occur more frequently in the anterior segment with phacoemulsification than with ECCE; the reported postoperative prevalence is 0.45%–1.70%, but the actual rates may be higher because of unrecognized cases. During phacoemulsification, intraocular turbulence may force small lens fragments to lodge in the angle or behind the iris, out of the surgeon's view. Femtosecond laser–assisted cataract surgery can also create many small nuclear fragments, some of which may be retained behind the iris. Dispersive OVDs may trap and retain more lens fragments than cohesive OVDs.

Patients with retained lens fragments present with varying degrees of inflammation, depending on the size of the lens fragment, the type of lens material, the time elapsed since surgery, and the patient's response. Clinical signs of retained lens material include uveitis, elevated IOP, focal corneal edema, and vitreous opacities. With persistent postoperative inflammation but no lens fragment seen on slit-lamp examination, gonioscopy is indicated to look for a retained lens fragment. When no fragment is detected on gonioscopy but suspicion of one is still high, ultrasound biomicroscopy can be used.

Retained cortical lens material or nuclear fragments may not require surgical intervention. In general, cortical material is better tolerated and more likely to be reabsorbed over time than nuclear material, which, even in small amounts, persists longer and is more likely to incite a significant inflammatory reaction, corneal edema, or elevated IOP.

Inflammation can be controlled with corticosteroid and NSAID eyedrops. Elevated IOP can be treated with aqueous suppressants. Surgical intervention may be necessary to remove residual lens fragments in the following situations:

- presence of a large or visually significant amount of lens material
- increased inflammation not readily controlled with topical medications
- medically unresponsive elevated IOP resulting from inflammation
- corneal edema
- associated retinal detachment or tears

For retained lens fragments in the anterior chamber with an intact posterior capsule, simple irrigation/aspiration or viscoexpression of the residual material may be performed through the original phacoemulsification incision.

The reported incidence of intravitreal retained lens fragments is between 0.1% and 1.6%. When lens material has migrated into the vitreous cavity through a defect in the zonular fibers or posterior capsule, referral to a vitreoretinal surgeon for pars plana vitrectomy (PPV) and removal of the lens material is indicated. If necessary, the vitreoretinal surgeon can delay intervention for more than a week after cataract surgery without jeopardizing a successful outcome.

Modi YS, Epstein A, Smiddy WE, Murray TG, Feuer W, Flynn HW Jr. Retained lens fragments after cataract surgery: outcomes of same-day versus later pars plana vitrectomy. *Am J Ophthalmol.* 2013;156(3):454-459.e1.

Vanner EA, Stewart MW. Vitrectomy timing for retained lens fragments after surgery for age-related cataracts: a systematic review and meta-analysis. *Am J Ophthalmol.* 2011; 152(3):345–357.e3.

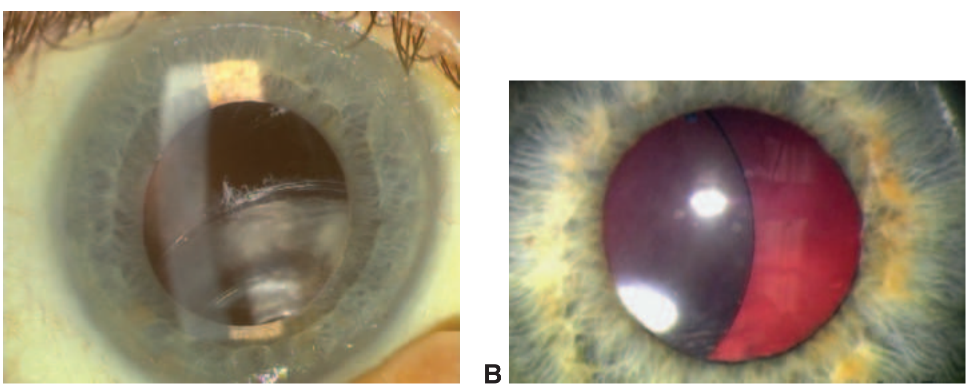
Vitreous Prolapse in the Anterior Chamber

Vitreous in the anterior chamber may lead to chronic intraocular inflammation, corneal edema, glaucoma, and CME. The pupil may be distorted by vitreous adherent to the incision. Progressive corneal decompensation as evidenced by serial endothelial cell counts or new CME should prompt intervention. Inflammation, symptoms of glare due to an exposed IOL edge, and patient dissatisfaction with the iris appearance may prompt intervention. In symptomatic patients, Nd:YAG laser vitreolysis or anterior vitrectomy may be considered when the response to topical anti-inflammatory therapy is inadequate. If the vitreous extends through the incision to the ocular surface, a vitrectomy is warranted. The exposed vitreous may act as a wick, enabling bacteria to enter the eye and increasing the risk of endophthalmitis. In cases of suspected corneal compromise, a posterior vitrectomy approach may be preferable to an anterior approach to reduce surgical trauma to the cornea.

Postoperative IOL Complications

Decentration and Dislocation

The reported incidence of symptomatic IOL decentration or dislocation after uncomplicated cataract surgery is 0.19%–3.00%. The decentered or dislocated IOL may be either inside the capsule (intracapsular) or outside it (extracapsular) (Fig 11-4). The most common cause of intracapsular IOL malposition is zonular degradation associated with



A B

Figure 11-4 Intraocular lens (IOL) dislocation. **A,** Intracapsular (in-the-bag) dislocation. **B,** Extracapsular (out-of-the-bag) dislocation. *(Part A reprinted with permission from Elsevier from Kristianslund O, Råen M, Østern AE, Drolsum L. Glaucoma and intraocular pressure in patients operated for late in-the-bag intraocular lens dislocation: a randomized clinical trial.* Am J Ophthalmol. *2017;176:219–227. Part B reprinted from Dorey MW, Condon GP. Management of dislocated intraocular lenses.* Focal Points: Clinical Modules for Ophthalmologists. *American Academy of Ophthalmology; 2009, module 9:2.)*

pseudoexfoliation syndrome. Insufficient zonular support may also be associated with trauma, previous vitreoretinal surgery, capsular contraction, retinitis pigmentosa, high myopia, uveitis, or congenital conditions that affect zonular integrity. Asymmetric bag/sulcus haptic positions (ie, 1 haptic in the capsular bag and 1 in the sulcus) aggravated by capsular fibrosis and contraction may also tilt or decenter an IOL. The most common cause of extracapsular IOL malposition is sulcus placement of an inadequately sized IOL, such as a smaller 3-piece IOL designed for intracapsular placement. Additional causes include a decentered or oversized capsulorrhexis, localized zonular defects, capsular defects, and IOL haptic damage.

IOL decentration can cause unwanted glare and reflections or multiple images if the lens edge is within the pupillary space. When an aspheric, multifocal, or accommodating IOL is decentered, the effectiveness of the lens is diminished. Decentration of any posterior chamber IOL (PCIOL) may lead to pupillary capture or UGH syndrome due to contact with uveal tissue.

Minor decentration may be treated with miotics to constrict the pupil over the IOL optic; in cases of pigment dispersion or recurrent hyphema, treatment with cycloplegic agents can reduce iris chafing by the IOL optic or haptics. Laser pupilloplasty, which may be performed to realign the pupillary aperture with the IOL optical center, may be particularly useful with multifocal lenses. Severe cases of IOL decentration or dislocation are managed with IOL repositioning, stabilization with sutures, or exchange.

An extracapsular decentered IOL may be rotated and repositioned into a stable axis if there is sufficient support. Many extracapsular and selected intracapsular 3-piece IOL dislocations can be managed with peripheral iris suture fixation using a McCannel suture or Siepser sliding knot technique with a nonabsorbable monofilament suture, such as 9-0 or 10-0 polypropylene (Video 11-1; Fig 11-5). Iris fixation has some advantages over scleral fixation, including decreased risks of late suture erosion or breakage, IOL tilting, and endophthalmitis. Disadvantages include possible posterior iris pigment chafing, pupil distortion, pseudophacodonesis, and hyphema. One-piece uniplanar acrylic IOLs are not suitable for secondary sulcus or iris fixation because of iris pigment chafing (Fig 11-6) and the possible development of UGH syndrome.

VIDEO 11-1 Iris fixation of IOL.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

When irregular capsular fibrosis decenters an IOL placed in the capsular bag, deformation of the haptics may limit rotation for surgical IOL recentering. In such cases, the IOL haptics may need to be moved into the ciliary sulcus or the lens replaced. When the optic is removed before implantation of a new IOL, haptics fixated in the capsular bag or sulcus can be either amputated and left in place or slipped out of a fibrous cocoon.

Severe pseudophacodonesis or intracapsular (in-the-bag) IOL dislocation due to zonular loss may be managed with haptic fixation to the sclera. There are many ab externo (Fig 11-7) and ab interno (Fig 11-8) approaches and suture configurations, including scleral suture fixation (Video 11-2); intrascleral haptic fixation in Scharioth tunnels, also

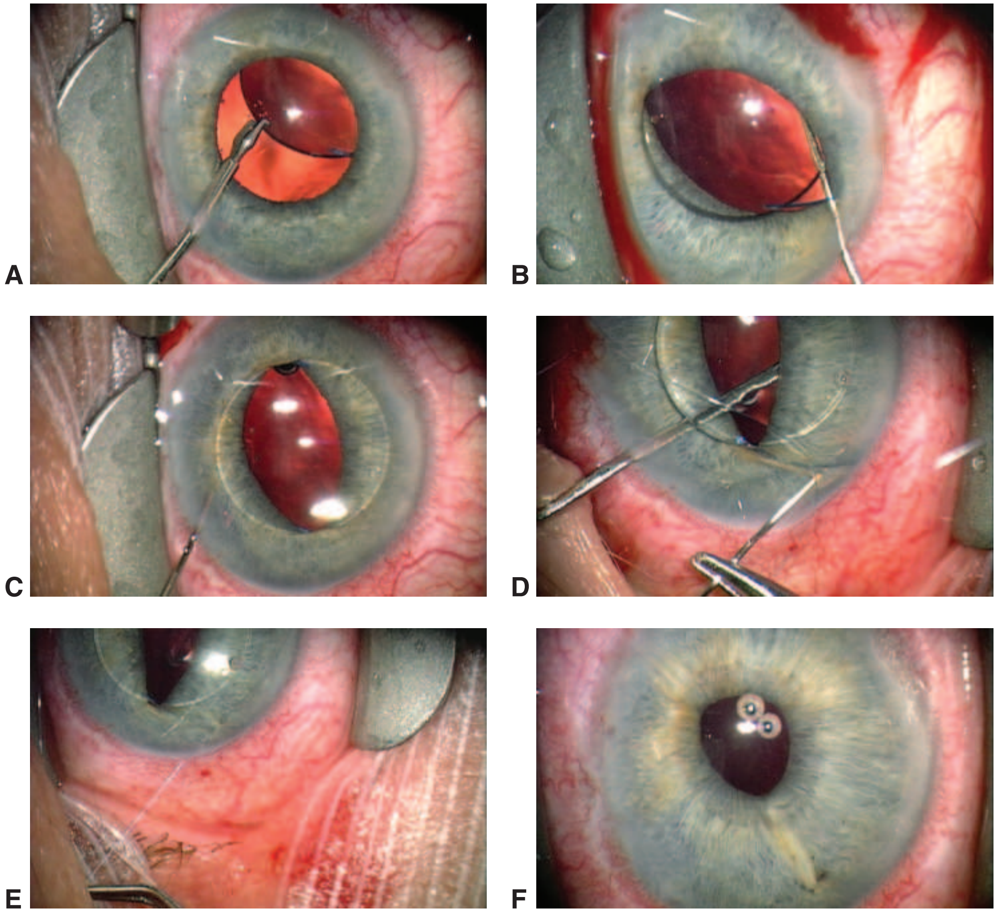


Figure 11-5 Peripheral iris suture fixation technique for IOL dislocation out of the capsular bag. **A,** The IOL is grasped and rotated with microsurgical forceps. **B,** Iris hooks are used to bring the optic above the iris plane. **C,** Optic capture by the pupil is completed through the addition of acetylcholine to induce miosis. **D,** The needle has been passed through a paracentesis incision, then through the iris and behind the haptic, and then back out through the iris and distal clear cornea. **E,** A Siepser sliding knot is used to secure the haptic to the peripheral iris. **F,** After both haptics are secured, the optic is prolapsed back into the posterior chamber. The sutures are minimally visible at the 5- and 10-o'clock positions. *(Parts A–C and F reprinted with permission from Condon GP. Following a posterior capsular rent, the sulcus-fixated intraocular lens has become decentered. How should I proceed? In: Chang DF, ed.* Curbside Consultation in Cataract Surgery: 49 Clinical Questions. *Slack; 2007:227–232. Part D courtesy of Garry P. Condon, MD.)*

called the glued IOL technique (Fig 11-9; Video 11-3); and intrascleral flanged-haptic fixation, also referred to as Yamane technique (Fig 11-10; Videos 11-4, 11-5).

VIDEO 11-2 Ab externo IOL fixation (sutured).
Courtesy of the University of Iowa; Jesse Vislisel, MD, and Kenneth M. Goins, MD.
Available at: aao.org/bcscvideo_section11

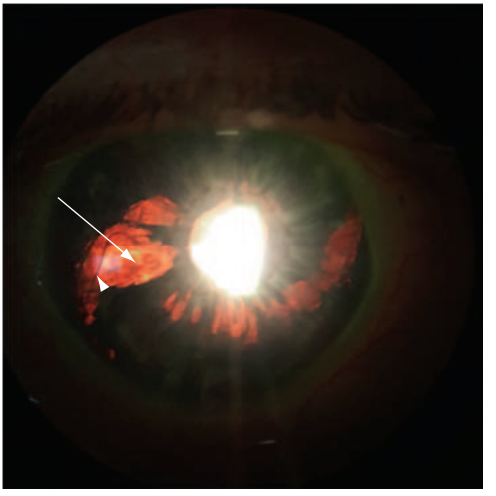


Figure 11-6 Transillumination defects of the iris from sulcus placement of a uniplanar 1-piece acrylic IOL. An *arrow* points out the optic edge; an *arrowhead* denotes the haptic edge. *(Courtesy of Charles Cole, MD.)*

VIDEO 11-3 Intrascleral haptic fixation with Scharioth tunnel (glued).
Courtesy of the University of Iowa; Jesse Vislisel, MD, and A. Tim Johnson, MD, PhD.
Available at: aao.org/bcscvideo_section11

VIDEO 11-4 Ab externo flanged-haptic IOL fixation, Yamane technique.
Courtesy of Charles Cole, MD.
Available at: aao.org/bcscvideo_section11

VIDEO 11-5 Double-needle intrascleral flanged-haptic IOL fixation, Yamane technique.
Courtesy of Wesley Green, MD, and Arsham Sheybani, MD.
Available at: aao.org/bcscvideo_section11

For sutureless techniques, IOLs with haptics made of a material such as polyvinylidene fluoride are preferable, as the polymethylmethacrylate (PMMA) haptics of a 3-piece foldable IOL can be brittle and prone to kinking or breaking with manipulation. A concurrent anterior vitrectomy is often necessary. Iris retractors may be used for better visualization or to stabilize the haptics during suturing. To prevent erosion through the conjunctiva, sutures through the scleral wall can be buried in a partial-thickness scleral groove or covered by a scleral flap. The scleral flap can be created through a conjunctival incision or a tunnel incision dissected posteriorly from the limbus (eg, Hoffman pockets; Video 11-6).

VIDEO 11-6 Ab externo IOL reposition with Hoffman pockets.
Courtesy of Jason Leng, MD.
Available at: aao.org/bcscvideo_section11

When IOL dislocation is complete, PPV techniques are required to retrieve the lens or lens–capsule complex and elevate it safely into the anterior segment for fixation to the iris or sclera by various techniques. In some cases, the implant may be removed and replaced with either an ACIOL (see Chapter 8) or an iris- or scleral-fixated PCIOL.

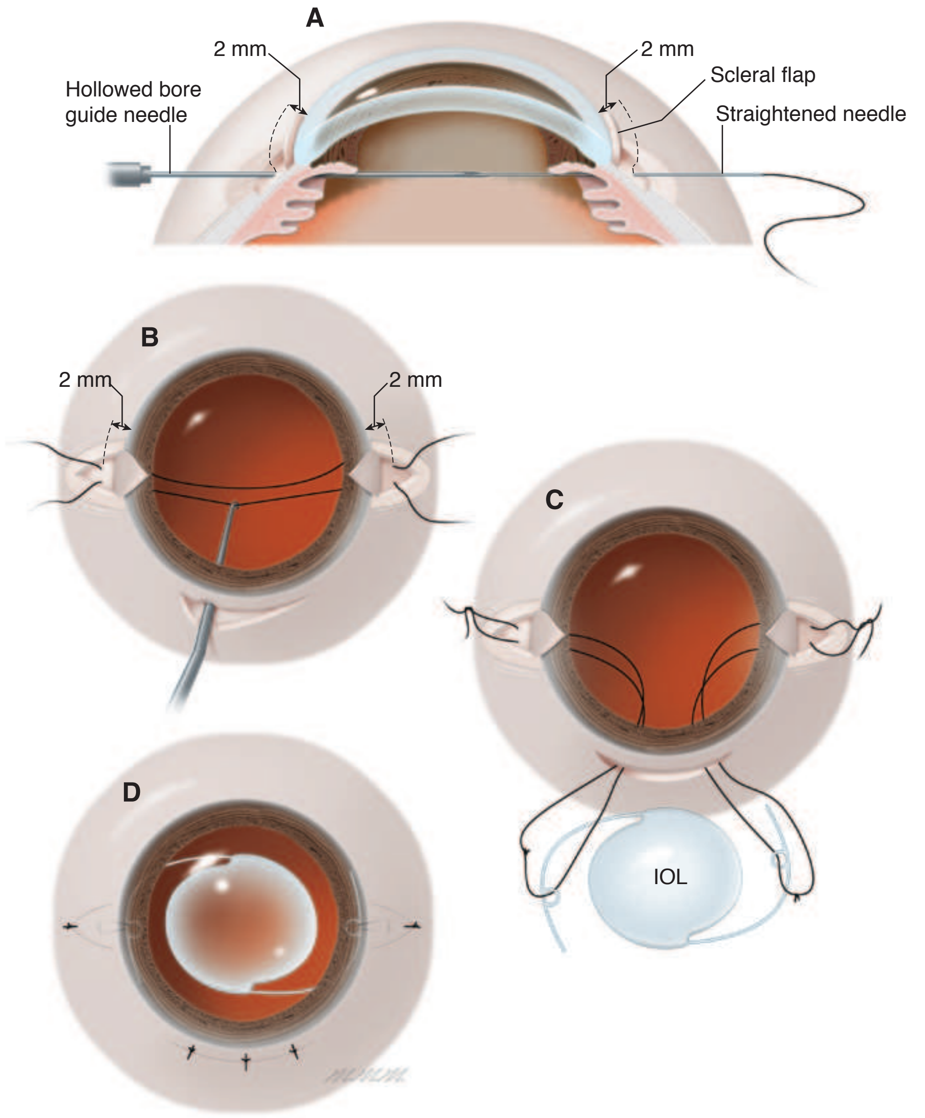


Figure 11-7 Illustration showing ab externo scleral fixation technique. **A,** Scleral flaps are created 180° apart. A single-armed suture on a straightened needle is passed under the scleral flap approximately 2 mm posterior to the limbus. The suture needle is retrieved by a hollow-bore guide needle under the opposite scleral flap. This process is repeated from the opposite direction. **B,** The 2 suture loops are externalized through the main limbal incision. **C,** The cut suture ends are tied to eyelets of the IOL haptic. The IOL is internalized through the limbal incision, and the sutures are tied under the scleral flaps. **D,** The limbal incision, scleral flaps, and conjunctiva are closed. *(Illustration by Mark Miller.)*

Suture breakage and subluxation of scleral-fixated sutured IOLs using 10-0 polypropylene fixation sutures have been reported 3–9 years after implantation. Double-fixation techniques and thicker 9-0 polypropylene or CV-8 Gore-Tex sutures (off-label use; W.L. Gore & Associates) are currently recommended for IOL scleral fixation. Other complications of sutured IOLs include vitreous or suprachoroidal hemorrhage, lens tilting,

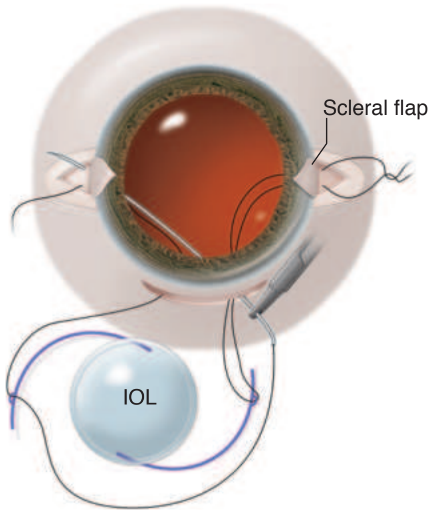


Figure 11-8 Illustration of ab interno IOL fixation. Double-armed sutures are secured to the eyelets of the IOL haptics. The needles are passed under the iris to exit the eye 1.5 mm posterior to the limbus under the scleral flaps. After the IOL is internalized, the sutures are tightened to center the IOL and tied under the scleral flaps. *(Illustration by Mark Miller.)*

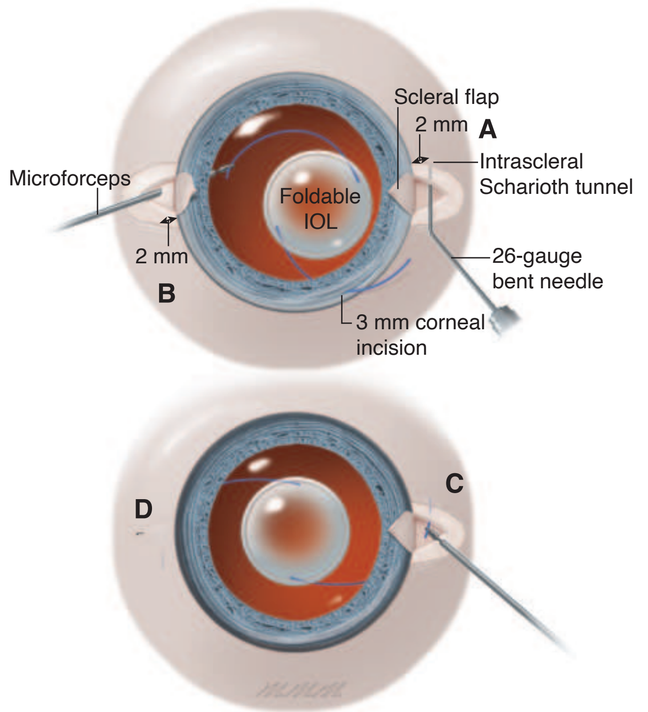


Figure 11-9 Illustration of intrascleral glued haptic IOL fixation. **A,** Scleral flaps are created 180° apart. Intrascleral Scharioth tunnels are created parallel to the limbus with a bent 26-gauge needle. **B,** A 3-piece foldable IOL is injected into the eye while a microforceps is used to grasp the leading haptic and externalize it. Similarly, the trailing haptic is then externalized under the opposite scleral flap. **C,** The haptics are tucked into intrascleral tunnels. **D,** The flaps and conjunctiva are sealed with tissue glue. *(Illustration by Mark Miller.)*

CME, retinal tears or detachment, suture erosion, and endophthalmitis. See also BCSC Section 12, *Retina and Vitreous.*

An ACIOL may be associated with decentration, iris tucking, UGH syndrome, corneal edema, or pseudophacodonesis, all of which may require lens repositioning or exchange with either a differently sized flexible ACIOL or a sutured PCIOL. An ACIOL associated with pseudophakic bullous keratopathy is treated by endothelial keratoplasty, usually with IOL exchange.

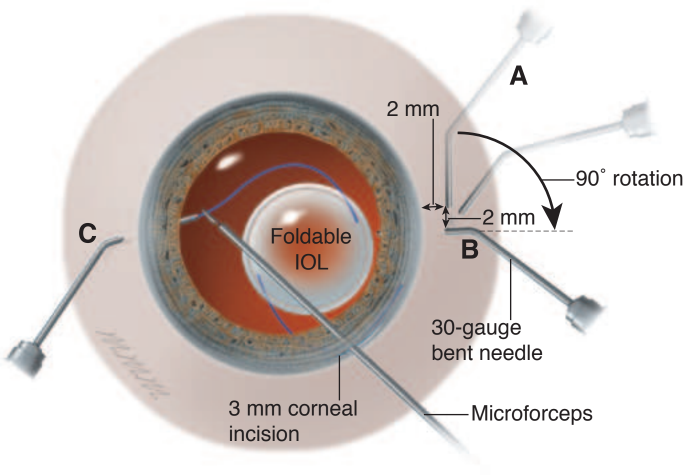


Figure 11-10 Illustration of intrascleral flanged haptic IOL fixation (Yamane technique). **A,** Transconjunctival scleral tunnels (180° apart) are made parallel to the limbus 2 mm posterior to the limbus with thin-walled (wide-bore) 30-gauge needles. Each tunnel is approximately 2 mm long. **B,** The needles are turned perpendicular *(arrow)* to the limbus to enter the eye. **C,** The leading haptic of a 3-piece foldable IOL is guided into the bore of the needle with microforceps under direct visualization. The same is done for the trailing haptic, and both are simultaneously externalized where noncontact thermal cautery is used to create a flange prior to replacement into the sclera (not shown; see Video 11-4). *(Illustration by Mark Miller.)*

When an iris-supported lens becomes dislocated or associated with corneal edema or UGH syndrome, IOL exchange is warranted, if possible.

Agarwal A, Jacob S, Kumar DA, Agarwal A, Narasimhan S, Agarwal A. Handshake technique for glued intrascleral haptic fixation of a posterior chamber intraocular lens. *J Cataract Refract Surg*. 2013;39(3):317–322.

Jacob S. Management of late lens implant and capsule dislocation. *Focal Points: Clinical Practice Perspectives*. American Academy of Ophthalmology; 2017, module 3.

Yamane S, Sato S, Maruyama-Inoue M, Kadonosono K. Flanged intrascleral intraocular lens fixation with double-needle technique. *Ophthalmology*. 2017;124(8):1136–1142.

Pupillary Capture

Postoperative pupillary capture of the IOL optic can have several causes, such as the formation of synechiae between the iris and underlying posterior capsule, improper placement of the IOL haptics, anterior chamber shallowing, or anterior displacement of the PCIOL optic. The last of these is associated with the placement of nonangulated IOLs in the ciliary sulcus, the upside-down placement of an angulated IOL so that it vaults anteriorly, excessive Soemmering ring formation (see the section Posterior Capsule Opacification), and asymmetric capsule contraction. Placement of a posteriorly angulated PCIOL in the capsular bag and the creation of an anterior capsulorrhexis smaller than the lens optic decreases the likelihood of pupillary capture.

Pupillary capture may be simply a cosmetic concern. If the condition is chronic and the patient is asymptomatic, it can be left untreated. Surgical IOL repositioning may be indicated if pupillary capture causes glare, photophobia, chronic uveitis, unintended myopia, or monocular diplopia. In an acute pupillary capture, pharmacologic manipulation of the pupil with the patient in the supine position sometimes frees the optic. If conservative management fails, surgical intervention may be required to free the iris, lyse synechiae, manage capsule contraction or residual lens proliferation, and reposition the lens (Fig 11-11).

Capsular Block Syndrome

Postoperative capsular block syndrome (CBS) is caused by the intracapsular accumulation of liquefied material posterior to the IOL and the subsequent occlusion of the anterior capsulotomy. Early postoperative CBS may occur when residual OVD becomes trapped within the capsular bag, between the posterior capsule and the posterior surface of the IOL, causing a myopic shift in the refractive error from an anterior displacement of the lens optic. Anterior displacement of the iris diaphragm with anterior chamber shallowing may also occur, which must be differentiated from a ciliary block mechanism. If left untreated, CBS may lead to posterior synechiae and secondary glaucoma. Nd:YAG laser anterior capsulotomy peripheral to the optic or posterior capsulotomy releases the trapped fluid, resulting in the posterior movement of the IOL optic to its intended position, anterior chamber deepening, and resolution of the myopic shift.

Late postoperative CBS may occur years after surgery with the accumulation of a turbid or milky fluid between the posterior capsule and the IOL that is consistent with the byproducts of trapped, residual lens epithelial cells (Fig 11-12). Myopic shift is uncommon in these cases, and the patient may be asymptomatic. Nd:YAG laser posterior capsulotomy usually resolves this condition without complications.

Uveitis-Glaucoma-Hyphema Syndrome

UGH syndrome was first described in the context of rigid or closed-loop ACIOLs, as covered in the Introduction. Today, it may occur in patients with PCIOLs due to contact between lens haptics and uveal tissue in the posterior chamber. Single-piece acrylic IOL haptics should not be placed in the sulcus because of the high risk of UGH syndrome. The classic triad or individual components of the syndrome may also occur as a result of inappropriate IOL sizing, contact between the implant and vascular structures, or defects in implant manufacturing.

Figure 11-11 Pupillary capture by an angulated posterior chamber IOL in a patient who was assaulted 2 months after lens implantation surgery. *(Courtesy of Steven I. Rosenfeld, MD.)*

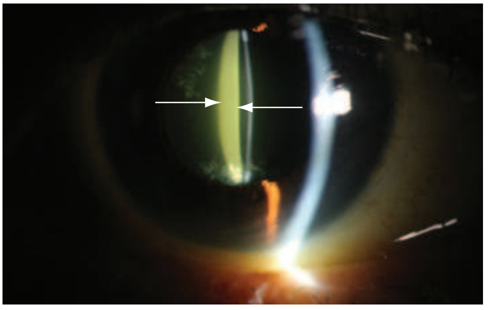


Figure 11-12 Late postoperative capsular block. *Arrows* show the posterior edge of the IOL and the posterior capsule containing turbid fluid. *(Courtesy of Chad Brasington, MD.)*

Uveitis, glaucoma, and/or hyphema may respond to treatment with cycloplegics and topical anti-inflammatory or ocular hypotensive medications. If medical therapy does not sufficiently address the findings or if inflammation threatens either retinal or corneal function, IOL removal must be considered. This procedure may be complicated because of inflammatory scars, particularly in the anterior chamber angle or posterior to the iris. If such scarring is present, the surgeon may need to amputate the haptics from the optic and remove the lens piecemeal, rotating the haptic material out of the synechial tunnels to minimize trauma to the eye. In some cases, leaving portions of the haptics in place is safer. Early lens explantation may reduce the risk of corneal decompensation and CME.

Pseudophakic Bullous Keratopathy

Certain IOL designs, particularly iris-clip lenses (iris-fixated lenses with the optic anterior to the iris) and closed-loop flexible ACIOLs as described in the Introduction, have been associated with an increased risk of corneal decompensation. Thus, these 2 lens types are no longer in clinical use.

With modern phacoemulsification and current IOLs, the risk of corneal decompensation is increased with prolonged surgical time using high ultrasound energy, excessive use of ultrasound in the anterior chamber (as opposed to the iris plane or within the capsule), and inadequate protection of the corneal endothelium with OVD. Underlying corneal endothelial dysfunction such as Fuchs corneal dystrophy also increases the risk of postoperative corneal edema. The surgeon can use OVD to protect the corneal endothelium and avoid contacting the endothelium with instruments or lens particles.

Initial treatment of pseudophakic bullous keratopathy (Fig 11-13) entails controlling postoperative inflammation while avoiding elevated IOP. As discussed earlier in this chapter (see the section Corneal Edema), topical hypertonic sodium chloride eyedrops or ointment can be a conservative short-term treatment to decrease corneal edema. A bandage contact lens and topical antibiotics may be necessary for ruptured bullae.

Decreased vision, recurrent keratitis, and pain are indications for endothelial keratoplasty, which may successfully restore clear corneas and improve vision. Bullae and associated pain may also be alleviated with phototherapeutic keratectomy, cautery of the Bowman layer, anterior stromal micropuncture, or corneal crosslinking. When comfort is the primary goal in an eye with little or no vision potential, a Gundersen conjunctival flap or amniotic membrane graft is an option; neither of these carries greater risks of keratoplasty. See also BCSC Section 8, *External Disease and Cornea.*

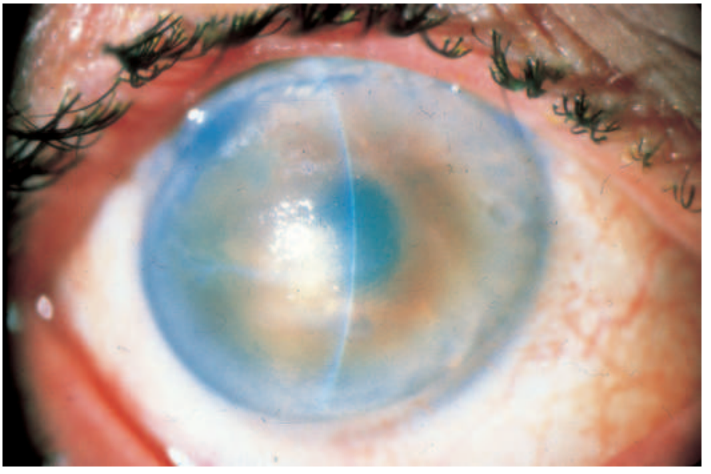


Figure 11-13 Pseudophakic bullous keratopathy. *(Courtesy of Karla J. Johns, MD.)*

IOL Opacification

Several types of IOLs have developed opacities or discoloration (Fig 11-14), either immediately after implantation or progressively over the years. Five general processes of IOL opacification have been identified:

- deposits or precipitates on the surface of or within the IOL
- influx of water in hydrophobic optic material (glistenings)
- IOL staining by capsular dyes or medications
- IOL coating by substances such as ophthalmic ointment or silicone oil
- progressive degradation of the IOL material (eg, snowflake degeneration in PMMA IOLs)

Calcium deposition on the surface of or within hydrophilic acrylic lenses can degrade the quality of vision, and IOL explantation may be required. Calcium deposits on silicone lenses have been reported in eyes with asteroid hyalosis, usually after posterior capsulotomy.

Glistenings are fluid-filled microvacuoles that form within an IOL optic in an aqueous environment. They are observed within all IOL materials but are associated primarily with certain hydrophobic acrylic IOLs. Glistening formation and intensity increase with time. Although their appearance may be striking on slit-lamp examination, glistenings have not been shown to affect best-corrected visual acuity. Although studies have documented a negative effect on contrast sensitivity at high spatial frequency, IOL explantation for glistenings is rarely reported.

IOL explantation has been required when interlenticular opacification occurred between piggyback PCIOLs, especially when both lenses were made of hydrophobic acrylic material and were placed in the capsular bag. Using IOLs made of 2 different materials, enlarging the capsulorrhexis, and placing 1 lens in the capsular bag and 1 in the sulcus may reduce the incidence of opacification.

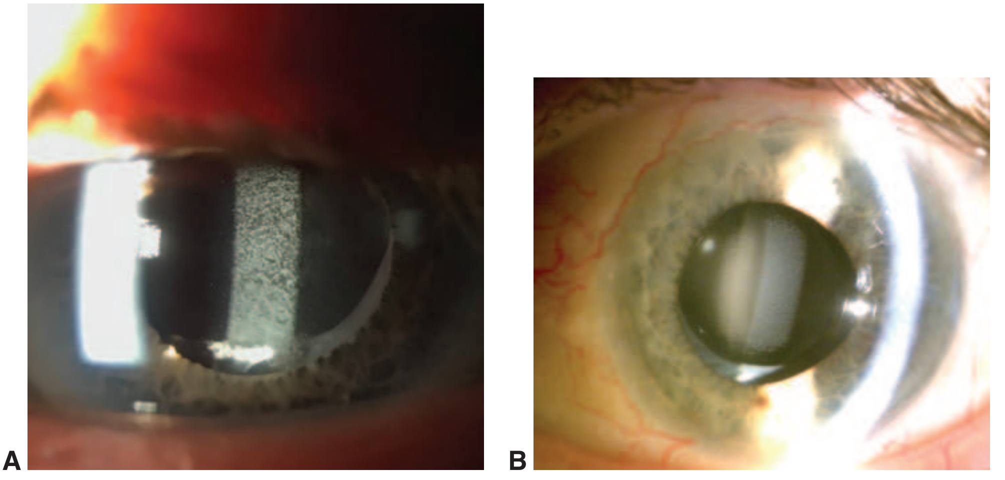


Figure 11-14 IOL opacifications. **A,** Softec IOL. **B,** Hydrophilic IOL after multiple glaucoma procedures. *(Part A courtesy Stephen M. Hamilton, MD; Part B courtesy of Richard R. Schulze, MD.)*

Espandar L, Mukherjee N, Werner L, Mamalis N, Kim T. Diagnosis and management of opacified silicone intraocular lenses in patients with asteroid hyalosis. *J Cataract Refract Surg.* 2015;41(1):222–225.

IOL Glare and Dysphotopsia

Lens decentration and opacification can cause glare symptoms, which can also occur when the diameter of the IOL optic is smaller than the diameter of the scotopic pupil. IOLs with a square-edge design and multifocal IOLs are more likely to produce glare and halos, even when well centered. When the pupil is dilated, spherical aberration may cause some degree of distortion or glare under scotopic conditions even when the iris covers the lens optic edge. Aspheric IOLs may reduce some of these phenomena and improve contrast sensitivity. Although spherical aberration of the cornea varies in the population and changes with keratorefractive surgery, various aspheric and spherical IOLs can be matched to the degree of corneal asphericity (see Chapter 7).

Patients with diffractive or refractive multifocal IOLs are more likely to experience glare, decreased contrast sensitivity, or loss of desired multifocality with minor IOL decentration, altered pupil diameter or position, or posterior capsule opacity. An accommodating IOL may vault anteriorly (a condition known as *Z syndrome*) because of misplaced haptics or asymmetric capsular contraction. This syndrome can often be managed by posterior capsulotomy, but the lens may need to be surgically repositioned or explanted.

Dysphotopsias are abnormal visual symptoms related to light rays interacting with IOL optics (see BCSC Section 3, *Clinical Optics and Vision Rehabilitation*). Current research indicates that a central neuroadaptive component may also be involved in patient perceptions of dysphotopsia, more for negative dysphotopsia than for positive dysphotopsia.

Positive dysphotopsia is

- described as glare, streaks, flashes, arcs, or halos of light in the midperiphery
- more common with truncated square-edge IOLs and those manufactured from higher-index materials, as well as with multifocal IOLs

Negative dysphotopsia is

- described as an arcuate dark or dim crescent-shaped region, usually in the temporal visual field
- likely to occur in the routine setting of a PCIOL centered in the capsular bag with the anterior capsule edge overlapping the lens optic
- possible with any type of IOL placed within the capsular bag
- not seen with ACIOLs and sulcus- or scleral-fixated lenses
- more common in the left eye and in women
- possibly more common with acrylic, square-edge optics with a higher index of refraction

In susceptible eyes, temporal light rays may interact with the nasal lens edge and overlying anterior capsule, causing a shadow (penumbra) on the nasal retina. This effect is more common with a miotic or nasally located pupil and may be relieved with dilation or by blocking light from the temporal side.

Although negative dysphotopsia symptoms are common in the early postoperative period (affecting approximately 15% of all patients), they improve over time in most patients, presumably because of neuroadaptation or anterior capsule opacification. Thus, observation is initially advised. For the approximately 3% of patients who report prolonged symptoms and compromised vision 1 year after surgery, optic repositioning anterior to the capsulorrhexis by reverse optic capture through the capsulorrhexis (with the haptics in the capsular bag) or sulcus fixation of an appropriate PCIOL is successful. However, when reverse optic capture is performed at the time of initial IOL implantation with cataract surgery, the reported rate of posterior capsule opacification requiring Nd:YAG laser posterior capsulotomy by 3 months postoperatively is 100%. Implantation of a piggyback IOL in the ciliary sulcus, partial nasal anterior capsulotomy, or truncation of the nasal optic within the capsular bag has also been successful in some cases.

Masket S, Fram NR. Pseudophakic dysphotopsia: review of incidence, cause, and treatment of positive and negative dysphotopsia. *Ophthalmology*. 2021;128(11):e195–e205.

Masket S, Fram NR, Cho A, Park I, Pham D. Surgical management of negative dysphotopsia. *J Cataract Refract Surg*. 2018;44(1):6–16.

Unexpected Refractive Results

Cataract surgery and IOL implantation can often provide patients with the refractive outcome they desire. See Chapter 7 and BCSC Section 13, *Refractive Surgery,* for a discussion of cataract surgery as a refractive procedure, including toric IOL implantation.

Unintended postoperative refractive errors may be the result of a preoperative error in the measurement of axial length or the keratometry readings. Choosing the correct IOL power is difficult in patients with high hyperopia, high myopia, or prior vitrectomy; patients undergoing simultaneous penetrating keratoplasty; patients with silicone oil in the vitreous cavity; and patients with prior refractive surgery (see Chapter 7). Failure to confirm the planned IOL at the time of surgery may result in the implantation of an incorrect lens.

Toric IOLs must be oriented on a precise axis for maximal astigmatic correction; they can be checked for correct axis placement and may need to be repositioned if they are placed improperly or rotate postoperatively. Refer to Chapter 7 for further discussion of these lenses, including risk factors for postoperative toric IOL rotation.

Unexpected postoperative refractive results may be due to the inversion of an angulated IOL or placement of the lens in the sulcus when it was calculated for placement in the capsular bag, either of which results in anterior displacement and changes the effective IOL power. In addition, other potential causes of an anterior or posterior shift in IOL position, such as posterior capsule rupture, capsular block, or aqueous misdirection, should be addressed. Mislabeling or manufacturing defects cause these problems only in rare cases. If the visual acuity is less than expected early in the postoperative course and is confirmed by refraction, incorrect IOL power may be suspected. Regardless of the source of the error, medical record documentation and full disclosure to the patient are necessary.

If the magnitude of the postoperative refractive error produces symptomatic ametropia, anisometropia, or patient dissatisfaction, the surgeon can consider several options:

- refraction for glasses or contact lens wear
- rotation of toric IOL if off-axis
- IOL exchange
- insertion of a piggyback IOL
- secondary keratorefractive procedure

Capsular Opacification and Contraction

Posterior Capsule Opacification

The most common late occurrence after cataract surgery via ECCE or phacoemulsification is posterior capsule opacification (PCO) (Fig 11-15). In addition, contracture of a continuous curvilinear capsulorrhexis may occlude the visual axis because of anterior capsule fibrosis and phimosis.

Capsular opacification stems from the continued viability of lens epithelial cells that remain after removal of the nucleus and cortex. Opaque secondary membranes are formed by proliferating lens epithelial cells, fibroblastic metaplasia, and collagen deposition. Lens epithelial cells proliferate in several patterns. Sequestration of nucleated bladder cells *(Wedl cells)* in a closed space between the adherent edges of the anterior and posterior capsule results in a doughnut-shaped configuration, referred to as a *Soemmering ring.* If the epithelial cells migrate out of the capsular bag, translucent globular masses resembling fish eggs (*Elschnig pearls*) form on the edge of the capsular opening. The so-called pearls can fill the pupil or remain hidden behind the iris. Histologic examination shows that these "pearls" are nucleated bladder cells, identical to those proliferating within the capsule of a Soemmering ring but usually lacking a basement membrane. If the epithelial cells migrate across the anterior or posterior capsule, they may cause capsular wrinkling and

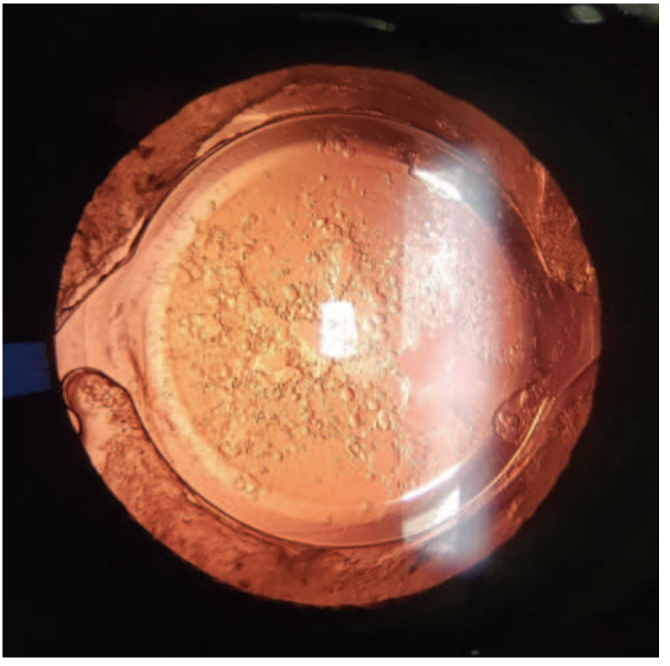


Figure 11-15 Posterior capsule opacification, seen with retroillumination. *(Courtesy of Charles Cole, MD.)*

opacification. These lens epithelial cells, which are capable of undergoing metaplasia with conversion to myofibroblasts, can produce a matrix of fibrous and basement membrane collagen. Contraction of this collagen matrix causes wrinkles in the posterior capsule, with resultant distortion of vision and glare.

The reported incidence of PCO varies widely but has been diminishing as a result of modern IOL designs and placement. Older studies reported that the frequency of Nd:YAG laser capsulotomy varied between 3% and 53% within 3 years of cataract surgery. More recent clinical series with a 3- to 5-year follow-up of cases with either hydrophobic acrylic or silicone square-edge IOL design show PCO rates up to 18.6% at 3 years and 22.6% at 5 years.

IOL design is now considered the dominant factor both in inhibiting posterior migration of lens epithelial cells and influencing the rate of PCO. The IOL material also has a modest effect on opacification rates. Hydrogel IOLs are associated with the highest rate, followed by PMMA, then silicone; IOLs made of hydrophobic acrylic material are associated with the lowest rate. Compared to round-edge optics, the truncated square-edge optic design is associated with lower rates of PCO in both silicone and acrylic IOLs, although these lenses may increase the incidence of undesirable optical reflections and positive dysphotopsias. See BCSC Section 3, *Clinical Optics and Vision Rehabilitation,* for further discussion of IOL design.

Other factors thought to increase the rate of PCO include

- younger age of the patient
- history of intraocular inflammation
- pseudoexfoliation syndrome
- anterior capsulorrhexis that does not cover 360° of the IOL edge
- incomplete cortical cleanup

- round-edge design of the IOL optic
- more time elapsed since surgery
- presence of silicone oil

There is no reported difference in PCO rates with prolonged use of postoperative topical corticosteroids or NSAIDs.

Ursell P, 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.* 2022;34(5):960–968.

Anterior Capsule Fibrosis and Phimosis

Capsular fibrosis is associated with clouding of the anterior capsule. If a substantial portion of the IOL optic is covered by the opaque anterior capsule, including portions exposed through the undilated pupil, the patient may experience symptoms such as glare—especially at night because of physiologic mydriasis in darkness—or a perception that their vision has become cloudy or hazy. The term *capsular phimosis* describes the postoperative contraction of the anterior capsule opening because of circumferential fibrosis. Phimosis produces symptoms similar to and often more pronounced than those of fibrosis alone.

Fibrosis and anterior capsule contraction occur more frequently with smaller capsulorrhexis openings, underlying pseudoexfoliation syndrome, and abnormal or asymmetric zonular support (eg, penetrating or blunt trauma, Marfan syndrome, or surgical trauma). Anterior capsule contraction may contribute to late pseudophacodonesis or in-the-bag IOL subluxation due to stress on the zonular apparatus.

Anterior capsule contraction, but not PCO, may be reduced with anterior capsule polishing to remove residual lens epithelial cells. Capsular phimosis (Fig 11-16) can be treated with several radial Nd:YAG laser anterior capsulotomies to release the annular contraction, reduce the traction on the zonule, and enlarge the anterior capsule opening (Fig 11-17).

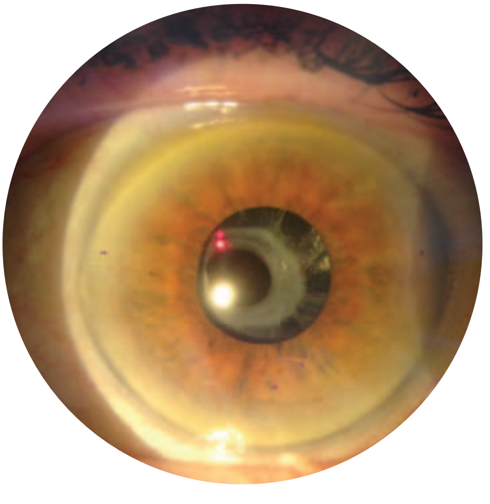


Figure 11-16 Severe anterior capsular phimosis. *(Courtesy of Stephen M. Hamilton, MD.)*

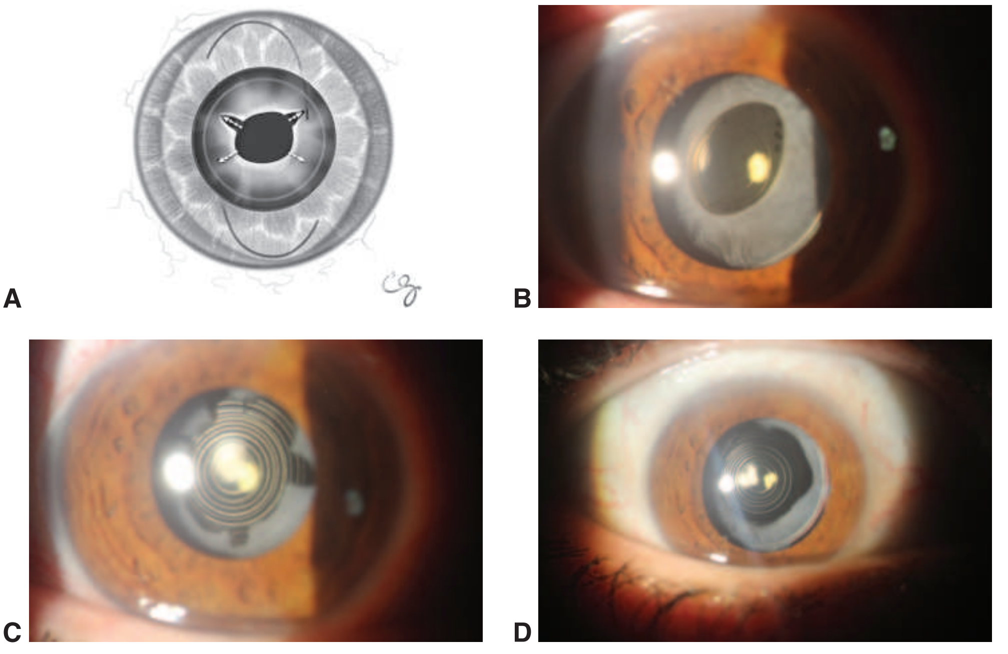


Figure 11-17 Nd:YAG laser anterior capsulotomy. **A,** Multiple radial anterior capsulotomies *(arrows)* can relieve anterior capsule phimosis and traction on the zonular fibers. **B,** Anterior capsule phimosis. **C,** After YAG laser radial relaxing cuts. **D,** 1 month after YAG laser radial relaxing cuts. *(Part A by Christine Gralapp. Parts B, C, and D courtesy of Alejandro Navas, MD.)*

This procedure is performed similarly to Nd:YAG laser posterior capsulotomy, with care taken to not defocus too far posteriorly and damage the underlying IOL with laser pitting. In general, the anterior capsule tissue or a fibrotic ring is tougher and thus requires more laser power than the posterior capsule.

Nd:YAG Laser Capsulotomy

The Nd:YAG laser is used to treat secondary opacification of the posterior capsule and/or contraction of the anterior capsule. Alternatively, intraocular surgical cleaning of the capsule may be performed during concurrent anterior segment surgery to maintain an intact posterior capsule, if desired. To reduce the possibility of vitreous prolapse around the IOL and into the anterior chamber, posterior capsulotomy would ideally be delayed until there is adequate apposition and fusion of the anterior and posterior capsules peripheral to the lens optic. Otherwise, the ideal time to treat symptomatic posterior capsule opacity with posterior capsulotomy has not yet been established.

In addition to capsulotomy, the Nd:YAG laser can be used for vitreolysis, synechiolysis, iris cystotomy, iridotomy, anterior hyaloidotomy for aqueous misdirection, removal of precipitates and membranes from an IOL surface, and fragmentation of retained cortical material.

Indications

The success rate of Nd:YAG laser posterior capsulotomy exceeds 95%. Indications for Nd:YAG capsulotomy include the following:

- visual acuity symptomatically decreased as a result of PCO
- a hazy posterior capsule preventing the clear view of the ocular fundus required for diagnosis and therapy
- monocular diplopia, a Maddox rod–like effect, or glare caused by posterior capsule wrinkling or by the encroachment of a partially opened posterior capsule into the visual axis
- contraction of anterior capsulotomy (capsular phimosis) causing encroachment on the visual axis, excessive traction on the zonular fibers, or alteration of the lens optic position (see also the section Anterior Capsule Fibrosis and Phimosis)
- capsular block syndrome

Contraindications

Contraindications for Nd:YAG laser capsulotomy include the following:

- inadequate posterior capsule visualization
- a patient who is unable to remain still or hold fixation during the procedure (use of a contact lens or retrobulbar anesthesia may enhance the feasibility of a capsulotomy in such patients)
- active intraocular inflammation, uncontrolled glaucoma, high risk of retinal detachment, and suspected CME (all relative contraindications)

Procedure

The desired site for posterior capsulotomy is the center of the visual axis, usually 3–4 mm in diameter. Dilation is not always necessary for the procedure, but it may be helpful when a larger opening is desired.

A high-plus–powered anterior segment laser lens may improve ocular stability and enlarge the cone angle of the beam, reducing the depth of focus. The smaller focus diameter facilitates the laser pulse puncture of the capsule, and structures in front of and behind the point of focus are less likely to be damaged.

Capsulotomy can be performed in a cruciate or inverted D–shaped pattern (Fig 11-18) or in a complete circle, beginning in the periphery to reduce the likelihood of central optic pitting until ideal energy levels and focus have been established. Occasional IOL dislocation into the vitreous has been reported after capsulotomy, particularly with silicone plate–haptic lenses. The diameter of the capsulotomy should not exceed that of the IOL optic.

When minimal laser energy is applied, the anterior vitreous face may remain intact. A ruptured anterior vitreous face will usually not result in anterior chamber prolapse due to the barrier effect of a PCIOL, although in rare instances vitreous strands can migrate around the lens and through the pupil.

Any PCIOL can be damaged by laser energy, but the threshold for lens damage appears to be lower for silicone than for other materials. The surgeon focuses the laser just

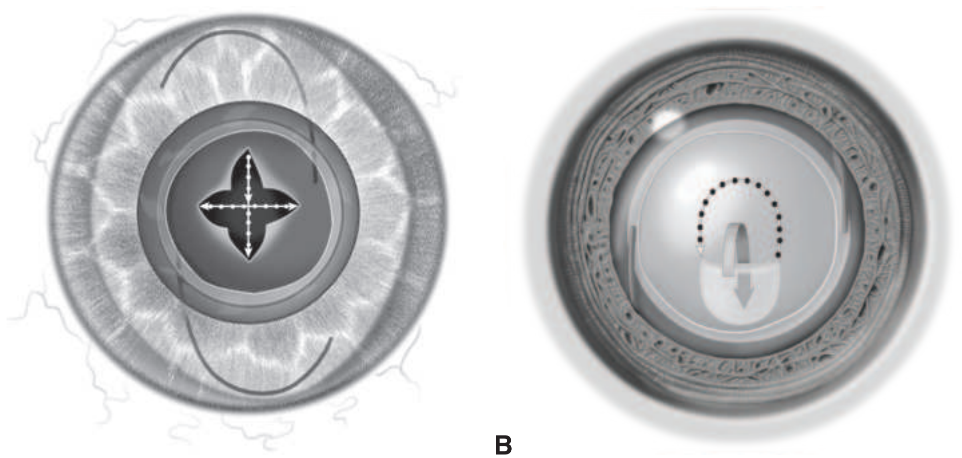


Figure 11-18 Illustrations of Nd:YAG laser posterior capsulotomy. A cruciate pattern **(A)** or inverted D–shaped pattern **(B)** with an inferior flap hinge allows for initial punctures in the periphery and may help reduce the risk of central IOL laser damage. *(Illustration part A by Christine Gralapp; part B by Mark Miller.)*

behind the posterior capsule; pulses too far behind the IOL will be ineffective. The safest approach is to focus the laser beam slightly behind the posterior surface of the capsule for the initial application and then move anteriorly for subsequent applications until the desired puncture is achieved.

In cases of anterior capsule contraction, multiple relaxing incisions of the fibrotic ring relieve the contracting force and create a larger optical opening (see Fig 11-17).

Occasionally, the Nd:YAG laser is insufficient to address exceptionally dense fibrosis, which may require surgical manipulation with a discission knife, vitrectomy handpiece, or scissors.

Complications

Potential complications of Nd:YAG laser capsulotomy include

- transient or long-term elevated IOP
- CME
- hyphema
- IOL damage or dislocation
- corneal edema
- corneal abrasions (from the focusing contact lens for the laser surgery)
- retinal detachment

Transient IOP elevation occurs in some patients, with pressure levels peaking 2–3 hours after surgery. This elevation is likely due to obstruction of the outflow pathways by debris scattered by the laser treatment. It is more common in eyes with vitreous prolapse, those without in-the-bag IOL fixation, or those with preexisting glaucoma. Such elevation responds quickly to topical glaucoma medications, which can be continued for 3–5 days after the procedure.

To reduce the risks of post-procedure IOP spikes, inflammation, and CME following any type of laser capsular surgery, many surgeons prescribe prophylactic preoperative and postoperative ocular hypotensive medications (α-adrenergic agonist or β-blocker eyedrops), as well as either topical corticosteroids or NSAIDs, although there is insufficient evidence to uniformly recommend these prophylactically in patients without additional risk factors. In patients with a history of CME or in high-risk patients such as those with diabetic retinopathy, the prophylactic use of topical corticosteroids or NSAIDs may be beneficial.

Nd:YAG laser capsulotomy may increase the risk of retinal detachment, with some reports showing no increased risk and some showing a slightly increased risk (RR 1.57). Approximately 50%–75% of retinal detachments after cataract extraction occur within 1 year of surgery or 6 months of capsulotomy, often in association with posterior vitreous detachment (PVD). In many cases, it is difficult to determine whether the retinal detachment is related to the capsulotomy or to the cataract surgery itself, or whether it is simply a consequence of a naturally occurring PVD. Factors that increase the risk of retinal detachment after Nd:YAG capsulotomy include axial myopia, male sex, young age, trauma, vitreous prolapse, a family history of retinal detachment, and preexisting vitreoretinal pathology. It is important to instruct all patients to promptly report any new symptoms suggesting a PVD or retinal tear.

Elbaz U, Hakkala L, Hecht I, Achiron A, Gershoni A, Tuuminen R. Nd:YAG capsulotomy is not a risk factor for retinal detachment after phacoemulsification cataract surgery. *Acta Ophthalmol.* 2021;99(7):e1018–e1026.

Liu H, Liu X, Chen Y, et al. Effect of Nd:YAG laser capsulotomy on the risk for retinal detachment after cataract surgery: systemic review and meta-analysis. *J Cataract and Refract Surgery.* 2022;48:238–244.

Miller KM, Oetting TA, Tweeten JP, et al. American Academy of Ophthalmology. Cataract and Anterior Segment Preferred Practice Pattern Panel. Cataract in the Adult Eye Preferred Practice Pattern. *Ophthalmology.* 2016;129(1):1–126. doi:10.1016/jophtha.2021.10.006

Diplopia

A thorough discussion of diplopia is presented in BCSC Section 6, *Pediatric Ophthalmology and Strabismus,* and Section 5, *Neuro-Ophthalmology.* The 2 types of diplopia, monocular and binocular, can be easily differentiated by covering the eyes. If the diplopia is present only with both eyes open, then it is binocular. If it is still present with only 1 eye open, then it is monocular. As it pertains to cataract surgery, monocular diplopia generally results from optical aberrations in the operative eye. Binocular diplopia results from ocular misalignment or anisometropia (Table 11-3). It is important to document preoperative ocular misalignment, which is present in 13%–16% of patients undergoing cataract surgery. Regarding intractable binocular diplopia, a 2008 study of patients found that the most common cause was extraocular muscle restriction or paresis in the anesthetic block group and decompensation of a preexisting phoria in the topical group.

Table 11-3 Common Causes of Postoperative Diplopia

Monocular	Binocular
Keratitis (eg, keratitis sicca)	Extraocular muscle damage (eg, myotoxicity from local anesthetic or bridle suture placement)
Uncorrected refractive error (eg, astigmatism)	Decompensated phoria
Corneal edema	Nerve palsy (may be unrelated to surgical procedure)
Irregular corneal epithelium (eg, corneal abrasion or epithelial basement membrane dystrophy)	Disruption of binocular fusion (eg, from anisometropia or aniseikonia)
Keratoconus	
Posterior capsule wrinkle or opacification	
IOL decentration or opacification	
Macular pathology: ERM, macular edema, maculopathy	

ERM = epiretinal membrane.

Corneal topography may be useful to determine a corneal cause of diplopia. OCT may help exclude macular causes of monocular diplopia. Treatment of monocular diplopia is directed at the source, as is the treatment of persistent binocular diplopia. Disruption of fusion and anisometropia may be managed by proper optical correction with a prism and slab-off bifocal if necessary. Cataract surgery on the contralateral eye or contact lens correction may be required. If a muscle paresis/restriction is present, prism correction often is adequate; however, referral to a strabismus specialist may be necessary.

Inflammatory and Infectious Complications

Postoperative Uveitis

After cataract extraction, nearly all eyes exhibit some degree of intraocular inflammation. With uncomplicated cataract surgery and the use of postoperative topical corticosteroids and/or NSAIDs, most eyes are typically free of inflammation by 3–4 weeks postoperatively. Complicated cases requiring the manipulation of intraocular tissues (eg, iris stretching, sphincterotomy, iridectomy, or repair), involving vitreous loss or prolapse, or requiring sulcus fixation of an IOL may have a more prolonged recovery. Increased inflammation may also be seen in children; patients with diabetes mellitus; those with previous surgery, pseudoexfoliation syndrome, or pigment dispersion syndrome; and patients with long-term miotic use.

Low-grade inflammation lasting more than 4 weeks raises the possibility of chronic infection, retained lens fragments, or other causes of chronic inflammation such as IOL malposition. The presence of vitritis or a hypopyon warrants investigation to determine the source of inflammation and to rule out an infectious cause. In patients with persistent uveitis but without a history of inflammation, investigation for possible microbial endophthalmitis is also indicated. Chronic uveitis after cataract surgery has been associated with low-grade infections with bacterial pathogens, including *Propionibacterium acnes* and *Staphylococcus epidermidis*. Such patients may have an unremarkable early postoperative course and lack the classic findings of acute endophthalmitis. Weeks or months after surgery, however, they develop chronic uveitis that is variably responsive to topical corticosteroids. This condition is usually associated with granulomatous keratic precipitates and, less commonly, with hypopyon. A localized focus of infection sequestered within the capsular bag may occasionally be observed (Fig 11-19).

Diagnosis of endophthalmitis requires a high level of clinical suspicion, coupled with examination and cultures of appropriate specimens of aqueous, vitreous, and (where applicable) retained lens material that may harbor a nidus of infection. Appropriate intravitreal antibiotic therapy is indicated. If this treatment fails, the clinician may need to search for and remove any visible focus of infection to sterilize the eye. In some cases, the residual capsule and IOL must be removed.

Patients with preexisting uveitis may have excessive postoperative inflammation but generally do well with small-incision cataract surgery with IOL implantation in the capsular bag. Some surgeons prefer acrylic IOL material over silicone in patients with preexisting uveitis or a risk of chronic inflammation.

Management of chronic uveitis focuses on the cause. Surgery is used for the correction of mechanical issues with IOL malposition, vitreous incarceration, or retained lens fragments. If no obvious etiology can be found, prolonged use of topical or subconjunctival corticosteroids is indicated, with continued efforts to identify a cause.

Toxic Anterior Segment Syndrome

Toxic anterior segment syndrome (TASS) is an acute sterile postoperative inflammation. The symptoms and signs of TASS may mimic those of infectious endophthalmitis and include photophobia, a severe reduction in visual acuity, corneal edema, and marked anterior chamber reaction, occasionally with hypopyon (Fig 11-20). However, TASS presents within 12 to 48 hours of surgery, whereas acute infectious endophthalmitis typically develops 3–10 days postoperatively. Other potentially distinguishing features of TASS include diffuse, limbus-to-limbus corneal edema; anterior chamber fibrinous exudate; a dilated, irregular, or nonreactive pupil; and elevated IOP. The pathologic changes are limited to the anterior chamber. Pain is typically much milder than that experienced with an infection. When endophthalmitis is suspected, diagnostic and therapeutic interventions (described later in this chapter) are indicated.

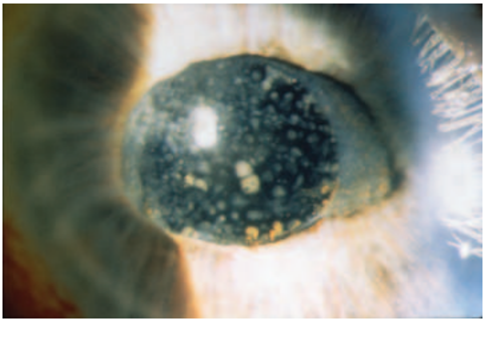


Figure 11-19 *Propionibacterium acnes* on a lens capsule. *(Courtesy of Thomas L. Steinemann, MD.)*

Figure 11-20 Toxic anterior segment syndrome. *(© 2019, American Academy of Ophthalmology.)*

TASS is thought to be caused by the inadvertent introduction of a substance toxic to the corneal endothelium or uvea. A 2018 report by a TASS task force showed the risk factors to be inadequate flushing and rinsing of handpieces, use of enzymatic detergents, and use of ultrasonic baths. Ultrasonic baths are susceptible to contamination with gram-negative bacteria and may result in residue on instruments of heat-stable bacterial endotoxin. It is necessary to properly clean and maintain ultrasound baths if they are used.

RECOMMENDATIONS FOR AVOIDING TASS

- Use preservative- and bisulfite-free medications.
- Properly mix and dose any intracameral antibiotics, anesthetics, or other medications.
- Thoroughly flush OVDs from ophthalmic instruments.
- Thoroughly flush all handpieces and reusable cannulas to remove debris.
- Avoid the use of enzymes and detergents for cleaning ophthalmic instruments.
- Avoid the use of ultrasound water baths for cleaning ophthalmic instruments.
- Properly clean and maintain autoclave steam sterilizer systems.
- Follow strict protocol for the general cleaning and sterilization of ophthalmic instruments.
- Separate ophthalmic instruments from other surgical instruments for cleaning and sterilization.

Other causes of TASS include surgical glove residue or talc on instruments or IOLs; use of a denatured OVD; substitution of sterile water for balanced salt solution; intraocular use of inappropriate irrigating solutions, antibiotics, or anesthetics; and inadvertent introduction of substances into the anterior chamber. Subconjunctival antibiotic injections and topical ophthalmic ointments applied with patching have been reported to enter the anterior chamber through corneoscleral incisions. Skin cleansers containing chlorhexidine gluconate have caused irreversible corneal edema and opacification after coming into contact with the endothelium. Clusters of TASS due to irrigation fluids tainted with bacterial endotoxin have also been reported. Ideally, all solutions used intracamerally are free of stabilizers and preservatives and buffered to physiologic osmolarity and pH.

Treatment of TASS consists of intensive topical corticosteroids until the inflammation subsides. In addition, a brief course of systemic corticosteroids may be beneficial. Frequent follow-up is needed to monitor IOP and to reassess for signs of bacterial infection.

After treatment, eyes that have had TASS can recover with a good visual outcome, but there can be sequelae. The most common are iris abnormalities with focal iris atrophy, pupil distortion, and pupil mydriasis. Capsular bag alterations, including anterior capsular phimosis and posterior capsular opacification, are frequently detectable by the 6-month follow-up visit but are treatable with Nd:YAG laser procedures. Rarer sequelae are corneal decompensation and secondary glaucoma (Fig 11-21).

Bodnar Z, Clouser S, Mamalis N. Toxic anterior segment syndrome: update on the most common causes. *J Cataract Refract Surg.* 2012;38(11):1902–1910.

Chang DF, Mamalis N; Ophthalmic Instrument Cleaning and Sterilization Task Force. Guidelines for the cleaning and sterilization of intraocular surgical instruments. *J Cataract Refract Surg*. 2018;44(6):765–773.

Endophthalmitis

Endophthalmitis is a rare but dreaded complication of cataract surgery that may lead to severe loss of vision or even loss of the eye. The symptoms of endophthalmitis include mild to severe ocular pain, vision loss, floaters, and photophobia. Early diagnosis and prompt treatment are essential because delayed treatment can substantially worsen the visual prognosis. Recent large retrospective studies of endophthalmitis incidence after cataract surgery reveal rates for this condition between 0.04% and 0.20%. Factors that increase the risk of infection include diabetes mellitus, older age, male sex, complicated or

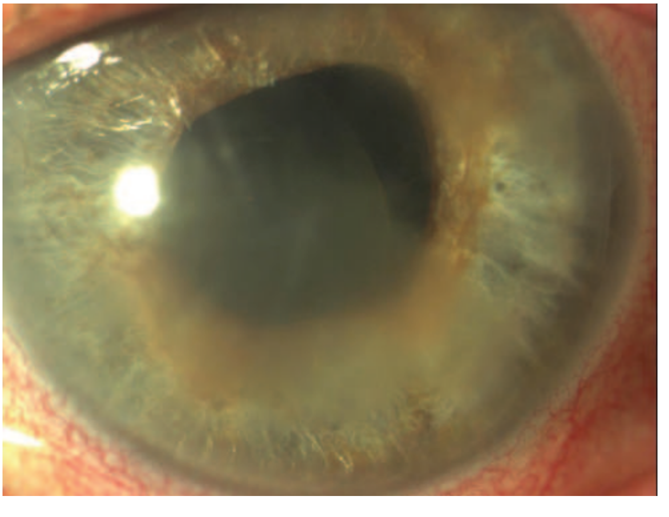


Figure 11-21 Iris atrophy and cornea decompensation after TASS. *(Courtesy of Antonio Scialdone, MD.)*

prolonged surgery, vitreous loss, posterior capsule rupture, wound leaks, and possibly the use of clear corneal incisions.

Prevention

To reduce the incidence of postoperative endophthalmitis, it is important to use preoperative povidone-iodine skin prep, povidone-iodine 5% eyedrops, careful eyelid and eyelash draping, and sterile technique. Meticulous attention to watertight incision closure is also important in preventing endophthalmitis, particularly when clear corneal incisions are used. Prophylactic preoperative and postoperative topical antibiotics are often prescribed for cataract surgery, although no randomized clinical studies support this practice.

In 2006, the Endophthalmitis Study Group of the European Society of Cataract and Refractive Surgeons (ESCRS) conducted a prospective, randomized, partially masked cataract surgery study and reported that the endophthalmitis rate was 0.07% in patients given intracameral cefuroxime 1 mg at the conclusion of surgery compared with a rate of 0.34% in patients given topical levofloxacin eyedrops alone. The ESCRS also reported a 5.88-fold increase in risk with the use of clear corneal incisions instead of scleral tunnels.

A report based on outcomes of more than 600,000 consecutive cataract operations performed between 2014 and 2016 at Aravind Hospitals in India showed a decrease in endophthalmitis rates from 0.07% without intracameral antibiotics to 0.02% with intracameral moxifloxacin. In the phacoemulsification group, the incidence decreased from 0.07% to 0.01% with intracameral moxifloxacin.

Despite numerous studies showing a reduced incidence of endophthalmitis with the use of intracameral antibiotics after cataract surgery, no antibiotics are currently approved by the US Food and Drug Administration for this indication. Many US surgeons use an intraocular antibiotic such as preservative-free moxifloxacin, cefuroxime, or vancomycin at the conclusion of cataract surgery. Multiple licensed 503B compounding pharmacies provide preservative-free medications for intraoperative use. Surgeons must consider the reduction in endophthalmitis rates against the risk of TASS from dilutional errors for intraocular medications. The use of intraocular vancomycin for prophylaxis has decreased since reports of vancomycin-associated hemorrhagic occlusive retinal vasculitis (HORV; see the discussion of HORV later in this chapter).

See BCSC Section 12, *Retina and Vitreous,* for additional discussion of endophthalmitis.

Endophthalmitis Study Group, European Society of Cataract & Refractive Surgeons. Prophylaxis of postoperative endophthalmitis following cataract surgery: results of the ESCRS multicenter study and identification of risk factors. *J Cataract Refract Surg.* 2007;33(6):978–988.

Haripriya A, Chang DF, Ravindran RD. Endophthalmitis reduction with intracameral moxifloxacin prophylaxis: analysis of 600 000 surgeries. *Ophthalmology*. 2017;124(6): 768–775.

Shorstein NH, Winthrop KL, Herrinton LJ. Decreased postoperative endophthalmitis rate after institution of intracameral antibiotics in a Northern California eye department. *J Cataract Refract Surg.* 2013;39(1):8–14.

Diagnosis

Infectious endophthalmitis may present in an acute form or a more indolent, or chronic, form. *Acute* endophthalmitis, defined as inflammation occurring within 6 weeks of surgery, typically develops 3–10 days postoperatively and runs a fulminant course. The hallmark of acute endophthalmitis is vitreous inflammation, but other signs include eyelid or periorbital edema, ciliary injection, chemosis, anterior chamber inflammation, hypopyon, decreased visual acuity, corneal edema, and retinal hemorrhages (Fig 11-22, Table 11-4).

Acute infectious endophthalmitis must be differentiated from TASS (discussed earlier in this chapter). The clinical presentation is often diagnostic, but occasionally the clinician may be able to diagnose sterile endophthalmitis only by excluding possible infectious causes with appropriate aqueous and vitreous cultures.

Figure 11-22 Endophthalmitis. *(Courtesy of Karla J. Johns, MD.)*

Table 11-4 TASS Versus Endophthalmitis

	TASS	Endophthalmitis
Timing	Acute (12–24 hours)	Acute (3–7 days, but can be <12 hours)
Pain	None/mild	Moderate/severe
Visual acuity	Moderate decrease	Moderate/severe decrease
Symptoms	Photophobia	Photophobia, new floaters
IOP	Normal to increase	Normal
Corneal edema	Severe (limbus-to-limbus)	Variable
Hypopyon	Minimal/absent	Present (typically)
Fibrin	Mild/absent	Present (typically)
Vitreous cell	Mild/absent	Present (typically)
Diagnosis	Clinical suspicion, resolution with steroids without antibiotics	Clinical suspicion, vitreous tap
Treatment	Steroids, cycloplegia	Antibiotics (intravitreal) and/or PPV

PPV = pars plana vitrectomy; TASS = toxic anterior segment syndrome.

In contrast, *chronic* endophthalmitis may develop weeks or months after surgery. It may be characterized by chronic iridocyclitis or granulomatous uveitis and is often associated with decreased vision, little or no pain, and a nidus of the infectious agent within the eye. The chronic form is associated with organisms of lower pathogenicity; the most common are *P acnes, S epidermidis,* and fungi. See also BCSC Section 9, *Uveitis and Intraocular Inflammation,* and Section 12, *Retina and Vitreous.*

In the Endophthalmitis Vitrectomy Study (EVS), most cases of endophthalmitis presented within 3–10 days of cataract surgery, with a median of 6 days, and 25% presented without pain. Later onset also occurred: 22% of cases presented 2–6 weeks after surgery. The most common bacterial causes in that study were gram-positive coagulase-negative *S epidermidis* (70%), *Staphylococcus aureus* (9.9%), *Streptococcus* species (9.0%), other gram-positive bacteria (3.1%), *Enterococcus* species (2.2%), and gram-negative bacteria (5.9%). Most infections are caused by organisms similar to the patients' periocular bacterial flora, and drug-resistant strains are becoming more common.

Endophthalmitis Vitrectomy Study Group. Results of the Endophthalmitis Vitrectomy Study: a randomized trial of immediate vitrectomy and of intravenous antibiotics for the treatment of postoperative bacterial endophthalmitis. *Arch Ophthalmol.* 1995;113(12): 1479–1496.

Treatment

The recommended approach to postoperative endophthalmitis management is based on the EVS results. As soon as a clinical diagnosis of endophthalmitis is suspected, an assessment of visual acuity will help direct management decisions. Immediate PPV and antibiotic injections are indicated when the patient's visual acuity is light perception or worse. When the visual acuity is hand motions or better, a less-invasive anterior chamber and/or vitreous biopsy for cultures with immediate subsequent intravitreal injection of antibiotics are indicated (a "tap-and-inject" procedure).

A tap-and-inject procedure can be performed in the office under sterile conditions. Because clinical features do not distinguish between gram-positive and gram-negative organisms, the mainstay of treatment remains broad-spectrum intravitreal antibiotics for both classes of bacteria. Currently, vancomycin 1 mg and ceftazidime 2.25 mg are preferred, with amikacin 0.4 mg administered for cephalosporin-allergic patients. Topical cycloplegic and corticosteroid eyedrops may be helpful. Although oral or intravenous antibiotics, fortified topical or subconjunctival antibiotics, and intravitreal corticosteroids are sometimes used, they were not beneficial in a controlled study. The eventual outcome depends on the virulence and antibiotic susceptibility of the causative organism, and on other factors such as timing of presentation and access to care.

Chronic or delayed-onset endophthalmitis is also best treated with vitreous biopsy and intraocular antibiotics. However, because of the sequestration of infectious material in the capsular bag or vitreous, a vitrectomy and complete capsulectomy or IOL exchange is often required to remove the nidus of infection.

Retinal Complications

Cystoid Macular Edema

Cystoid macular edema (CME), previously known as *Irvine-Gass syndrome,* is a common cause of decreased vision after cataract surgery. Although the exact pathogenesis of CME is unknown, the final common pathway appears to be increased perifoveal capillary permeability with accumulation of fluid in the inner nuclear and outer plexiform layers. CME is often associated with intraocular inflammation and may be mediated through the release of prostaglandins and leukotrienes.

CME may be recognized by an otherwise unexplained reduction in vision, by the characteristic petaloid appearance of cystic spaces in the macula on ophthalmoscopy (Fig 11-23A) or fluorescein angiography (Fig 11-23B), or by cystlike areas of low reflectivity and retinal thickening on OCT (Fig 11-23C). Most affected patients are asymptomatic,

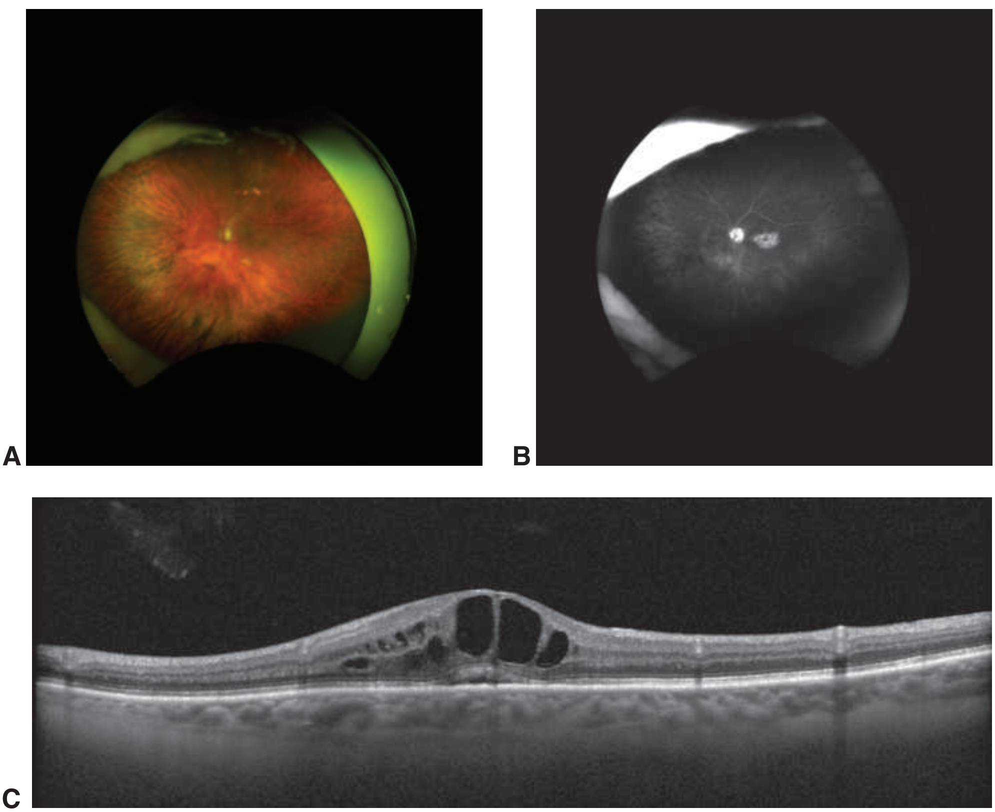


Figure 11-23 Cystoid macular edema. **A,** Color photograph. **B,** Fluorescein angiogram demonstrates late pooling of dye in a petaloid pattern in the macula and staining of the optic nerve head. **C,** Spectral-domain optical coherence tomography (SD-OCT) scan shows diffuse retinal thickening with cystic areas of low reflectivity predominantly in the inner nuclear and outer plexiform layers. *(Courtesy of Kavita Bhavsar, MD.)*

although they may have some loss of contrast sensitivity even in the absence of reduced Snellen visual acuity. In addition, patients with angiographic CME after phacoemulsification score substantially higher in logMAR (logarithm of the minimum angle of resolution) visual acuity than do patients with no CME, even though their Snellen visual acuities remain better than 20/40. The incidence of clinically relevant pseudophakic CME, which includes reduced vision in the presence of CME, is 1–2%. For more information, see BCSC Section 12, *Retina and Vitreous.*

The incidence of both angiographic and clinical CME peaks 6–10 weeks after surgery. Spontaneous resolution occurs in approximately 95% of uncomplicated cases, usually within 3–12 months. In rare cases, CME may develop many years after surgery, especially with delayed postoperative rupture of the anterior vitreous face. CME has also been associated with the use of topical epinephrine and dipivefrin for the treatment of aphakic glaucoma. Prostaglandin analogues have been associated with reversible CME in eyes that have undergone recent intraocular surgery, although a causal relationship has not been established. The risk is believed to be greater in the absence of an intact posterior capsule. Table 11-5 lists risk factors for CME.

The risk of early postoperative CME is reduced with prophylactic postoperative use of topical corticosteroids and/or NSAID eyedrops. Multiple regimens of NSAIDs with or without steroids and starting before or after surgery have been shown to be effective as prophylaxis for macular thickening after cataract surgery. Level 1 evidence that NSAID therapy prevents vision loss from CME at 3 months or longer after cataract surgery is lacking.

Medical treatment of chronic postoperative CME typically begins with a course of anti-inflammatory drugs such as topical corticosteroids and/or NSAIDs. A prospective randomized clinical trial of chronic CME found that combination therapy with ketorolac 0.5% and prednisolone acetate 1.0% 4 times a day was more effective than either drug alone in improving visual acuity. Topical anti-inflammatory therapy may take 3–6 months to resolve chronic CME, and the condition may recur after therapy ends. Sub-Tenon steroid injection or intravitreal injections of corticosteroids alone or via a sustained drug-delivery system may be effective. In refractory cases, systemic carbonic anhydrase inhibitors may be beneficial. Intravitreal vascular endothelial growth factor inhibitors have been successful in chronic CME cases that do not respond to conventional treatment.

Table 11-5 Risk Factors for Cystoid Macular Edema

Preoperative	Surgical and Postoperative
Uveitis	Posterior capsule rupture
Epiretinal membrane	Vitreous loss
Vitreomacular traction	Iris manipulation
Diabetes mellitus	Prolonged surgical time
Diabetic retinopathy	Improper intraocular lens positioning
Retinal vein occlusion	Retained lens fragments
Retinitis pigmentosa	Poorly controlled postoperative inflammation
Previous occurrence of cystoid macular edema	Transient or prolonged hypotony

When the inciting source of chronic CME can be defined and the edema fails to respond to medical therapy, surgery may be indicated. Any retained lens fragments should be removed. Nd:YAG laser vitreolysis or vitrectomy can be used to remove vitreous adhering to the cataract incision and relieve iris deformity or vitreomacular traction. If the IOL is malpositioned and contributing to chronic uveitis, repositioning or exchange may be helpful. For further discussion of CME, see BCSC Section 12, *Retina and Vitreous.*

Erichsen JH, Holm L, Jacobsen MF, Forman J, Kessel L. Prednisolone and ketorolac vs ketorolac monotherapy or sub-tenon prophylaxis for macular thickening in cataract surgery: a randomized clinical trial. *JAMA Ophthalmology.* 2021;139(10):1062–1070.

Wielders LHP, Schouten JSAG, Winkens B, et al; ESCRS PREMED Study Group. 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(7):836–847.

Hemorrhagic Occlusive Retinal Vasculitis

Hemorrhagic occlusive retinal vasculitis (HORV) is a rare but serious complication characterized by delayed-onset painless vision loss, mild anterior chamber and vitreous inflammation, retinal ischemia with sectoral hemorrhages in areas of ischemia, and predilection for venules and peripheral involvement. The disease was first reported as a complication associated with intraoperative use of intraocular vancomycin in 2015. The mechanism of HORV is presumed to be a delayed hypersensitivity immune response occurring 1–21 days after surgery. Because of the delayed onset, some patients have experienced bilateral HORV, with the second eye undergoing cataract surgery before the first eye exhibited signs of HORV.

Outcomes are poor despite aggressive corticosteroid therapy and other treatments, with 1 series reporting that 61% of eyes had visual acuity ≤20/200 and 22% had no light perception. When choosing an appropriate antibiotic for intraocular prophylaxis, it is important for the surgeon to consider this rare but severe complication of intraocular vancomycin.

Witkin AJ, Chang DF, Jumper JM, et al. Vancomycin-associated hemorrhagic occlusive retinal vasculitis: clinical characteristics of 36 eyes. *Ophthalmology.* 2017;124(5):583–595.

Retinal Light Toxicity

Prolonged exposure to the illuminating filament of an operating microscope can increase the risk of CME or a retinal pigment epithelium (RPE) burn. The risk of an RPE burn is particularly high during cataract surgery, when the filtering effects of the natural lens (cataract) are removed, exposing the vulnerable RPE to unfiltered blue light and near-ultraviolet radiation. If a burn occurs, a central or paracentral scotoma may result. Minimizing retinal exposure to the operating microscope light, filtering light wavelengths lower than 515 nm, and, when possible, using pupillary shields and oblique lighting reduce the risk of this complication (Fig 11-24).

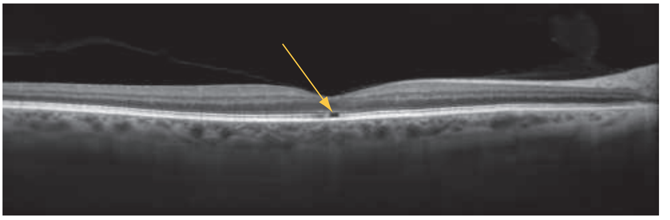


Figure 11-24 SD-OCT reveals focal loss of the ellipsoid zone (*arrow*) due to retinal pigment epithelium burn. *(Courtesy of Kavita Bhavsar, MD.)*

Delayed Suprachoroidal Hemorrhage

For a discussion of *intraoperative* suprachoroidal hemorrhage, please see Chapter 10. Delayed suprachoroidal hemorrhage may occur in the early postoperative period, presenting with sudden onset of pain, loss of vision, and shallowing of the anterior chamber. Predisposing factors for postoperative choroidal hemorrhage or effusion include prolonged hypotony, wound leak, unrecognized scleral perforation, trauma, uveitis, cyclodialysis, and excessive filtration. This condition is far more common after glaucoma filtering procedures than routine cataract surgery and may also arise after laser photocoagulation or cryotherapy.

When an incision remains intact and IOP can be controlled medically, limited suprachoroidal hemorrhage may be observed and frequently will resolve spontaneously. If the incision is not intact, surgical revision may be sufficient to allow the hemorrhage to resolve. Medical management consists of systemic corticosteroids, topical and oral ocular hypotensive agents for elevated IOP, topical cycloplegia, and close observation. Surgical drainage of the suprachoroidal space is indicated when there is a flat anterior chamber, medically uncontrolled glaucoma, or persistent or adherent (kissing) choroidal detachments.

Retinal Detachment

The incidence of pseudophakic rhegmatogenous retinal detachment (RRD) has been reported as 0.2%–3.6%, depending on follow-up time and patient demographics. RRD occurs most frequently within 1 year of cataract surgery. During the first postoperative year after phacoemulsification, the incidence of RRD ranges from 0.6% to 1.7%. The incidence of RRD is lower with small-incision phacoemulsification surgery than with large-incision ECCE and ICCE.

For all age groups and both sexes, eyes that have undergone cataract surgery have an approximately 4-fold-higher risk of RRD than fellow phakic eyes. Uncomplicated cataract surgery and laser posterior capsulotomy are reported risk factors for RRD in part because they are risk factors for early onset of PVD. Myopic eyes have a much higher risk of RRD, whether phakic or pseudophakic, and this risk rises with each additional millimeter of axial length. Additional risk factors for RRD include axial myopia (6- to 10-times-greater risk with axial length >25 mm), younger age (4-times-greater risk with age <60 years), male sex, lattice degeneration of the retina, a previous retinal tear or detachment in the surgical eye, a history of retinal detachment in the fellow eye, and a family history of retinal detachment.

After cataract surgery complicated by posterior capsule rupture, the risk of postoperative RRD is increased compared with pseudophakic eyes with an intact capsule (odds ratio = 2.38). Some studies have reported that Nd:YAG laser posterior capsulotomy increases the risk for RRD, whereas other studies found no evidence of increased risk with capsulotomy. Neither the capsulotomy size nor the total energy delivered is thought to increase risk.

PPV, with or without a scleral buckle, is most commonly used to repair RRD. The success rate is approximately 85% with 1 operation and ultimately 98% with multiple procedures. See also BCSC Section 12, *Retina and Vitreous.*

Bjerrum SS, Mikkelsen KL, La Cour M. Risk of pseudophakic retinal detachment in 202,226 patients using the fellow nonoperated eye as reference. *Ophthalmology.* 2013;120(12): 2573–2579.

Thylefors J, Jakobsson G, Zetterberg M, Sheikh R. Retinal detachment after cataract surgery: a population-based study. *Acta Ophthalmol*. 2022;100(8):e1595–e1599.

CHAPTER 12

Preparing for Cataract Surgery in Special Situations

This chapter includes related videos. Go to aao.org/bcscvideo_section11 or scan the QR codes in the text to access this content.

Highlights

- Special considerations are needed for patients with psychological disorders, systemic diseases, external ocular abnormalities, corneal pathologies, glaucoma, uveitis, or retinal conditions.
- Cataract surgeons need to be prepared for nonroutine procedures on eyes compromised by limited visualization of the lens, loss of integrity of the lens or capsule, zonular weakness, trauma, or extremely long or short axial length.
- Microinvasive procedures allow for glaucoma treatment at the time of cataract extraction.
- An emphasis on preoperative planning, the use of emerging technological devices during surgery, and appropriate intraocular lens calculation help enable a safe and successful surgery, even in challenging situations.

A complete discussion of the indications for and technique of cataract surgery in the pediatric age group is presented in BCSC Section 6, *Pediatric Ophthalmology and Strabismus.*

Psychosocial Considerations

Claustrophobia

Patients with claustrophobia may find it helpful to be given details about the operating room and sterile-draping requirements prior to surgery. The medical team can make accommodations for a patient who becomes anxious and extremely uncomfortable when confined to a small space or when covered by a surgical drape over the head. The anesthetist can titrate intravenous sedation and hold the patient's hand to provide comfort and reassurance. When feasible, the surgeon can supplement topical or local ocular anesthesia with soothing vocal support (ie, a "vocal local"). Options for reducing the sensation of claustrophobia and avoiding retention of carbon dioxide under the drape include placing a suction catheter under the drape, tenting open the side of the drape, or placing an elevated Mayo stand over the patient's torso. Using a transparent or translucent drape also can help mitigate claustrophobia. General anesthesia can be given when these measures are not adequate.

Neurocognitive and Neurodevelopmental Disorders

When dementia or other central nervous system impairment interferes with a patient's ability to communicate symptoms of cataract, the patient's functional deficit must be evaluated by other methods, such as discussion with surrogates about the patient's capacity to carry out activities of daily living. To estimate the visual impairment resulting from the cataract, the surgeon may have to rely on objective findings, such as degradation of the red reflex, slit-lamp abnormalities, and visualization of the retina, rather than subjective measurements of visual acuity. The patient's ability to tolerate sedation and draping throughout surgery must be appraised, and general anesthesia can be considered for the patient who cannot cooperate. However, the surgeon must consider the risk of progression of cognitive impairment in patients with preexisting neurocognitive issues due to the potential neurotoxic effects of surgical stress and/or general anesthesia. When general anesthesia is required, the surgeon also may consider bilateral cataract extraction in the same surgical session to limit exposure to general anesthesia (see Chapter 6). In general, the decision to proceed with cataract extraction in complex cases is based on the following aims:

- potentially rehabilitating vision
- improving visualization of the fundus to monitor and treat retinal disease
- enhancing quality of life

Belrose JC, Noppens RR. Anesthesiology and cognitive impairment: a narrative review of current clinical literature. *BMC Anesthesiol.* 2019;19(1):241. doi: 10.1186/s12871-019-0903-7

Patient Communication During Eye Surgery

All patients benefit from a preoperative discussion of the surgical experience, especially those with hearing loss and those who speak a language different from that of the surgical team. For a patient with bilateral hearing aids, the ipsilateral hearing aid often is removed to avoid the risk of water damage during surgery. A patient may wear their hearing aid in the ear contralateral to the eye being treated to allow communication. Moreover, the ipsilateral hearing aid can remain in place if it is covered carefully by multiple layers of occlusive dressing. The surgeon, anesthetist, and patient can determine how best to communicate in the operating room. Simple hand signals between the patient and the anesthetist can be effective. If the patient is very anxious and cannot communicate adequately, general anesthesia could be considered instead of topical or local anesthesia. However, light sedation combined with peribulbar or retrobulbar block often can allow for a safe procedure with decreased risk of postoperative delirium. For a patient who speaks a different language than the surgical team does, having a medical interpreter available to facilitate communication should be considered.

Systemic Considerations

Medical Status

Medical evaluation by the patient's primary care physician may be part of the preoperative planning process. Conditions such as hypertension and diabetes mellitus should be stabilized. Patients often are required to fast prior to surgery; insulin or oral hypoglycemic medication may need to be adjusted in diabetic patients. For these patients, it is preferable to schedule procedures early in the day to minimize large fluctuations in blood glucose levels.

In patients with lung disease, pulmonary function should be optimized prior to and during surgery; for instance, patients may be permitted to bring their inhalers into the operating room. Patients with lung disease may be prone to coughing, which can damage ocular structures during surgery and threaten wound security. Medication can be used to control coughing, and the patient can be advised to tell the surgeon of any need to cough. The risk of intraoperative complications can be reduced and wound security enhanced with small-incision surgery. Patients with chronic obstructive pulmonary disease, bronchitis, congestive heart failure, or obesity may benefit from being placed in the reverse Trendelenburg position to reduce venous congestion in the head and neck and lessen the risk of vitreous loss and choroidal hemorrhage.

Patients with severe arthritis may have difficulty lying comfortably during surgery. The surgical table can be adjusted, and pillows can be added to provide comfort without interfering with surgical access to the eye. Patients with ankylosing spondylitis and cervical immobility present an extreme challenge in surgical positioning (Fig 12-1); if no systemic medical contraindications exist and if adequate access cannot be attained otherwise, general anesthesia can be considered. Gentle Trendelenburg positioning of the bed can improve the surgical view and ergonomics.

Figure 12-1 Inflammatory systemic disease. Individuals with ankylosing spondylitis, such as the patient shown in these photos, often have cervical immobility. Evaluating patients in the office examination chair allows the surgeon to anticipate accommodations necessary for carrying out surgery safely and comfortably for both patient and surgeon in the operating room. This patient requires adjustment of the headrest to provide adequate support of his head and neck. *(Courtesy of Lisa F. Rosenberg, MD.)*

Patients with prostate conditions and those with hypertension may be on α-antagonist medication. The surgeon may encounter intraoperative floppy iris syndrome (IFIS) in these patients. For further discussion of ocular surgery in patients with systemic disease, see BCSC Section 1, *Update on General Medicine.*

Anticoagulation Therapy or Bleeding Disorders

In patients receiving anticoagulation therapy, clear corneal cataract surgery performed with topical anesthesia is not associated with an increased risk of vision-threatening hemorrhagic complications. Minor bleeding problems, such as eyelid ecchymosis, hyphema, and subconjunctival hemorrhage, are more common with anticoagulant use, but these are transient and self-limited. If a retrobulbar block is used, the risk of retrobulbar hemorrhage is not higher in patients on a single anticoagulant, though there is inadequate data for patients on multiple anticoagulants. Caution should also be exercised in patients on anticoagulants during combined cases of cataract and microinvasive glaucoma surgery (MIGS). It is important to weigh the systemic risks of discontinuing anticoagulation or antiplatelet therapy with the surgical risks of continuing therapy.

If anticoagulation therapy is to be discontinued or adjusted for surgery, coordination with the prescribing physician is recommended. Discontinuation of anticoagulants is recommended in patients who have previously experienced a suprachoroidal hemorrhage because these patients are predisposed to recurrent bleeding. Time to restoration of normal coagulation is variable and depends on the specific anticoagulant in use; warfarin usually requires 3–5 days. Platelet function resumes 10–21 days after antiplatelet therapy is stopped. Typically, it is recommended that patients restart anticoagulant or antiplatelet therapy within the first postoperative day. It is important to ask the patient about the use of all medications, including nonprescription items that may contain aspirin, vitamin E, or vitamin K, which could affect coagulation status. Table 12-1 presents a list of anticoagulant and antiplatelet agents approved by the US Food and Drug Administration (FDA).

The patient's coagulation profile should be reviewed preoperatively for systemic conditions that might alter clotting ability. For further discussion of ocular hemorrhage, see Chapter 10.

Table 12-1 Anticoagulant and Antiplatelet Medications Approved by the US FDA[a]

Anticoagulants	Antiplatelet Agents
Apixaban (Eliquis)	Anagrelide (Agrylin)
Dabigatran (Pradaxa)	Aspirin/dipyridamole (Aggrenox)
Edoxaban (Savaysa)	Cilostazol (Pletal)
Enoxaparin (Lovenox)	Clopidogrel (Plavix)
Fondaparinux (Arixtra)	Dipyridamole (Persantine)
Rivaroxaban (Xarelto)	Prasugrel (Effient)
Warfarin (Coumadin)	Ticagrelor (Brilinta)
Betrixaban (Bevyxxa)	Ticlopidine (Ticlid)
	Vorapaxar (Zontivity)

FDA = Food and Drug Administration.
[a]Approved as of 2023.

Grzybowski A, Ascaso FJ, Kupidura-Majewski K, Packer M. Continuation of anticoagulant and antiplatelet therapy during phacoemulsification cataract surgery. *Curr Opin Ophthalmol.* 2015;26(1):28–33.

External Ocular Abnormalities

Blepharitis and Acne Rosacea

To reduce bacterial colony counts on the ocular surface, preoperative control of blepharitis, which is particularly common in patients with acne rosacea, is recommended. Uncontrolled blepharitis that causes irritation and an unhealthy tear film may adversely affect the quality of the patient's vision after cataract surgery. Treatments for anterior blepharitis include hot compresses and eyelid scrubs. The mainstay of therapy for meibomian gland dysfunction involves saponification of inspissated meibomian secretions with systemic tetracycline, doxycycline, or minocycline. Topical ointments poorly penetrate meibomian orifices, but newer topical eyedrops, such as azithromycin, reduce bacterial flora at the surface of the meibomian glands. Thermal pulsation or devices that clean the eyelid margin may improve eyelid hygiene preoperatively in severe cases. For a detailed description of the signs and symptoms of blepharitis, see BCSC Section 8, *External Disease and Cornea.*

Atopic Dermatitis

See Chapter 5 for a discussion of atopic dermatitis.

Keratoconjunctivitis Sicca

Optimizing therapy for dry eye disease (keratoconjunctivitis sicca, also known as dysfunctional tear syndrome) before cataract surgery improves visual outcomes. This can be especially important in patients who desire excellent refractive outcomes with the placement of premium intraocular lenses (IOLs), such as toric and multifocal lenses. There are numerous aqueous-layer supportive treatments, including

- topical preserved and nonpreserved liquid tear preparations, gels, and ointments
- topical cyclosporine or lifitegrast
- punctal plugs

For additional detail on dry eye therapy, see BCSC Section 8, *External Disease and Cornea.*

During the procedure, the surgeon can prevent desiccation of the corneal epithelium by frequently hydrating the area with irrigating solution or by coating the cornea with a topical ophthalmic viscosurgical device (OVD). Visual recovery may be delayed if the patient's dry eye condition is exacerbated; in these cases, preoperative or postoperative placement of punctal plugs can be helpful.

Patients with dry eyes associated with collagen vascular disease, rheumatoid arthritis, Sjögren syndrome, neurotrophic keratitis, mucous membrane pemphigoid, or Stevens-Johnson syndrome present a special challenge to the cataract surgeon. Close observation of these patients in the weeks following surgery is warranted to identify and treat toxic keratoconjunctivitis and corneal ulceration resulting from collagenase activation secondary to postoperative corticosteroid therapy. If prescribed, topical nonsteroidal anti-inflammatory drugs (NSAIDs) should be used with caution because of the increased risk of corneal melting. In extreme cases, persistent epithelial defects with stromal loss may require a bandage (therapeutic) contact lens, tarsorrhaphy, or an amniotic membrane transplant.

In addition, patients with keratoconjunctivitis sicca should be counseled regarding the need for lifelong maintenance to optimize visual outcomes after cataract surgery, which is particularly important in patients with multifocal or extended depth of focus intraocular lenses (see Chapter 7 and BCSC Section 8, *External Disease and Cornea*).

Mucous Membrane Pemphigoid

Eyes with mucous membrane pemphigoid (MMP; formerly called ocular cicatricial pemphigoid) are severely dry due to scarring of the meibomian glands and accessory lacrimal glands that results in occlusion of the lacrimal gland orifices. Corneal haze or opacification impairs the surgeon's view into the anterior segment intraoperatively. Extensive symblepharon or ankyloblepharon may limit positioning and exposure of the eye during surgery. The eyelid speculum should be placed carefully to avoid traction and pressure on the globe, and care should be taken to avoid trauma to symblepharon during surgery. Systemic control of inflammation associated with MMP should be achieved to minimize postoperative complications and improve surgical outcomes of cataract surgery (see BCSC Section 8, *External Disease and Cornea*), as any ocular procedure can exacerbate the disease.

Exposure Keratitis and Cranial Nerve VII Palsy

Patients with paralytic or mechanical eyelid abnormalities may have significant corneal dryness, which can be exacerbated by cataract surgery. Administration of topical anesthetics preoperatively may desiccate the corneal epithelium. A peribulbar or retrobulbar block can produce a neurotrophic cornea that persists for hours after surgery; a large corneal abrasion may also develop, unless a pressure patch is applied. Lubrication with antibiotic ointment may be necessary in the early postoperative period to facilitate healing of the epithelial surface and to control pain from an abrasion. Extended-wear therapeutic contact lenses can promote rapid healing of the epithelium and be employed as a moisture chamber in cases of exposure keratitis, in conjunction with preventive local antibiotic treatment and patient adherence.

Corneal Pathologies

Corneal Disease

The cornea has the most refractive power of any structure in the eye. Preoperatively, the surgeon evaluates the cornea for abnormalities that might impair vision and diminish the expected improvement in vision:

- corneal scars
- tear film abnormalities (these should be addressed as described in the previous section, Blepharitis and Acne Rosacea)

- epithelial basement membrane dystrophy
- irregular astigmatism (this can be assessed by corneal topography and masked by a gas-permeable trial contact lens to determine the effect on vision impairment)

Corneal irregularities affect the accuracy of keratometry and lead to erroneous calculation of lens power. In an eye with epithelial basement membrane dystrophy, epithelial debridement may help produce a smoother corneal surface (Fig 12-2). After debridement, it is necessary to wait a few weeks before repeating keratometry so that the corneal surface can become smooth and stable. Mild corneal stromal opacities are unlikely to reduce vision in the presence of a pristine anterior refractive surface.

In patients with a history of herpes simplex virus (HSV) infection, epithelial or stromal keratitis may be exacerbated after cataract surgery. Although the Herpetic Eye Disease Study did not specifically address HSV following surgery, the results did show that prophylactic treatment with oral acyclovir (400 mg, twice daily) reduces the incidence of recurrent HSV keratitis. Because recurrent stromal keratitis may result in loss of visual acuity, many ophthalmologists use oral acyclovir, famciclovir, or valacyclovir perioperatively and observe the patient closely for recurrent keratitis postoperatively.

Cataract surgery in patients with keratoconus poses a challenge in IOL calculation. These patients have increased potential for unexpected refractive outcomes, given the irregular astigmatism and potentially abnormal keratometry values. Preoperatively, it is important to inform patients with significant keratoconus that they likely will need contact lens correction of the irregular astigmatism after cataract surgery. The surgeon can attempt to stabilize the keratoconus (eg, with collagen crosslinking) to improve the stability of refractive outcomes.

Acyclovir for the prevention of recurrent herpes simplex virus eye disease. Herpetic Eye Disease Study Group. *N Engl J Med.* 1998;339(5):300–306.

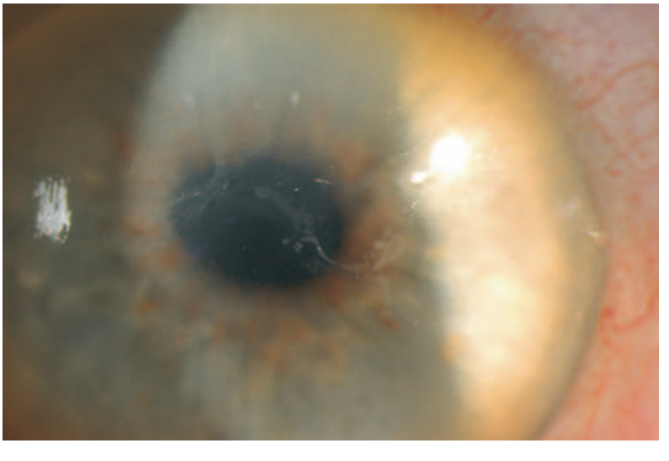


Figure 12-2 Irregular corneal astigmatism occurs in patients with epithelial basement membrane dystrophy. This corneal condition can further decrease vision in a patient with cataract-related vision impairment, in which case the vision improvement after cataract surgery might be less than expected. *(Courtesy of Christopher J. Rapuano, MD.)*

Cataract and Keratoplasty

When both cataract and corneal opacity contribute to a patient's vision loss, the surgeon has 3 options:

1. Remove the cataract first.
2. Repair the cornea first.
3. Combine the procedures.

This decision is often based on the severity of the corneal pathology and cataract and their relative impacts on the patient's visual function. However, even if the cataract is not the primary source of vision impairment, it may be advisable to extract it at the time of corneal surgery. The eventual need for cataract removal, the possible progression of cataract due to prolonged postoperative corticosteroid therapy, and the risk of additional damage to the corneal transplant's endothelium during secondary surgery are reasons for concomitant cataract removal.

Removing the cataract first requires adequate visualization of the anterior segment. It may be possible to remove the cataract and monitor the patient for worsening corneal opacity; however, eyes that exhibit corneal endothelial dysfunction are at higher risk of corneal decompensation following cataract surgery. Signs and symptoms of corneal endothelial dysfunction are microcystic edema, stromal thickening, low cell count on endothelial imaging, and/or diurnal fluctuations in vision with prolonged blurred vision upon waking. Endothelial keratoplasty is indicated in these eyes.

Penetrating keratoplasty (PKP) or endothelial keratoplasty (EK) may be performed in patients with decompensated corneal endothelial disease, either as primary surgery or as part of a combined procedure with cataract extraction (ie, a triple procedure). The decision to perform staged cataract surgery first, with EK later, is at the discretion of the surgeon. The advantages of performing keratoplasty as a stand-alone procedure include less postoperative inflammation and more reliable keratometry readings for future calculation of IOL power. In patients with primarily corneal endothelial disease, the advantages of EK over PKP include faster rehabilitation and more dependable keratometry readings with which to calculate IOL power. However, a mild hyperopic shift may be encountered. Cornea surgeons often find EK easier to perform in a pseudophakic eye than in a phakic eye.

A triple procedure (combined keratoplasty [PKP or EK], cataract extraction, and IOL implantation) may be chosen if both the cataract and the corneal disease are significant and the patient would benefit from concurrent treatment. Advantages of the triple procedure include a single visit to the operating room, which reduces the attendant perioperative surgical risks, and relatively rapid rehabilitation. Disadvantages of PKP with cataract surgery are decreased predictability of IOL calculation and a period of "open sky"; that is, exposure of the intraocular contents while the cataract is removed and the IOL is placed, prior to replacement of the corneal button. In addition, IOL power calculation may be less reliable for eyes that have undergone PKP than for those that have undergone EK. Table 12-2 presents advantages and disadvantages of EK versus PKP in conjunction with cataract surgery.

Table 12-2 Advantages and Disadvantages of EK (vs PKP) in Conjunction With Cataract Surgery

Advantages	Disadvantages
Faster corneal and vision rehabilitation	Potential for damage to grafted corneal endothelium resulting from the additional entry into the anterior chamber
Lower likelihood of irregular postoperative astigmatism	Possible disruption of the graft
Relative ease of regrafting	Risk of pupillary block from intracameral gas injection
Lower rates of corneal rejection	Risk of graft detachment requiring postoperative rebubbling
Lower likelihood of anisometropia and asthenopia	

EK = endothelial keratoplasty; PKP = penetrating keratoplasty.

For a detailed discussion of keratoplasty procedures, see BCSC Section 8, *External Disease and Cornea.*

Hwang RY, Gauthier DJ, Wallace D, Afshari NA. Refractive changes after Descemet stripping endothelial keratoplasty: a simplified mathematical model. *Invest Ophthalmol Vis.* 2011; 52(2):1043–1054.

Cataract Following Keratoplasty

Cataract formation soon after keratoplasty may be caused by lens trauma during the transplantation procedure or by prolonged corticosteroid use to prevent graft rejection. It is preferable to delay cataract surgery in an eye with a history of PKP until the corneal contour and surface are stable and reliable keratometry readings are obtained. The probability of graft survival 5 years after cataract surgery is at least 80%; nevertheless, a corneal graft may not survive even routine cataract surgery.

Preoperatively, the surgeon evaluates the corneal graft for thickening and anticipated reduced intraoperative clarity through the graft. A scleral tunnel approach has the benefits of being farther from the corneal transplant and minimizing endothelial trauma during surgery. The risk of postoperative graft failure is lowest when the corneal endothelium is protected with a dispersive OVD during surgery and when postoperative inflammation is aggressively treated.

Selecting the IOL power before the cornea is fully healed can lead to implantation of an incorrectly powered IOL and symptomatic anisometropia. Posterior chamber lenses are preferred because they minimize contact between the optic and the corneal endothelium. If capsular support is inadequate for IOL placement in the capsular bag (ie, “in-the-bag”), a posterior chamber scleral fixation suture or iris suture may be placed. If the additional manipulation required for a sutured lens poses a risk of excessive endothelial trauma, insertion of a flexible anterior chamber IOL (ACIOL) is an option. A modified IOL target may be considered in patients who have had previous corneal transplantation and are undergoing cataract surgery. The goal of this is to balance the 2 eyes.

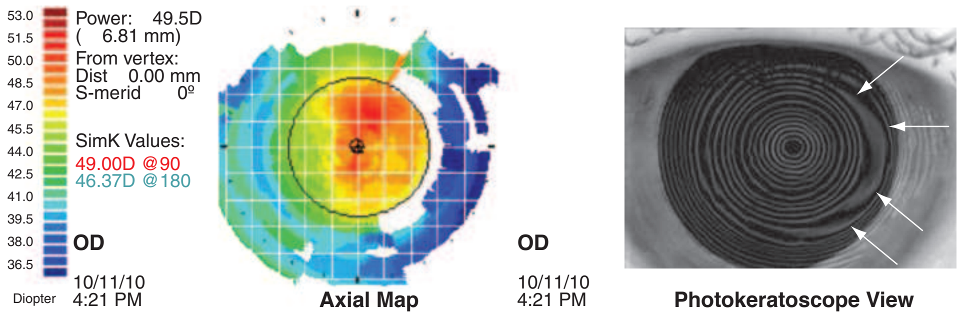


Figure 12-3 Accurate lens implant power is difficult to determine when the corneal surface is abnormal, as shown here by an irregular corneal topographic map *(left)* and distorted corneal rings *(right, arrows)*. *(Courtesy of Lisa F. Rosenberg, MD.)*

Cataract Following Refractive Surgery

Patients who have undergone corneal refractive surgery and later develop a visually significant cataract present several unique challenges. Measurement of corneal power after refractive surgery is problematic, requiring multiple instruments and/or formulas to try to determine the new corneal power. Moreover, accurate axial length measurement (eg, with optical biometry) is required. Advanced calculations are used to determine the appropriate IOL power. (For a detailed discussion of IOL power calculation, see Chapter 7 in this volume and BCSC Section 13, *Refractive Surgery*.) Irregular astigmatism resulting from a refractive surgical procedure may compromise the ultimate vision outcome after cataract removal (Fig 12-3). Because unanticipated postoperative refractive results may occur, it is important to inform the patient about the limits of precision in lens power calculation and the possible requirement for postsurgical refractive correction to obtain optimal vision.

In general, postoperative hyperopia is more commonly encountered after cataract surgery in patients who have undergone previous refractive surgery. The corneal refractive incisions in eyes that have undergone radial keratotomy (RK) often swell after cataract surgery, thereby flattening the cornea and inducing hyperopia. Swelling may require more than 3 months to resolve. If a clear corneal incision is chosen, it should be placed between the RK incisions. Violating a prior RK incision can destabilize the wound, causing it to pull apart. The presence of multiple deep RK incisions or unstable wounds increases the likelihood of AC shallowing during cataract surgery and makes final closure of the wound difficult. Unless adequate clearance between RK incisions can be ensured with a clear corneal approach, a scleral tunnel incision is preferable to reduce the likelihood of violating an RK incision.

In eyes that have undergone laser in situ keratomileusis (LASIK), the surgeon should make the clear corneal cataract incisions posterior enough and avoid a long tunnel that could disrupt the LASIK flap. Corneal swelling after LASIK may require more than 1 month to resolve. Cataract surgery in eyes that have undergone photorefractive keratectomy (PRK) does not present the same type of technical challenges of surgery in post-LASIK eyes.

Because patients who have undergone refractive surgery may have corneal aberrations from the initial surgery, it is important to carefully assess the use of multifocal, extended depth of focus, or toric lenses.

Compromised Visualization of the Lens

Small Pupil

Operating through a small pupil may increase the risk of intraoperative complications. It is important to note the maximum pharmacologic pupil dilation in the preoperative evaluation. A small pupil that is minimally responsive to dilating agents may be widened intraoperatively. The pupil can be bimanually stretched with Kuglen or Lester hooks, the iris can be tethered with hooks (Fig 12-4), or pupil-expansion devices can be employed (Fig 12-5). Viscodilation with a high-viscosity OVD is another method for pupil enlargement. These maneuvers break posterior synechiae and release the pupillary sphincter. However, with excessive manipulation of the iris, the risk of postoperative inflammation increases. Also, because the iris tends to be flaccid and floppy after manual stretching and release, it is more likely to be damaged by the phaco tip.

To enlarge a small pupil resulting from IFIS, most surgeons prefer to use pupil-expansion devices because unless the pupil is held open mechanically, progressive miosis of the floppy iris tends to occur as the surgery proceeds (Video 12-1). IFIS is a common cause of small pupils; as discussed in detail in Chapter 10, planned adjustments can be considered.

VIDEO 12-1 Malyugin ring insertion and removal.
Courtesy of Nathan Hesemann, MD.
Available at: aao.org/bcscvideo_section11

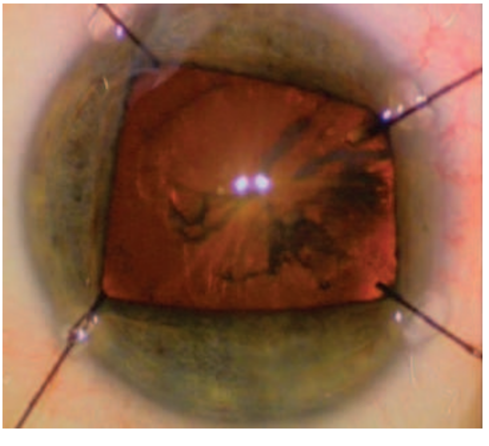


Figure 12-4 A pupil that dilates insufficiently to allow access to the lens may be widened with iris hooks. In this case, 4 hooks are placed to expose the lens for surgery. *(Courtesy of Lisa F. Rosenberg, MD.)*

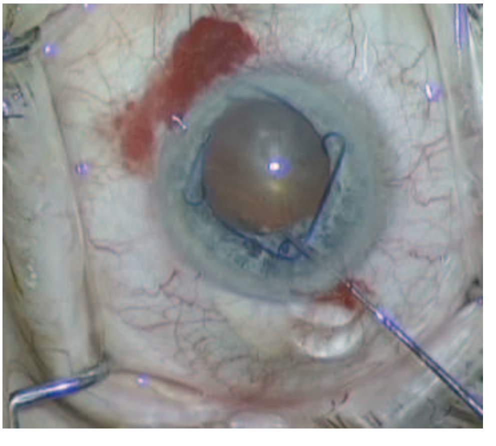


Figure 12-5 A Malyugin ring is positioned at the pupillary margin circumferentially. *(Courtesy of Steven Vold, MD.)*

Poor Red Reflex

As discussed in Chapter 8, creation of a continuous curvilinear capsulorrhexis (CCC) is a key component of safe phacoemulsification. An abnormal red reflex makes it difficult for the surgeon to discriminate the capsular edge, thus increasing the risk of an incomplete or errant capsulorrhexis. In an eye with dense brunescent or cortical cataract, the capsule is prone to radial tears. The tears result from vaulting of the anterior capsule, which is caused by increased lens thickness and cortical hydration. Corneal scars compromise the surgeon's view of the capsule and make intraocular manipulation treacherous. These challenges can be addressed by staining the capsule with trypan blue (Fig 12-6).

Prior to capsulotomy, AC fluid can be replaced with air, and a small amount of OVD can be used to occlude the paracentesis site. Alternatively, a high-viscosity OVD can be instilled to fill approximately two-thirds of the anterior chamber. The surgeon then injects trypan blue through a 27-gauge blunt cannula, starting as far away from the paracentesis incision as possible to deliver the dye directly to the capsule. In the presence of a healthy endothelium, the trypan blue can be injected without prior air or viscoelastic injection. The dye is then rinsed from the AC with balanced salt solution (BSS) and replaced with a high-viscosity OVD, under which the stained anterior capsule is easily visible. The high-viscosity OVD exerts pressure on the anterior capsule, maintaining chamber depth and flattening the capsule to prevent radial extension of the capsular tear. A CCC is then created (Video 12-2).

VIDEO 12-2 Capsule staining with trypan blue dye.
Courtesy of Nathan Hesemann, MD.
Available at: aao.org/bcscvideo_section11

Jacobs DS, Cox TA, Wagoner MD, Ariyasu RG, Karp CL; American Academy of Ophthalmology; Ophthalmic Technology Assessment Committee Anterior Segment Panel. Capsule staining as an adjunct to cataract surgery: a report from the American Academy of Ophthalmology. *Ophthalmology.* 2006;113(4):707–713.

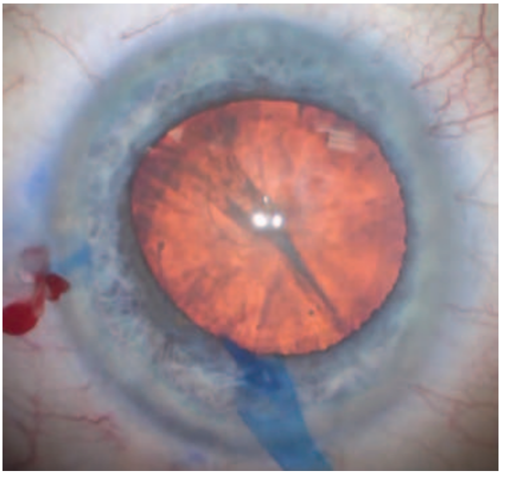


Figure 12-6 The anterior capsule is stained lightly with trypan blue, thereby aiding visualization of the capsule during creation of a capsulorrhexis. This technique is helpful in eyes with dense brunescent or cortical cataracts that interfere with the red reflex. *(Courtesy of Nathan Hesemann, MD.)*

Altered Lens and Zonular Anatomy

Intumescent Cataract

A cataract that is swollen with cortical material and often envelops a hard nucleus floating within the capsular bag is described as *intumescent*. This type of cataract presents specific challenges during phacoemulsification cataract surgery. Intumescent cataracts have weak zonular fibers and fragile capsules. Because intumescence creates positive pressure in the capsular bag, the initial incision in the capsule may extend peripherally (Video 12-3; also see the sidebar).

VIDEO 12-3 Intumescent mature cataract.
Courtesy of Virgilio Centurion, MD, and Juan Carlos Caballero, MD.
Available at: aao.org/bcscvideo_section11

PROPOSED INTERVENTIONS TO REDUCE THE INTRAOPERATIVE COMPLICATIONS ASSOCIATED WITH INTUMESCENT CATARACT

1. Stain the capsule with trypan blue and fill the AC with a high-viscosity OVD (as described in the previous section Poor Red Reflex).
2. Prior to capsulotomy, place a 25- or 27-gauge needle attached to a syringe at the center of the anterior capsule. While suction is applied, use the needle to pierce the anterior capsule, and aspirate the milky cortex. This decompresses the lens to avoid radial extension of the CCC.
3. Use a cystitome attached to the OVD syringe during creation of the CCC to enable injection of additional OVDs, which will clear away the milky egress.
4. Use caution during phacoemulsification, because the freely mobile lens, without an epinuclear barrier, makes segmentation challenging.

Advanced Cataract

In eyes with dense, brunescent cataracts, surgical manipulation increases the risks of iris trauma, zonular tearing, capsular rupture, vitreous loss, and the dropping of lens fragments into the posterior segment. The increased ultrasound energy required for phacoemulsification of dense lenses increases the risk of endothelial trauma and wound burn. Creation of a larger capsulorrhexis is helpful because it allows the surgeon to perform the maneuvers that are necessary to minimize these complications. Thorough hydrodissection and hydrodelineation of the nucleus facilitate smooth rotation during phacoemulsification. When the surgeon makes an initial groove in the hard nucleus, it is important that this is done with a deep and even pass. The aim is to crack the nucleus without leaving interdigitations, which would interfere with removal and potentially result in rupture of the posterior capsule. Viscodissection helps separate sticky cortical attachments that impede rotation. If the surgeon uses excessive mechanical force on a nucleus that does not freely rotate, zonular dialysis may result from transmittal of that force to the capsular bag. Mechanical segmentation techniques for nucleus disassembly, such as vertical and horizontal chopping, require less ultrasound energy and may induce less zonular stress than the "divide and conquer" method (see Chapter 8). Familiarity with multiple techniques, along with the ability to switch from one technique to another as the situation requires, enables the surgeon to minimize complications.

If phacoemulsification ceases to be appropriate for lens removal, conversion to an extracapsular technique can be considered. The surgeon may proceed through the corneal incision, enlarging it to permit passage of the cataract and lens implant. Alternatively, the surgeon may close the corneal wound and make a new, larger corneoscleral incision. Often, a corneoscleral incision is more stable than a large corneal wound and induces less astigmatism postoperatively.

Iris Coloboma and Corectopia

Zonular dehiscence or absence commonly occurs in the area of iris coloboma (Fig 12-7) or a misshapen pupil. Pharmacologic dilation can be carried out to assess the extent of zonular abnormality. Iris hooks can be used intraoperatively to pull a flaccid iris out of the way. The surgeon also has the option of repairing the coloboma with a suture at the conclusion of the case. When the iris defect is sufficiently large to indicate the use of a prosthesis, the surgeon can implant an artificial iris. In the presence of zonular dehiscence, trypan blue should be used with caution because it may also inadvertently stain the posterior capsule and vitreous, compromising visualization.

Posterior Polar Cataract

A weak or absent area of the posterior lens capsule in the region of a posterior polar opacity places the eye at increased risk of capsular rupture during surgery. Accordingly, the surgeon should avoid exerting excessive pressure within the capsular bag or on the

Figure 12-7 Zonular dehiscence or absence is common in iris coloboma. Shown here is an iris coloboma with nuclear cataract. Absent or abnormal zonular fibers correlate with the area of the iris defect. A preoperative evaluation of associated posterior segment abnormalities is an important way to assess vision potential. *(Courtesy of Robert S. Feder, MD.)*

posterior capsule. Complete hydrodissection is also avoided because of possible tearing of the capsule directly under the opacity. Instead, the following procedure is undertaken:

1. Deliver small volumes of fluid around the cortex up to, but not across, the opacity.
2. Perform gentle hydrodelineation, leaving a generous amount of epinuclear bowl in which to mobilize the nucleus and protect the capsule.
3. Maintain the AC depth and limit fluctuations in IOP by low irrigation and aspiration.

After the nucleus is removed, OVD is used for viscodissection of the epinucleus from the capsular bag. The posterior polar opacity is removed last; viscodissection can be performed for this step as well. If the central portion of the posterior capsule is missing, filling the capsular bag with OVD before removing the irrigating phaco handpiece from the eye will stabilize the chamber for lens insertion. Alternatively, if the posterior polar opacity is very adherent, it can be left in place, assessed for its impact on vision postoperatively, and treated with laser capsulotomy, if indicated. After the IOL is placed in the capsular bag in an uncomplicated procedure, movement of the bag can be minimized with slow and gentle OVD removal.

Zonular Dehiscence With Lens Subluxation or Dislocation

Common causes of zonular incompetence include pseudoexfoliation syndrome (Fig 12-8), ocular trauma, prior vitrectomy, prior trabeculectomy, and high myopia. Marfan syndrome, Ehlers-Danlos syndrome, homocystinuria, hyperlysinemia, and Weill-Marchesani syndrome are less-common sources of inadequate zonular support. Iridodonesis, detected at the slit lamp, is often an initial finding that signals zonular weakness or absence. If the

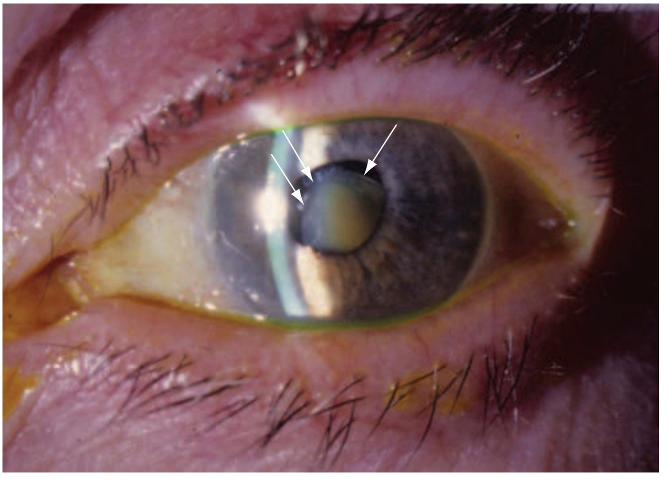


Figure 12-8 Subluxed lens. This lens with pseudoexfoliation is displaced inferiorly because zonular fibers at the superior edge of the lens are stretched, damaged, or broken. *Arrows* indicate the superior edge of the inferiorly displaced lens. Cataract surgery on a displaced lens requires meticulous preoperative planning to minimize surgical complications. *(Courtesy of Lisa F. Rosenberg, MD.)*

entire lens becomes dislocated into the posterior segment, surgical removal of the lens may not be necessary, unless uveitis develops. In some eyes, the remaining zonular fibers tether the lens within the anterior vitreous such that when the patient sits upright at the slit lamp, the lens seems accessible for extraction. However, when that patient is supine during surgery, the lens tilts backward, out of the surgeon's reach. Thus, when iridodonesis or phacodonesis is detected preoperatively, it is helpful to confirm lens position with the patient supine during the preoperative examination.

Zonular status may be determined by direct visualization of the lens equator through a widely dilated pupil or by use of a goniolens to visualize zonular fibers behind the dilated pupil. If zonular disruption is extensive preoperatively, the surgeon may consider removal of the cataract using one of the following:

- extracapsular cataract extraction (ECCE)
- intracapsular cataract extraction (ICCE)
- phacoemulsification with capsular hooks followed by suturing a capsular segment to stabilize the capsule during and after surgery

Zonular incompetence becomes apparent intraoperatively with phacodonesis, decentration of the capsular bag, and sometimes vitreous prolapse into the AC. If phacodonesis prevents the use of a CCC or if zonular disruption is extensive, the surgeon may convert from phacoemulsification to ECCE or ICCE. Otherwise, phacoemulsification can proceed safely with application of the same measures recommended in the Advanced Cataract section, earlier in this chapter. Reducing the flow rate diminishes turbulence and fluctuation in AC depth, lowering the risk of vitreous prolapse through the area of zonular absence. A larger capsulorrhexis enables easier separation of lens components within the capsular bag. Thorough hydrodissection and hydrodelineation of the nucleus facilitate smooth rotation during phacoemulsification. Viscodissection helps separate cortical attachments that may impede rotation. Excessive mechanical maneuvers during nucleus disassembly and cortical aspiration, as well as inadvertent aspiration of the anterior capsule edge, contribute to further zonular compromise. Viscodissection of cortical remnants and IOL insertion prior to complete cortical removal are maneuvers that help maintain capsular integrity. Tangential, rather than radial, removal of cortex from the bag minimizes zonular stress. Pars plana lensectomy may be preferred to lens extraction in cases of severe zonular loss and in the absence of contraindicating ocular comorbidities.

If capsular support is insufficient for safe phacoemulsification, capsular hooks, a capsular tension ring (CTR), or CTR segments can be used (Videos 12-4, 12-5). Capsular hooks (Fig 12-9) support the anterior capsule edge in the area of weakened zonular fibers. They are placed through paracentesis incisions, and adjustment of tension on each hook centers the capsule for phacoemulsification. CTRs provide support by exerting an outward force against the capsule equator in areas of absent or weakened zonular fibers. With a CTR in position, the surgeon can proceed to nuclear and cortical removal more safely and can place the chosen IOL in the capsular bag (ie, an "in-the-bag" IOL). A standard CTR may be insufficient in eyes with more than 4 clock hours of zonulopathy; in these eyes, endocapsular scleral-fixated devices such as modified CTRs or capsular tension segments

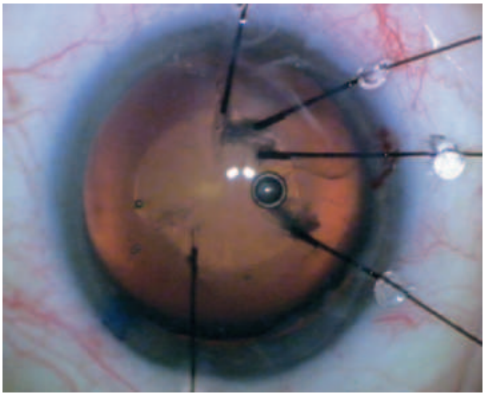


Figure 12-9 Hooks are placed around the anterior capsule edge to stabilize the capsular bag during phacoemulsification in this eye with a subluxed lens. Trypan blue is used to aid visualization of the capsular edge. *(Courtesy of Lisa F. Rosenberg, MD.)*

(CTS) may be more appropriate. If there is severe instability, the help of a vitreoretinal surgeon may be enlisted to employ a pars plana approach to remove the cataract.

VIDEO 12-4 Insertion of capsular tension ring.
Courtesy of David F. Chang, MD.
Available at: aao.org/bcscvideo_section11

VIDEO 12-5 *Capsule hooks and capsular tension ring.*
Courtesy of David F. Chang, MD.
Available at: aao.org/bcscvideo_section11

If zonular support is insufficient to use a 1-piece IOL in the capsular bag, the surgeon can choose from the following options:

- a 3-piece IOL with the haptics placed in the capsular bag in the location of zonular weakness
- a 3-piece IOL placed in the ciliary sulcus (with or without optic capture)
- a transscleral-fixated or iris-fixated posterior chamber IOL (PCIOL)
- an ACIOL

It is preferable to avoid the use of premium IOLs, such as multifocal and toric lenses, in eyes with capsular decentration or significant potential for decentration.

Pseudoexfoliation Syndrome

Eyes with pseudoexfoliation are characterized by poor pupillary dilation and weakened zonular fibers. These findings increase the likelihood of intraoperative complications such as lens dislocation, capsular rupture, and vitreous loss. Safe cataract surgery in these eyes involves the same techniques as in eyes with advanced cataract and zonular dehiscence (discussed earlier in this chapter). Progressive capsular contraction, or capsular phimosis, is common in eyes with pseudoexfoliation. Dislocation of the implant into the vitreous is also possible. In eyes without phacodonesis, neither placement of a 3-piece or 1-piece IOL nor use of a CTR affects visual outcomes or rates of IOL decentration. However, use of a CTR should be considered because its presence may facilitate surgical correction of late subluxation. If capsular phimosis occurs, a Nd:YAG laser may be used to create radial incisions in the anterior capsule to release tension on the zonular fibers and maintain the lens centrally (see Chapter 11 for further discussion).

Haripriya A, Ramulu PY, Schehlein EM, et al. The Aravind Pseudoexfoliation Study: 5-year postoperative results. The effect of intraocular lens choice and capsular tension rings. *Am J Ophthalmol.* 2020;219:253–260.

Cataract in Aniridia

The lens capsule in patients with aniridia is thin and fragile, which makes performing a capsulorrhexis more challenging. Ideally, the edge of a well-centered capsulorrhexis overlaps the optic edge by 1 mm. Corneal haze and neovascularization are common in these eyes because of limbal stem cell deficiency; capsular staining may aid visualization through the cornea during creation of an adequately sized capsular opening. Use of a high-viscosity OVD also optimizes visualization while stabilizing the capsular surface.

The surgeon should avoid working inside the capsular bag, which could place tension on the capsular rim. Low infusion helps reduce turbulence and capsular fluctuation. The capsule in aniridic eyes acts as a pseudoiris when it opacifies. An alternative is the CustomFlex artificial iris, which was approved for use by the FDA in 2022 for the treatment of full or partial aniridia and was found to be safe and effective for treatment of congenital or acquired iris defects. Close postoperative follow-up in aniridic eyes is necessary to monitor for the development of epithelial defects or keratopathy. Caution is advised regarding use of NSAIDs in the postoperative period. Preservative-free eyedrops may mitigate risks to the cornea. See Chapter 10, Video 10-5, for demonstration of artificial iris implantation.

Ayres BD, Fant BS, Landis ZC, et al. Results of the United States Food and Drug Administration clinical trial of the CustomFlex Artificial Iris. *Ophthalmology.* 2022; 129(6):614–625.

Conditions Associated With Extremes in Axial Length

High Myopia

When the surgeon introduces the phaco tip into the anterior chamber of a highly myopic eye, the chamber may deepen dramatically, making lens manipulation difficult. To avoid extensive deepening of the anterior chamber, the surgeon is advised to reduce the intraocular pressure setting on latest generation phaco machines (lower the infusion bottle height on older phaco machines) and increase the flow rate before entering the eye with the phaco tip. Placing a second instrument between the iris and the anterior capsule prior to turning on infusion may prevent excess deepening. Despite this maneuver, highly myopic eyes are susceptible to lens–iris diaphragm retropulsion syndrome (LIDRS), wherein 360° of iridocapsular contact occurs, causing reverse pupillary block, pupillary dilation, and pain. A defect or laxity in the zonular fibers predisposes myopic eyes to LIDRS. Manual separation of the iris from the anterior capsule rim using a sideport instrument corrects the situation (see Chapter 10).

It is important to calculate IOL power preoperatively for highly myopic eyes to determine whether a special-order IOL, such as a plano-power or minus-power implant, is required. It is preferable that the patient receive an IOL when possible; the lens implant serves as a barrier to movement of the vitreous base and associated traction on the retina. Because myopic eyes are at increased risk of retinal detachment postoperatively, acrylic lens implants are favored when there is a strong possibility that the patient will later undergo a vitreoretinal surgery. During vitreoretinal surgery involving an open posterior capsule, silicone IOLs develop condensation that compromises visualization into the eye. Silicone lenses have also been observed to migrate through the capsular opening into the vitreous.

To avoid unexpected difficulty with glasses postoperatively, it is helpful to discuss anisometropia with a patient who has high myopia and does not wear a contact lens in the other eye.

High Hyperopia and Nanophthalmos

An eye with cataract and high hyperopia often has a shallow AC and is prone to uveal prolapse, iris damage, and excessive corneal endothelial trauma during cataract surgery. Deepening of the AC and protection of intraocular tissue can be achieved with a high-viscosity OVD, a low aspiration rate, and increasing the phaco IOP setting (equivalent to elevating the irrigation bottle on older phaco machines) prior to insertion of the phaco tip. Mannitol may be administered preoperatively to dehydrate the vitreous volume in a patient with no systemic contraindications. Iris prolapse is avoided by entering through a longer and more anterior corneal incision and by taking care not to overfill the eye with OVD. If all these measures fail to provide sufficient AC volume for cataract removal, a small amount of liquid vitreous can be withdrawn using a vitrectomy handpiece through a pars plana puncture.

Nanophthalmos is a rare condition in which the eye is extremely short and the ratio of lens volume to eye volume is larger than normal. Diagnostic criteria vary, but these eyes generally have shallow anterior chambers, narrow angles, and thickened sclerae, with little room for the surgeon to maneuver. Axial length is shortened by at least 2 standard deviations below age-matched controls—usually to 20 mm or less. Small-incision bimanual surgery may be considered for these eyes. Because nanophthalmic eyes are at high risk of uveal effusion, precautions include the following measures:

- maintaining positive pressure in the AC and limiting the time used to perform the procedure to help prevent intraoperative uveal effusion
- considering creation of a scleral window as a prophylactic measure
- suturing the wound to help prevent hypotony and consequent uveal effusion postoperatively

Hypotony

A shortened axial length with choroidal thickening is often accompanied by chronic hypotony and posterior scleral flattening. Hypotony makes biometry technically challenging and complicates calculation of IOL power. The clinician should attempt to determine the cause of hypotony and undertake specific treatment before cataract surgery. If the cataract obscures examination of the posterior segment, B-scan ultrasonography is helpful in revealing posterior segment pathology. A cyclodialysis cleft or retinal detachment requires a more extensive procedure when combined with cataract surgery. Severe hypotony or pre-phthisis is a poor prognostic indicator for improvement in vision after cataract extraction.

Glaucoma

Assessment

When cataract surgery is being considered in a patient with glaucoma, it is important to assess how well the glaucoma is controlled preoperatively. It can be challenging to predict the visual outcome in an eye with both cataract and glaucoma because both conditions can contribute to blurred vision, and the patient's visual symptoms may not be exclusively attributable to one condition or the other. An advanced visual field defect may limit vision improvement after cataract surgery. In contrast, an advanced cataract may exaggerate a mild visual field abnormality. Surgical options include cataract surgery alone, combined cataract and glaucoma surgery, and staged procedures of glaucoma surgery (eg, trabeculectomy or drainage device) followed by cataract surgery in a subsequent session. Uncomplicated phacoemulsification alone may lower the IOP by 10%–34%, but this decrease diminishes over time. MIGS can be combined with cataract extraction to further reduce IOP in a blebless, conjunctiva-sparing manner. Small-incision cataract surgery with a clear corneal approach minimizes conjunctival damage; this is essential if filtering surgery is likely to be required in the future. In an eye with a functioning filtering bleb, a small incision in a temporal location makes cataract surgery straightforward and is less likely to compromise IOP control. Issues influencing determination of the surgical approach include

- preoperative IOP
- desired postoperative IOP
- degree of damage to the optic nerve and visual field
- number of medications required to control IOP
- expected patient adherence to the medication regimen
- potential adverse effects of the medications
- potential impact on quality of life

Surgical decision making in the glaucomatous eye and combined cataract and glaucoma surgery are discussed in BCSC Section 10, *Glaucoma.*

Most surgical challenges in eyes with both glaucoma and cataract are not unique. For instance, zonular compromise and phacodonesis can complicate capsulorrhexis creation and lens removal in eyes with traumatic or pseudoexfoliation glaucoma. When a peripheral iridotomy (PI) is performed, the surgeon may inadvertently hydrate the vitreous, and caution is advised while injecting dye into the AC to avoid vitreous staining by dye injected through the PI. Uveitic glaucoma and miotic therapy may limit pupillary dilation and increase the risk of postoperative macular edema. After surgery, the IOP can increase, owing to retained OVD or inflammation; pressure rises to a higher level in glaucomatous eyes with reduced outflow through the trabecular meshwork.

The use of topical prostaglandin medication may be associated with postoperative cystoid macular edema (CME), although there are few proven cases. In part, this is because clinically significant CME after uncomplicated phacoemulsification occurs only in rare instances. In cases of early postoperative CME, discontinuation of prostaglandin is advisable to determine whether this medication is contributing to the edema.

Mansberger SL, Gardiner SK, Gordon M, Kass M, Ramulu P; Ocular Hypertension Treatment Study Group. Cataract surgery lowers intraocular pressure and medication use in the medication group of the Ocular Hypertension Treatment Study. *Am J Ophthalmol.* 2022;236:53–62.

Mansberger SL, Gordon MO, Jampel H, Bhorade A, Brandt JD, Wilson B, Kass MA; Ocular Hypertension Treatment Study Group. Reduction in intraocular pressure after cataract extraction: the Ocular Hypertension Treatment Study. *Ophthalmology.* 2012;119(9):1826–1831.

Cataract Surgery in an Eye With a Functioning Filter

Small-incision cataract surgery can be performed in glaucomatous eyes without affecting the results of the previous filtering surgery. With a temporal corneal incision, the surgeon avoids the superior conjunctiva and the site in which filtering surgery was conducted. If conversion to an extracapsular technique is indicated (eg, in extreme phacodonesis with zonular instability or in capsular rupture with vitreous present in the AC), the surgeon may extend the clear corneal or scleral incision to permit removal of the crystalline lens. Aggressive control of postoperative inflammation is vital to ensure continued bleb function.

Francis BA, Singh K, Lin SC, et al. Novel glaucoma procedures: a report by the American Academy of Ophthalmology. *Ophthalmology.* 2011;118(7):1466–1480.

Combining MIGS With Cataract Surgery

MIGS comprises a diverse group of IOP-lowering procedures that have a better safety profile than do trabeculectomy and glaucoma drainage devices. Performing MIGS at the time of cataract extraction can benefit patients with mild to moderate glaucoma, especially those who cannot adhere to or tolerate IOP-lowering eyedrops. Even a modest pressure decrease following a combined MIGS/cataract surgery may lead to future dependency on fewer classes of eyedrops. This translates to improvement in quality of life. Surgeons who perform MIGS may utilize FDA-approved or FDA-cleared ab interno trabecular bypass devices and implants or subconjunctival-space implants (see BCSC Section 10, *Glaucoma*, for details).

Five-year results of the HORIZON randomized multicenter clinical study showed significant IOP reduction, decreased medication use, and lower risk of additional incisional glaucoma surgery among patients with mild-to-moderate primary open angle glaucoma who received the Hydrus stent in combination with phacoemulsification, compared with patients who underwent phacoemulsification alone. Safety profiles were similar for the 2 arms. The iStent and iStent inject in combination with phacoemulsification also resulted in significant IOP reduction and decreased need for glaucoma medications versus phacoemulsification alone, with no safety differences. The market withdrawal of the CyPass Micro-Stent (Alcon) because of increased endothelial cell loss in patients who received this device at the time of cataract surgery emphasizes the importance of long-term clinical trials to evaluate the safety of relatively new devices.

Ahmed IIK, De Francesco T, Rhee D, et al. HORIZON Investigators. Long-term outcomes from the HORIZON Randomized Trial for a Schlemm's canal microstent in combination cataract and glaucoma surgery. *Ophthalmology.* 2022;129(7):742–751.

Arriola-Villalobos P, Martínez-de-la-Casa JM, Díaz-Valle D, et al. Combined iStent trabecular micro-bypass stent implantation and phacoemulsification for coexistent open-angle glaucoma and cataract: a long-term study. *Br J Ophthalmol*. 2012;96(5):645–649.

Francis BA, Minckler D, Dustin L, et al. Combined cataract extraction and trabeculotomy by the internal approach for coexisting cataract and open-angle glaucoma: initial results. *J Cataract Refract Surg*. 2008;34(7):1096–1103.

Helmut H, Ahmed IIK, Grisanti S, et al. Early postoperative safety and surgical outcomes after implantation of a suprachoroidal micro-stent for the treatment of open-angle glaucoma concomitant with cataract surgery. *J Cataract Refract Surg*. 2013;39(3):431–437.

Maeda M, Watanabe M, Ichikawa K. Evaluation of trabectome in open-angle glaucoma. *J Glaucoma*. 2013;22(3):205–208.

Malvankar-Mehta MS, Iordanous Y, Chen YN, et al. iStent with phacoemulsification versus phacoemulsification alone for patients with glaucoma and cataract: a meta-analysis. *PLoS One*. 2015;10(7):e0131770. doi:10.1371/journal.pone.0131770

Samuelson TW, Sarkisian SR Jr, Lubeck DM, et al. iStent inject Study Group. Prospective, randomized, controlled pivotal trial of an ab interno implanted trabecular micro-bypass in primary open-angle glaucoma and cataract: two-year results. *Ophthalmology.* 2019;126(6):811–821.

Uveitis

Chronic or recurrent uveitis and the corticosteroid therapy used to manage it contribute to cataract formation. Decreased vision due to cataract must be differentiated from that caused by coexisting macular edema or posterior segment pathology. Fluorescein angiography (FA) or optical coherence tomography (OCT) can be used preoperatively to identify CME. Complications can be minimized when inflammation has been controlled for several months before surgery and is treated aggressively after surgery. Topical and oral corticosteroids are the mainstay of therapy; topical NSAIDs and cytotoxic agents may be used to supplement treatment.

To minimize risk of scleral or corneal necrosis, it is important to preoperatively control ocular inflammation, such as scleritis and uveitis associated with connective-tissue or inflammatory diseases. The ophthalmologist can work with other physicians involved in the patient's care to monitor therapy with systemic corticosteroids and immunosuppressive agents.

Uveitic eyes may dilate poorly and require lysis of iridolenticular adhesions or pupil expansion. Any pupillary membrane should be incised and stripped to avoid interference with the capsulorrhexis. Vigorous stretching and manipulation of the pupil can lead to bleeding of the iris and fibrinous inflammation postoperatively. Meticulous cleanup of cortical material can help prevent exuberant postoperative inflammation. The use of prostaglandins for IOP control postoperatively is controversial because of the potentially increased risk of CME. Although there is no evidence for stopping prostaglandin analogue use pre- or postsurgically, caution is warranted with the use of these medications in complex eyes with retinal comorbidities that undergo cataract surgery.

Insertion of a silicone lens implant is discouraged because inflammatory precipitates can collect on the lens surface (Fig 12-10). Instead, acrylic PCIOLs placed in the capsular bag, which are well tolerated, are often used. When complications arise and a lens cannot be inserted into the capsular bag, the surgeon may decide against placing a lens in the ciliary sulcus or implanting an AC lens. Other options include leaving the eye aphakic or using a scleral-fixated lens. In uveitis associated with membrane formation, repeated Nd:YAG procedures may be necessary to clear the lens surface. (See also BCSC Section 9, *Uveitis and Ocular Inflammation.*)

Abela-Formanek C, Amon M, Kahraman G, Schauersberger J, Dunavoelgyi R. Biocompatibility of hydrophilic acrylic, hydrophobic acrylic, and silicone intraocular lenses in eyes with uveitis having cataract surgery: long-term follow-up. *J Cataract Refract Surg.* 2011;37(1): 104–112.

Hernstadt DJ, Hosain R. Effect of prostaglandin analogue use on the development of cystoid macular edema after phacoemulsification using STROBE statement methodology. *J Cataract Refract Surg.* 2017;43(4):564–569.

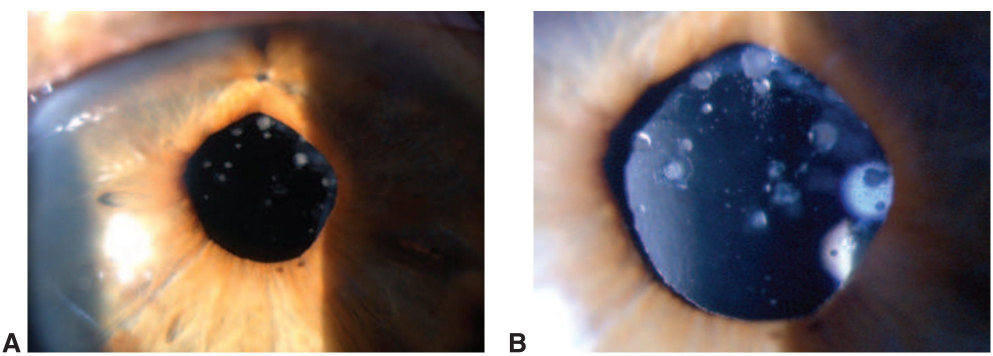


Figure 12-10 Low-power **(A)** and high-power **(B)** views of a silicone intraocular lens with lenticular precipitates. *(Courtesy of Steven Vold, MD; photography by Matthew Poe.)*

Retinal Conditions

Retinal Disease

The ocular records of a patient with retinal disease may indicate their visual acuity before the onset of cataract. Macular function tests, such as the macular photostress recovery test or the potential acuity pinhole test (see Chapter 6), can be employed to help predict visual outcomes in patients with retinal disease. The clinician must interpret test results with caution because poor or equivocal test performance does not rule out a benefit from cataract removal. OCT and FA can be used to detect the presence of diabetic or hypertensive retinopathy, degenerative changes, macular distortion, and leakage of fluid into the foveal area. Proper management of patient expectations is crucial in vision-threatening retinal disease.

If diabetic macular edema is present and the view of the retina is adequate preoperatively, the clinician may consider focal laser treatment or intravitreal injection of steroids or anti–vascular endothelial growth factor (anti-VEGF) medications. Ideally, cataract surgery is delayed until the macular edema has resolved; this may take several months. The clinician also may consider perioperative administration of topical NSAIDs. Researchers have found that this may decrease the incidence of postoperative CME and that NSAIDs are beneficial in preventing macular edema in patients with diabetes mellitus.

Patients known to have peripheral vitreoretinopathy should be examined by a retina specialist to determine whether pretreatment with laser therapy or cryotherapy would help reduce the risk of retinal tears or detachment. After prophylactic treatment, a period of a few weeks may elapse before elective cataract surgery. (See also BCSC Section 12, *Retina and Vitreous.*)

If visualization of the retina is restricted by a small pupil, cataract surgery can provide an opportunity to enlarge the pupil using stretch maneuvers, iris hooks, expansion devices, or multiple sphincterotomies. In addition, a generous anterior capsulotomy with complete cortical cleanup can enhance the view of the retinal periphery after surgery.

When safe, it is preferable that the patient receive a PCIOL. A silicone IOL should be avoided in a patient for whom vitrectomy is anticipated because condensation on the posterior surface of the implant limits visibility during pars plana vitrectomy.

Eriksson U, Alm A, Bjärnhall G, Granstam E, Matsson AW. Macular edema and visual outcome following cataract surgery in patients with diabetic retinopathy and controls. *Graefes Arch Clin Exp Ophthalmol.* 2011;249(3):349–359.

Shah AS, Chen SH. Cataract surgery and diabetes. *Curr Opin Ophthalmol.* 2010;21(1):4–9.

Cataract Following Pars Plana Vitrectomy

Nuclear cataract formation is common after pars plana vitrectomy, especially in patients older than 50 years. The use of silicone oil during retinal surgery typically promotes posterior subcapsular opacification. Posterior plaque may also be seen after pars plana vitrectomy. In the absence of a vitreous cushion, the posterior capsule becomes more mobile. Thus, careful attention to fluctuations in AC depth is important to avoid a surge upon breaking vacuum when a piece of lens is aspirated (see Chapters 8 and 10). Lowering the IOP setting (lowering the irrigation bottle) and decreasing the fluid flow rate prior to placing the phaco tip inside the eye are helpful. These maneuvers are also recommended when zonular integrity is altered as a result of prior retinal surgery or preexisting ocular disease. Note that overfilling the anterior chamber with OVD can cause zonular stretch and breakage. Extra caution is also necessary to prevent pieces of the lens from being lost during hydrodissection in case an inadvertent capsular break had occurred during the retinal surgery. A large capsulorrhexis allows prolapse of the nucleus during hydrodissection for an iris-plane phaco chop. If the surgeon selects an extracapsular surgical technique instead of phacoemulsification, the absence of vitreous reduces posterior pressure to aid lens expression. Alternatively, after capsulorrhexis and hydrodissection of the nucleus from its cortical attachments, the nucleus can be removed using a lens loop or irrigating vectis. Patients who receive intravitreal injections also may have an inadvertent opening of the posterior capsule; these patients may be treated similarly to postvitrectomy patients (described previously).

Cataract With Intraocular Silicone Oil

In an eye with silicone oil, the cataract usually is very soft. It is important to avoid pressurizing the eye with excessive OVD or a high infusion pressure of BSS. During cataract surgery, silicone oil can migrate through a break in the zonular fibers if the AC is overfilled with OVD. This can be counteracted with the use of low-flow irrigation or decreased aspiration rate during surgery. Droplets of silicone oil that were not apparent in the AC during surgery might become visible postoperatively. A few droplets are usually not toxic to the cornea. Silicone lens implants are contraindicated in these eyes because silicone oil adheres to the implant surface. The surgeon can create an inferior iridotomy if a patent one is not already present. (See Chapter 7 for a discussion of IOL calculations in eyes with silicone oil.)

Optic Nerve

Nonarteritic Ischemic Optic Neuropathy

Nonarteritic anterior ischemic optic neuropathy (NAION) has been reported after uncomplicated cataract surgery, but the absolute risk is low. However, the incidence is greater in patients who underwent cataract surgery than in those who did not. Therefore, in cases in which the contralateral eye has a history of NAION, the risks of cataract surgery should be discussed with the patient, and measures should be taken to avoid elevated IOP and inflammation to reduce this risk.

Shew W, Wang MTM, Danesh-Meyer HV. Nonarteritic anterior ischemic optic neuropathy after cataract surgery: a systematic review and meta-analysis. *J Neuroophthalmol.* 2023; 43(1):17–28.

Yang HK, Park SJ, Byun SJ, Park KH, Hwang JM. Risk of nonarteritic anterior ischemic optic neuropathy after cataract surgery. *Am J Ophthalmol.* 2019;207:343–350.

Ocular Trauma

Ocular Assessment

When a patient presents with a history of ocular trauma sufficient to cause a dense cataract, it is important to evaluate the other anterior segment structures, which also may be affected. If the corneal endothelium, zonular fibers, or anterior chamber angle have sustained damage, adjustments in surgical technique are needed. Gonioscopy is essential when IOL placement is planned, and the surgeon should exercise great care when evaluating ocular findings and determining the potential for visual recovery (discussed in Chapter 6). Cataract may occur acutely after substantial trauma (see Chapter 5). A slowly progressive cataract after ocular trauma can be monitored while intraocular inflammation and other comorbidities are treated.

Visualization During Surgery

Corneal laceration and edema can impair the view into the eye such that phacoemulsification cannot be performed safely. Instead, an extracapsular approach may be advisable. Hemorrhage during surgery can further reduce visualization of the anterior segment. The surgeon may use an OVD and inject air intracamerally to occlude vessels and marginalize bleeding. If visualization remains inadequate, the surgeon should close the wound and delay the operation.

Inflammation

Acute and chronic inflammation are common sequelae of ocular trauma. Severe uveitis may mimic infectious endophthalmitis. Fibrin membranes on the iris lead to synechiae formation, pupil seclusion, and miosis; these are treated with pupil-enlarging maneuvers (described previously in the section Small Pupil). In an inflamed eye, a peripheral iridotomy can help prevent pupillary block glaucoma. Inflamed uveal tissue bleeds upon the slightest manipulation. OVD should be used liberally to protect the corneal endothelium and to improve visualization of the anterior segment. Postoperative IOP elevation is typical and is exacerbated by the use of OVDs. Control of inflammation warrants cycloplegia and intensive topical and possibly oral corticosteroid therapy.

Retained Foreign Matter

A foreign body in the AC may be easier to see when the patient is seated upright at the slit lamp rather than positioned supine under the operating microscope. Irrigating solutions may dislodge a foreign body from its preoperative location. When an intraocular foreign body is suspected to be located in the posterior segment, indirect ophthalmoscopy is a viable option, provided ocular media are sufficiently clear. When the view is obscured by cataract or hemorrhage, a computed tomography (CT) scan, x-ray, or ultrasonogram can help the clinician determine the presence and location of the foreign body. Magnetic resonance imaging (MRI) is contraindicated if the foreign body is potentially metallic. A dense cataract may be removed by either a pars plana or an anterior approach, followed by pars plana vitrectomy and removal of the foreign body.

Cataract in an Eye With Damage to Other Ocular Tissues

Iris trauma commonly coexists with traumatic cataract (Fig 12-11). Sphincter ruptures result in irregular pupil size and shape. The surgeon can repair iridodialysis at the time of

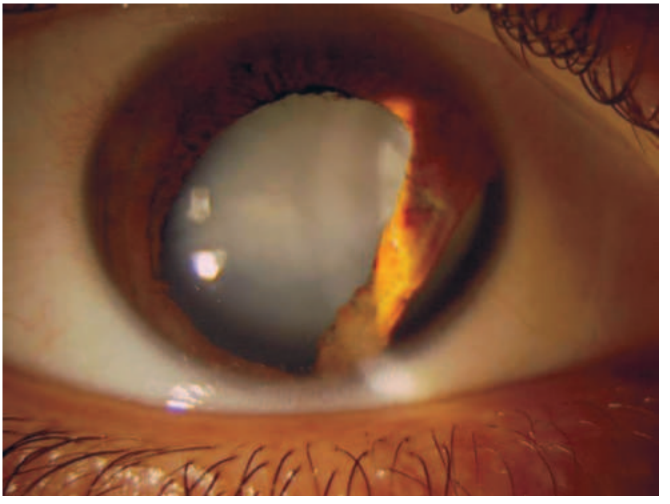


Figure 12-11 Traumatic cataract and iridodialysis secondary to a paintball injury. *(Courtesy of Mark H. Blecher, MD.)*

cataract removal by suturing the iris root to the scleral spur. Though not apparent on slit-lamp examination, corneal endothelial damage can be significant and may not manifest until after surgery, when severe corneal edema occurs. Preoperative specular microscopy can be helpful in determining the status of the corneal endothelium and its ability to withstand cataract surgery. Trauma sufficient to cause iris tears and cataract warrants careful inspection for zonular damage and insult to the posterior segment. If a retinal detachment is present, cataract removal may be necessary to allow adequate visualization for subsequent surgical repair.

Removal of Traumatic Cataract

A traumatic cataract may leak lens protein into the aqueous and vitreous, inciting uveitis and glaucoma. If cortical material is identified in the AC or if a mature cataract interferes with the diagnosis and treatment of injuries in the posterior segment, prompt removal of the cataract is warranted. Rupture of the capsule causes rapid hydration of the lens cortex, leading to formation of a milky-white cataract. This type of cataract is usually soft and can be aspirated through the large port of the irrigating/aspirating handpiece. It is important to be aware of the possibility of preexisting capsular rupture, which may not be visible on preoperative examination. In these cases, hydrodissection is best performed slowly to minimize the possibility of extending a capsular break and causing the lens to fall into the posterior segment.

If a hard nuclear cataract was present before the trauma, the surgeon employs techniques for cataract removal described in the earlier section, Zonular Dehiscence With Lens Subluxation or Dislocation. An OVD can be used to provide a tamponade to anterior vitreous movement in areas of zonular incompetence. If vitreous has migrated into the anterior chamber, an anterior vitrectomy is performed before removal of the lens to avoid vitreous manipulation and retinal traction.

When the nucleus is substantially subluxed and vitreous fills much of the AC, the surgeon can consider a pars plana lensectomy, in collaboration with a retinal surgeon (see BCSC Section 12, *Retina and Vitreous*).

Vision Rehabilitation

After ocular trauma, primary implantation of a posterior chamber lens is recommended, provided intraocular inflammation and hemorrhage are minimal and the view of anterior segment structures is good. An ACIOL or fixated posterior chamber lens may be necessary if there is inadequate capsular support for a PCIOL. In rare situations, the surgeon may decide against placing an IOL primarily and instead insert an IOL as a secondary procedure after sufficient evaluation of the anterior segment and anterior angle anatomy. Alternatively, the eye may be left aphakic and managed with a contact lens. Scarring from a corneal laceration changes the contour of the cornea, and inaccurate keratometry and biometry measurements can result in erroneous IOL power selection, increasing the risk of postoperative anisometropia. A rigid contact lens may be required to mask irregular astigmatism from a corneal scar.

IOL Selection After Trauma

The clinician tailors the lens implant to the patient's ocular anatomy and to the desired postoperative outcome. In patients with a history of uveitis, hydrophobic acrylic IOLs are preferred to silicone lens implants because vision-impairing inflammatory debris is more likely to collect on the surface of silicone lens implants (see Fig 12-10). Silicone lens implants are also not preferred in eyes that are likely to undergo vitreoretinal surgery in the future. In eyes with traumatic zonulopathy, capsular support devices should be considered (see section on zonular dehiscence previously in this chapter). Ultimately, the choice of IOL is determined by the surgeon's experience with lens options and implantation methods.

Additional Materials and Resources

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Basic Texts and Additional Resources

Agarwal S, Agarwal A, Agarwal A, et al, eds. *Phacoemulsification.* 3rd ed. Taylor & Francis; 2004.

Blumenthal M, Kansas P. *Small Incision Manual Cataract Surgery.* Highlights of Ophthalmology International; 2004.

Buratto L, Brint S, Romano M. *Cataract Surgery Complications*. Slack; 2012.
Buratto L, Werner L, Zanini M, Apple D. *Phacoemulsification: Principles and Techniques.* 2nd ed. Slack; 2003.
Chang DF, Lee BS, Agarwal A, eds. *Advanced IOL Fixation Techniques: Strategies for Compromised or Missing Capsular Support.* Slack; 2019.
Chang DF. *Phaco Chop and Advanced Phaco Techniques: Strategies for Complicated Cataracts.* 2nd ed. Slack; 2013.
Fishkind WJ. *Phacoemulsification and Intraocular Lens Implantation: Mastering Techniques and Complications in Cataract Surgery.* 2nd ed. Thieme; 2017.
Fry LL, Garg A, Guitérrez-Camona F, Pandey SK, Tabin G, eds. *Clinical Practice in Small Incision Cataract Surgery.* Taylor & Francis; 2004.
Garg A, Fine IH, Alió JL, et al, eds. *Mastering the Techniques of Advanced Phaco Surgery.* Jaypee Brothers Medical Publishers; 2008.
Garg S and Koch DD. *Steinert's Cataract Surgery.* 4th ed. Elsevier; 2023.
Henderson BA, ed. *Essentials of Cataract Surgery.* 2nd ed. Slack; 2014.
Henderson BA, ed. *Manual Small Incision Cataract Surgery.* Springer; 2016.
Kohnen T, Koch DD, eds. *Essentials in Ophthalmology—Cataract and Refractive Surgery.* Springer-Verlag; 2010.
Olsen RJ, Jin GJC, Ahmed IK, Crandall AS, Cionni RJ, Jones JJ. *Cataract Surgery from Routine to Complex: A Practical Guide.* Slack; 2011.
Seibel BS. *Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery.* 4th ed. Slack; 2004.
Tasman W, Jaeger EA, eds. *Duane's Ophthalmology on DVD-ROM*. Lippincott Williams & Wilkins; 2012.
Wilson ME, Trivedi RH, eds. *Pediatric Cataract Surgery: Techniques, Complications, and Management.* 2nd ed. Lippincott Williams & Wilkins; 2014.
Zhang F, Sugar A, Arbisser LB. *The Art of Refractive Cataract Surgery: For Residents, Fellows, and Beginners*. Thieme; 2022.

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Study Questions

Please note that these questions are not part of your CME reporting process. They are provided here for your own educational use and for identification of any professional practice gaps. The required CME posttest is available online (see "Requesting Continuing Medical Education Credit"). Following the questions are answers with discussions. Although a concerted effort has been made to avoid ambiguity and redundancy in these questions, the authors recognize that differences of opinion may occur regarding the "best" answer. The discussions are provided to demonstrate the rationale used to derive the answer. They may also be helpful in confirming that your approach to the problem was correct or, if necessary, in fixing the principle in your memory. The Section 11 faculty thanks the Resident Self-Assessment Committee for developing these self-assessment questions and the discussions that follow.

1. What systemic disorder increases the likelihood of developing a cataract?
   a. multiple sclerosis
   b. diabetes mellitus
   c. hypercholesterolemia
   d. ischemic cardiovascular disease

2. Where are the oldest layers of the lens located?
   a. capsule
   b. cortex
   c. epinucleus
   d. endonucleus

3. How is metabolic waste removed from the crystalline lens?
   a. It is broken down by lysosomes.
   b. It is removed by the venous system of the lens.
   c. It is stored in the lens and not removed, contributing to the increase in lens size throughout life.
   d. It is removed via the aqueous humor.

4. What common function do superoxide dismutase, catalase, and glutathione peroxidase have in lens physiology?
   a. adjust pH to act as a buffer
   b. control enzymatic functions in glucose metabolism
   c. convert water-soluble proteins to water-insoluble proteins
   d. protect against oxidative and free radical damage

5. What carbohydrate metabolism–related change occurs in the lens in the presence of high levels of glucose?
   a. Aldose reductase activity increases.
   b. Glucose that is not phosphorylated to glucose-6-phosphate (G6P) enters the Krebs cycle.
   c. The hexose monophosphate shunt is deactivated.
   d. Sorbitol is eliminated from the lens via simple diffusion through the capsule into the aqueous humor.

6. The lens has higher levels of what electrolyte in comparison to the surrounding aqueous and vitreous humors?
   a. chloride ions (Cl^-)
   b. potassium ions (K^+)
   c. sodium ions (Na^+)
   d. calcium (Ca^{2+})

7. With what congenital disorder is microspherophakia most commonly associated?
   a. Axenfeld anomaly
   b. Axenfeld-Rieger syndrome
   c. galactosemia
   d. Weill-Marchesani syndrome

8. What is the most common cause of acquired ectopia lentis?
   a. aniridia
   b. trauma
   c. Marfan syndrome
   d. Homocystinuria

9. Glaukomflecken are seen on examination. What is the histologic finding and most likely clinical scenario?
   a. endothelial cells associated with Cogan-Reese syndrome
   b. gray-white fibrillar material from pseudoexfoliative glaucoma
   c. macrophages engorged with phagocytosed proteinaceous, eosinophilic lens material from phacolytic glaucoma
   d. necrotic lens epithelial cells (LECs) and degenerated subepithelial cortex following angle-closure glaucoma

10. A 14-year-old female patient with atopic dermatitis has experienced decreased vision in both eyes. Her best-corrected visual acuity (BCVA) is 20/100 OD and 20/80 OS. What is the most likely cause of her decreased vision?
    a. anterior subcapsular cataract
    b. dry eye syndrome
    c. cystoid macular edema
    d. lens subluxation

11. A 47-year-old female vegan web developer spends 16 hours per day working on the computer, takes high-dose vitamin C supplements, and drinks an average of 3 glasses of wine each evening. She describes gradual, progressive bilateral blurry vision and has visually significant nuclear cataract in both eyes. Which of her lifestyle habits predisposed her to early cataract development?
    a. prolonged computer use
    b. veganism
    c. vitamin C supplementation
    d. alcohol consumption

12. After an episode of uveitis, what is the minimum amount of time, ideally, that the eye should be free from inflammation, without the use of topical corticosteroids, before cataract surgery is performed?
    a. 1 week
    b. 1 month
    c. 2 months
    d. 3 months

13. A patient with nystagmus has visually significant cataract and would like to undergo cataract surgery. He is capable of lying flat for surgery and prefers not to undergo general anesthesia. Aside from general anesthesia, what type of anesthesia would provide the best akinesia for his cataract surgery?
    a. intracameral anesthesia
    b. sub-Tenon anesthesia
    c. peribulbar anesthesia
    d. retrobulbar anesthesia

14. A patient with high axial myopia and regular against-the-rule astigmatism underwent uncomplicated cataract surgery with a toric intraocular lens (IOL). She was very pleased with her uncorrected vision in the operative eye on postoperative day 1, so immediately resumed her work, which involves several hours of computer use per day. She also resumed walking 2 miles per day on postoperative day 2. At postpoperative week 1, she noticed a reduction in the clarity of her uncorrected vision and was found to have rotation of her toric IOL off-axis. What most likely contributed to her postoperative toric IOL rotation?
    a. against-the-rule astigmatism
    b. high axial myopia
    c. excessive visual tasking
    d. walking long distances

15. What layers of the lens are separated from each other during hydrodelineation?
    a. capsule and cortex
    b. cortex and the epinucleus
    c. capsule and the nucleus
    d. epinucleus and the endonucleus

16. What type of effect (ie, direct or indirect) does a peristaltic pump (or “flow pump”) of a phacoemulsification machine have on the aspiration flow rate (AFR) and vacuum?
    a. It directly controls the AFR and directly produces the vacuum level.
    b. It indirectly controls AFR and directly produces the vacuum level.
    c. It directly controls AFR and indirectly produces the vacuum level.
    d. It indirectly controls the AFR and indirectly produces the vacuum level.

17. In manual small incision cataract surgery (MSICS), how does the width of the external scleral incision compare to the internal corneal incision?
    a. The width of the external scleral incision is greater than the width of the internal corneal incision.
    b. The width of the external scleral incision is equal to the width of the internal corneal incision.
    c. The width of the external scleral incision is smaller than the width of the internal corneal incision.
    d. The proportion of the external scleral incision to the internal corneal incision depends on the density of the nucleus being expressed.

18. An ophthalmologist is performing a routine phacoemulsification when she notes that the remaining half of the nucleus has suddenly dropped through an open posterior capsule and appears to be suspended on the anterior vitreous face. What is the best next step?
    a. immediate withdrawal of the phaco instrument and any secondary instrument from the eye
    b. injection of an ophthalmic viscosurgical device (OVD) to stabilize the anterior chamber
    c. lollipopping the nucleus with the phaco tip in order to pull it into the anterior chamber
    d. vigorous irrigation with a balanced salt solution to flush the remaining nucleus into the anterior chamber

19. During phacoemulsification, the surgeon notes loss of anterior chamber depth; the eye becomes firm, and the patient reports feeling pain. What should the surgeon do next?
    a. Ask the anesthesiologist to increase the patient's intravenous pain medication.
    b. Decrease the infusion pressure and increase the aspiration rate.
    c. Prepare for a pars plana vitrectomy.
    d. Suture the wounds closed and examine the fundus.

20. An eye with extreme increased axial length may be susceptible to what intraoperative issue?
    a. higher risk of endothelial damage
    b. higher risk of iris prolapse
    c. higher risk of wound burn
    d. lens–iris diaphragm retropulsion syndrome (LIDRS)

21. If vitreous prolapse occurs, what is the recommended technique for anterior vitreous removal by an anterior segment surgeon?
    a. coaxial anterior vitrectomy through the main corneal incision
    b. complete vitrectomy and lensectomy through 2 pars plana incisions
    c. manual externalization and cutting of vitreous through the main corneal incision
    d. 2-port bimanual anterior vitrectomy with instruments through new limbal incisions or cutting instrument through pars plana

22. After cataract surgery, a patient presents with a high intraocular pressure (IOP). On examination, the anterior chamber is shallow, the IOL is in the capsular bag, and there is no space between the IOL and the posterior capsule. A laser peripheral iridotomy fails to deepen the chamber or lower the IOP. What is the next most appropriate treatment?
    a. cyclophotocoagulation
    b. cycloplegia and aqueous suppression
    c. surgical vitrectomy
    d. topical miotics and a second laser peripheral iridotomy

23. A 74-year-old male patient undergoes uncomplicated cataract surgery and has a round-edge IOL placed in the capsular bag. The anterior capsulorrhexis was noted to be smaller than the optic of the IOL that was placed. Following cataract surgery, the patient was on a longer-than-usual course of topical corticosteroid for prophylaxis against cystoid macular edema (CME) due to the patient's pre-existing epiretinal membrane. In postoperative month 3, he was noted to have a visually significant posterior capsule opacification (PCO). What put him at greatest risk of developing a PCO?
    a. advanced age
    b. size of the capsulorrhexis
    c. longer course of topical corticosteroid postoperatively
    d. round-edge IOL

24. In postoperative month 1 following uncomplicated cataract surgery with a 1-piece posterior chamber IOL (PCIOL), a patient notices a persistent dark crescent in the temporal visual field of the operative eye. Confrontation visual fields are full in both eyes, and results of a dilated fundus examination in the operative eye are normal. What is the most appropriate next step in management?
    a. Observation.
    b. Perform a Nd:YAG laser posterior capsulotomy.
    c. Perform reverse optic capture of the existing lens.
    d. Exchange the 1-piece PCIOL for a 3-piece PCIOL in the sulcus.

25. What criterion determines the type of intervention that should be performed for acute post–cataract extraction endophthalmitis, based on the results of the Endophthalmitis Vitrectomy Study (EVS)?
    a. amount of time that has passed since surgery
    b. degree of inflammation in the vitreous
    c. presence of intact posterior capsule
    d. visual acuity

26. A patient has decreased visual acuity secondary to CME 1 month after uncomplicated cataract surgery. What is the next most appropriate step in management?
    a. observation
    b. treatment with topical corticosteroids and/or NSAIDs
    c. intravitreal injection of corticosteroids
    d. intravitreal injection of vascular endothelial growth factor inhibitors

27. During phacoemulsification, the surgeon realizes that there are 3 clock-hours (90°) of zonular dialysis present. How should the surgeon proceed?
    a. Increase the bottle height and flow rate to maintain adequate anterior chamber depth.
    b. Close the corneal incision and convert to an extracapsular cataract extraction.
    c. Proceed with phacoemulsification and place an anterior chamber intraocular lens (ACIOL).
    d. Place a capsular tension ring or capsular hooks, complete phacoemulsification, and place a PCIOL.

28. What surgical step should be avoided in a patient with a posterior polar cataract?
    a. hydrodissection
    b. hydrodelineation
    c. Little capsulorrhexis rescue technique
    d. viscodissection with OVD

29. What complication is common in cataract surgery in a patient with nanophthalmos?
    a. endophthalmitis
    b. irregular astigmatism
    c. rhegmatogenous retinal detachment
    d. uveal effusion

30. For a patient with mild glaucoma and visually significant cataract, what is the average extent of IOP lowering that may be expected from phacoemulsification and IOL implantation?
    a. <10%
    b. 10%–34%
    c. 35%–49%
    d. >50%

Answers

1. **b.** Diabetes mellitus is associated with accelerated development of all age-related lens changes. The proposed pathophysiologic reasons for these changes are multifactorial, including increased lens hydration from sorbitol accumulation, glycation of lens proteins, and increased oxidative stress. Multiple sclerosis, hypercholesterolemia, and ischemic cardiovascular disease are not associated with increased risk for developing cataracts.
2. **d.** The oldest layers of the lens are located in the center of the lens, or the endonucleus. This occurs because the new lens fibers are laid down in the periphery of the lens, compacting the previously formed fibers in the center of the lens. The outermost fibers of the lens are therefore the newest and make up the cortex of the lens. Of note: though there is no morphologic difference between the cortex, nucleus, epinucleus, or endonucleus, these structures appear different and behave differently during surgery.
3. **d.** After fetal development, the lens has no blood supply or organelles and depends on the aqueous humor for removal of metabolic waste. Changes in lens size occur throughout life as the lens epithelial cells (LECs) at the equator continue to divide.
4. **d.** Superoxide dismutase, catalase, and glutathione perioxidase work together to destroy the superoxide anion (O_2^-), protecting the lens against oxidative and free radical damage. There are no known repair mechanisms for free radical damage to proteins or membrane lipids in the lens cortex. Glutathione acts as a major free radical scavenger, along with vitamin E and ascorbic acid, in the lens. These 3 enzymes have no effect on the pH of the lens and do not participate in the carbohydrate metabolism of the lens. Conversion from water-soluble proteins to water-insoluble proteins appears to be a natural (age-related) process in lens fiber maturation and does not involve an enzymatic function.
5. **a.** When glucose concentration increases in the lens, the sorbitol pathway is activated; aldose reductase, which is the key enzyme in this pathway, is increased. Glucose that is not phosphorylated to glucose-6-phosphate (G6P) enters the sorbitol pathway, not the Krebs cycle. The hexose monophosphate shunt is also stimulated when glucose concentration in the lens is increased. Sorbitol accumulates in the lens both because of a low rate of metabolism and poor lens permeability, promoting lens opacification.
6. **b.** The lens has higher concentrations of potassium (K^+) and amino acids than the surrounding aqueous and vitreous humors. The lens has lower concentrations of sodium (Na^+), chloride (Cl^-), and calcium (Ca^{2+}) compared with the surrounding aqueous and vitreous. Recall that the Na^+/K^+-ATPase is located on the anterior lens capsule and creates a gradient of elevated intralenticular K^+ and elevated extralenticular Na^+.
7. **d.** Microspherophakia, a developmental abnormality in which the lens is small in diameter and spherical, is most often associated with Weill-Marchesani syndrome. It can also be associated with a variety of diseases, including Peters anomaly, Marfan syndrome, Alport syndrome, Lowe syndrome, and congenital rubella. It is not associated with Axenfeld-Rieger syndrome, galactosemia, or Axenfeld anomaly.
8. **b.** Trauma is the most common cause of acquired lens displacement. Aniridia is associated with lens opacities, poor zonular integrity, and ectopia lentis, but it is an uncommon panocular syndrome. Marfan syndrome and homocystinuria are also associated with ectopia lentis, but they are inherited disorders and less common than trauma as etiology for lens displacement.

9. **d.** Glaukomflecken are composed of necrotic lens epithelial cells (LECs) and degenerated subepithelial cortex that result from prolonged elevated intraocular pressure (IOP), as in acute angle-closure glaucoma. Glaukomflecken are not associated with the other findings and scenarios presented. Pseudoexfoliation syndrome is a systemic condition that is characterized by the production and progressive accumulation of a fibrillar material in tissues throughout the anterior segment and in the connective tissue of various visceral organs.
10. **a.** Atopic dermatitis is associated with cataract formation in up to 38% of affected patients. The cataracts are most often bilateral, anterior or posterior subcapsular opacities that resemble shieldlike plaques and usually develop in the second or third decade of life. Dry eye syndrome, cystoid macular edema, and lens subluxation are not associated with atopic dermatitis.
11. **d.** Excessive alcohol consumption (more than 14 standard drinks per week for men and 7 standard drinks per week for women) increases the risk for nuclear cataract. Computer use, veganism, and vitamin C supplementation are not associated with cataract development. Other lifestyle habits that increase the risk of cataract are tobacco use (both smoked and smokeless forms), long-term exposure to sunlight (due to damage from ultraviolet radiation), and high-dose vitamin B supplementation (more than 10 times the recommended daily allowance).
12. **d.** Ideally, the eye should be quiet without the use of topical corticosteroids after an episode of uveitis for at least 3 months before cataract surgery in order to minimize the risk of complications from postoperative inflammation, such as iris adhesion to the lens implant and macular edema.
13. **d.** Retrobulbar anesthesia provides excellent akinesia and anesthesia. Though peribulbar and sub-Tenon anesthesia can also provide akinesia, these methods may not provide akinesis as complete as retrobulbar injection does. Intracameral anesthetic does not provide akinesia during surgery.
14. **b.** High axial myopia predisposed this patient to postoperative toric IOL rotation, due to both the larger capsular bag size and the thinner optics of the lower-spherical-power IOL needed for myopes. Alignment of the toric IOL to correct with-the rule astigmatism, not against-the-rule astigmatism, also increases the risk of postoperative rotation. Excessive visual tasking is not associated with postoperative toric IOL rotation. Though vigorous physical activity can increase the risk of postoperative toric IOL rotation, walking would not.
15. **d.** Hydrodelineation is used to separate the harder endonucleus from the softer epinucleus, allowing the epinucleus to cushion the posterior capsule during phacoemulsification. Hydrodissection, on the other hand, is used to separate the cortex from the lens capsule, not only loosening the lens–cortex complex, but also facilitating nucleus rotation during phacoemulsification.
16. **c.** A peristaltic pump directly creates flow with a set of rollers that move along flexible tubing, pushing fluid through the tubing. The pressure differential between the lower-pressure aspiration tubing and the higher-pressure anterior chamber creates a relative vacuum. Although a vacuum limit is set on the machine, the peristaltic pump does not directly produce the level of vacuum. Rather, it controls the aspiration flow rate (AFR), which indirectly produces vacuum. In contrast, a Venturi (or vacuum) pump directly creates the vacuum based on the Venturi effect. Direct control of vacuum level in the pump

cassette then indirectly produces flow (while the aspiration port is not occluded) by “pulling” on the fluid in the aspiration tubing. In the absence of significant occlusion, higher vacuum levels produce a faster AFR.

17. **c.** In manual small incision cataract surgery (MSICS), the scleral tunnel is shaped like a trapezoid, such that the external scleral incision is narrower than the internal corneal incision, allowing for the delivery of the nucleus while maintaining a self-sealing external incision. The density of the nucleus being expressed does not affect the relative widths of the external scleral incision and the internal corneal incision.
18. **b.** If capsule rupture occurs during phacoemulsification, lens fragments may enter the posterior segment. At the time of posterior capsule rupture, the surgeon should stabilize the anterior chamber by reducing the high fluid flow and vacuum levels and by compartmentalizing the vitreous with an ophthalmic viscosurgical device (OVD) before removing the phaco instrument. The surgeon should avoid immediate withdrawal of the phaco instrument from the eye because that would result in an outward pressure gradient, bringing more vitreous forward into the anterior chamber and outward toward the incisions. OVD can also be introduced posterior to a suspended nuclear fragment in an effort to float it anteriorly. Insertion of a second instrument or lens glide behind the nuclear remnant may help prevent the remnant from being dislocated into the vitreous, whereas attempts to impale the nuclear fragment with the phaco tip may force the fragment posteriorly by either the tip or the irrigation, as might also occur with an attempt to flush the fragment with vigorous balanced salt solution irrigation. Lollipopping the nuclear fragment with the phaco tip may force it back and may transect the fragment, exposing the aspiration port and increasing the risk of aspirating vitreous.
19. **d.** With a suprachoroidal hemorrhage, the eye typically becomes very firm, and the patient becomes agitated and reports having pain. The surgeon should immediately close the incisions and confirm the diagnosis by examining the fundus with an indirect ophthalmoscope or fundus lens. If the hemorrhage or effusion is significant, the operation should be postponed.
20. **d.** Eyes with very high axial lengths are at risk for lens–iris diaphragm retropulsion syndrome (LIDRS), in which a reverse pupillary block occurs, and the anterior chamber becomes very deep, causing pain. Eyes with lax zonular fibers are more prone to this issue. Lifting the iris off the capsule with a second instrument and lowering the infusion bottle might help correct this problem. Endothelial damage and iris prolapse are more commonly associated with small eyes. Wound burn is more commonly associated with dense nuclei.
21. **d.** The surgeon should avoid manually externalizing and cutting vitreous through the incision. A 2-port bimanual anterior vitrectomy can be performed with separate infusion and aspirating/cutting instruments inserted through new, properly sized limbal incisions. Alternatively, the aspiration/cutting instrument may be placed through a pars plana incision while irrigation is continued through the limbus. This directs flow posteriorly and reduces the amount of vitreous that migrates into the anterior segment, thereby decreasing vitreoretinal traction. Coaxial anterior vitrectomy is no longer recommended.
22. **b.** Malignant glaucoma (also known as ciliary block glaucoma, aqueous misdirection, or vitreous block) results from ciliolenticular block induced by anterior movement of the lens–iris diaphragm, poor vitreous fluid conductivity, and choroidal expansion. These factors result in a shallow anterior chamber and secondary elevation of IOP as a

consequence of angle obstruction. IOP remains elevated despite the presence of a patent iridectomy or iridotomy. Medical treatment consists of cycloplegia and aqueous suppression. Use of miotics is not recommended because they can worsen malignant glaucoma by exacerbating anterior displacement of the lens–iris interface. Surgical intervention consists of Nd:YAG laser irido-zonulo-hyaloidotomy or vitrectomy to disrupt the anterior vitreous face and vitreous–ciliary body interface.

23. **d.** The round-edge design of the IOL optic put the patient at greatest risk of developing a posterior capsule opacification (PCO). The truncated square-edge optic design of an IOL is associated with lower rates of PCO formation; however, this type of IOL can increase the chance of developing positive dysphotopsias and other optical reflections. Other factors that can increase the rate of PCO include: younger patient age, history of intraocular inflammation, pseudoexfoliation syndrome, a larger capsulorrhexis (such that the anterior capsule does not cover 360° of the IOL edge), incomplete cortical cleanup, more time elapsed since surgery, and the presence of silicone oil. There is no difference in PCO rates with prolonged use of topical corticosteroids or nonsteroidal anti-inflammatory drugs (NSAIDs).
24. **a.** This patient is describing a negative dysphotopsia, which is common in the early postoperative period, affecting approximately 15% of all patients. Negative dysphotopsias usually improve over time, due to anterior capsular opacification and neuroadaptation; therefore, observation is advised initially. Only 3% of patients report symptoms 1 year after surgery. For patients with persistent symptoms, surgery can be offered, either by reverse optic capture of the existing posterior chamber IOL (PCIOL) or placement of an appropriate PCIOL in the sulcus. Nd:YAG posterior capsulotomy is not indicated for the treatment of negative dysphotopsia.
25. **d.** As a result of the Endophthalmitis Vitrectomy Study (EVS) findings, immediate pars plana vitrectomy and antibiotic injections are recommended when the patient's visual acuity is light perception. When the visual acuity is hand motions or better, a less-invasive anterior chamber and vitreous biopsy for cultures, with subsequent intravitreal injection of antibiotics, is sufficient. Time passed since surgery, degree of vitreous inflammation, and presence of intact posterior capsule were not used to determine management in the EVS study.
26. **b.** Topical anti-inflammatory drugs are the typical first-line treatment for CME and may take up to 6 months to resolve chronic cystoid macular edema (CME). Spontaneous resolution of CME occurs in approximately 95% of cases but may take 3 to 12 months. Though intravitreal injections of corticosteroids or vascular endothelial growth factor inhibitors can be successful in treating chronic CME, these treatments are usually reserved for those cases not responding to topical treatment.
27. **d.** For a patient with 90° of zonular dialysis, management consists of continued phacoemulsification and capsular tension ring (CTR) placement. The timing of the CTR placement depends on the extent of the zonular compromise and the surgeon's preference. Placement of the CTR before completion of phacoemulsification stabilizes the capsule for further lens manipulation and extraction but makes cortical aspiration more difficult. Thorough cortical aspiration is easier if CTR placement is delayed until just before IOL insertion. However, there is a risk of extending the zonular dialysis if phacoemulsification is performed without adequate capsule support. The flow rate and bottle height should not be increased, because doing so could cause vitreous to prolapse through the dialysis

and into the anterior chamber. OVD may be used as a tamponade against the forward movement of vitreous in the area of the dialysis. Unless the situation were to deteriorate further, neither conversion to extracapsular cataract extraction nor use of an anterior chamber IOL (ACIOL) would be necessary.

28. **a.** Hydrodissection should be avoided in a posterior polar cataract due to the possibility of tearing the posterior capsule directly under the region of the posterior polar opacity, because the posterior capsule may be weak or absent in this area. Gentle hydrodelineation, however, can be performed in order to leave an epinuclear bowl to protect the capsule during nucleus removal. After nucleus removal, OVD can be used for viscodissection of the epinucleus from the capsular bag. The Little capsulorrhexis rescue technique is not contraindicated in this situation.
29. **d.** Nanophthalmos is a rare condition in which the eye is extremely short (axial length <20 mm) and the ratio of lens volume to eye volume is higher than normal. These eyes have shallow anterior chambers, narrow angles, and thickened sclerae, with little room for the surgeon to maneuver. Small-incision bimanual surgery is an alternative technique to consider. Intraoperative or postoperative uveal effusion is a unique hazard in nanophthalmic eyes. Maintaining positive pressure in the anterior chamber and limiting the length of the procedure help prevent intraoperative uveal effusion. Scleral windows should be considered as a prophylactic measure to treat uveal effusion. A sutured wound prevents hypotony from contributing to this complication postoperatively. Endophthalmitis, irregular astigmatism, and rhegmatogenous retinal detachments are not common complications in these patients.
30. **b.** Uncomplicated phacoemulsification surgery lowers IOP between 10% and 34%, though this decrease diminishes over time. It can therefore be considered as a stand-alone procedure in eyes with mild to moderate glaucoma. Microinvasive glaucoma surgery (MIGS) can also be performed at the time of cataract surgery to benefit patients with mild to moderate glaucoma. For more advanced cases of glaucoma and visually significant cataract, adjunctive filtration procedures may need to be considered at the time of cataract surgery. Staged procedures can also be considered (either the cataract or glaucoma procedure first, then the second procedure at later date).

Index

(*f* = figure; *t* = table)