Cataract Surgery and Intraocular Lenses: The State of the Art

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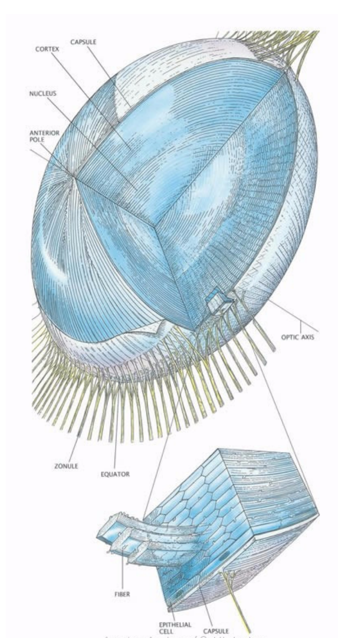
Anatomy & Physiology

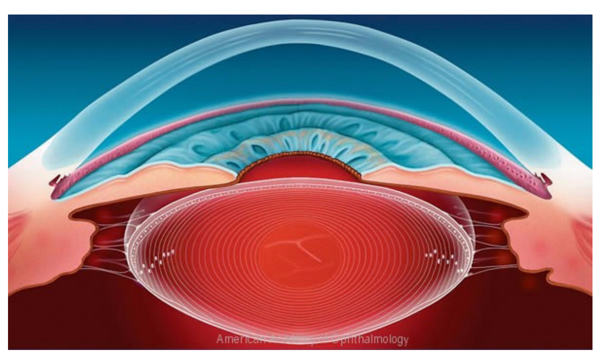
The human lens measures 6.4mm across and 3.5mm from anterior to posterior and weights about 90g at birth. The average adult lens measures 9mm across and 5mm from anterior to posterior and weighs around 255mg. However, the lens continues to grow throughout life.

The lens has no blood vessels (which is why it is clear and you can see through it), so it is dependent on the aqueous fluid for its metabolic needs. It is surrounded by an elastic, transparent **capsule** made of type 4 collagen, which is created by the lens epithelial cells. The capsule is thickest at its sides and thinnest posteriorly. The lens is suspended in place by numerous **zonules** that span from the ciliary body to the lens capsule.

Immediately beneath the capsule is a single layer of **lens epithelial cells**, which are metabolically active and generate new lens fibers. As the cells differentiate into lens fibers, they loose their organelles (nuclei, mitochondria, ribosomes, etc.), which makes them optically clear, but dependent on glycolysis for energy production.

As new fibers are laid down, the older fibers are pushed towards the center of the lens, called the **nucleus**. The outermost fibers are the most recently formed and make up the **cortex** of the lens. There is no morphologic distinction between these areas. However, we often refer to these areas during surgery as *cortex, epinucleus, and nucleus* depending on their behavior and appearance during surgical procedures.





The lens, along with the cornea, is responsible for focusing light into the eye. Of the 60D of refractive power needed to focus light onto the retina, 15-20D are contributed by the lens. In addition, the lens is able to change shape to allow for accommodation.

Aging of the Crystalline Lens

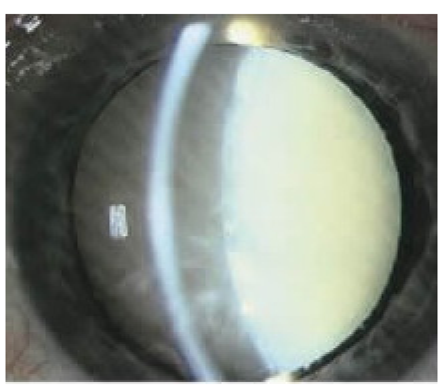
The relative thickness of the cortex increases with age. The lens adopts an increasingly curved shape so that older lenses have more refractive power. At the same time, the index of refraction decreases due to the presence of insoluble proteins. Therefore, the aging eye may become either more near-sighted or far-sighted depending on the balance of these opposing changes.

Etiology of Cataracts

Age-related cataract is multifactorial. As the new layers of cortical fibers are laid down, the lens nucleus becomes compressed and hard (***nuclear sclerosis***). As the nucleus becomes more dense, lens proteins are chemically modified and aggregate into high-molecular-weight proteins. These proteins tend to cause abrupt fluctuations in the refractive index of the lens and reduce transparency. In addition, the chemical modification causes the lens proteins to take on a yellow or brownish hue. Nuclear sclerosis typically occurs very slowly over time and may remain asymptomatic for years.

Changes in the hydration of the cortical fibers can lead to opacification, called ***cortical cataracts***. Early cortical changes are seen as *vacuoles*, small bubble-like pockets in the lens. Later changes cause the fibers to turn white, forming *cortical spokes*. When the entire cortex becomes white and opaque, the cataract is said to be mature. A *hypermature* cataract occurs when degenerated cortical material leaks through the lens capsule, leaving the capsule wrinkled. A *morgagnian* cataract occurs when further liquefaction of the cortex allows free movement of the nucleus within the capsular bag. Symptoms from cortical cataracts can vary widely, with glare and monocular diplopia being common.

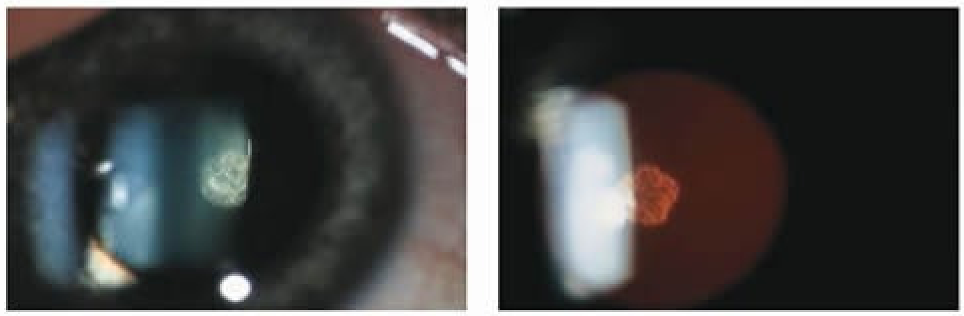
Vacuoles



Mature Cataract

Morgagnian Cataract

Posterior subcapsular cataracts (PSCs) form in the posterior cortical layer and usually occur in younger patients. The first sign is a subtle sheen against the posterior capsule at the slit lamp. Granular opacities then appear and eventually form a plaque-like opacity. PSCs tend to be more symptomatic, especially with glare under bright lighting conditions. Since we often measure visual acuity in a dark room, recording visual acuity with the room lights on may reveal much poorer vision than previously realized. PSCs can also occur as a result of trauma, corticosteroid use, inflammation, or radiation exposure. PSCs are best visualized with a dilated pupil using retroillumination.



Corticosteroid use is a common cause of cataract development. Long-term systemic (oral), topical, subconjunctival, intraocular and even topical nasal sprays can lead to PSC formation, and tends to be dose-dependent. One four-year study of patients treated with oral prednisone showed that 11% of patients treated with 10mg/day and 80% of patients treated with over 15mg/day developed cataracts.

Phenothiazines, a group of psychotropic medications that includes chlorpromazine and thioridazine, can cause pigmented deposits in the anterior lens epithelium. These changes are usually insignificant. Miotic use, amiodarone use and statins have also been implicated in cataract formations.

Trauma, both blunt and penetrating, can result in cataract formation. Trauma may also lead to zonular weakness or disinsertion of the zonules, which may make complicate surgery.

Disorders of metabolism can also cause cataracts, with diabetes mellitus being the most common. Galactosemia, hypocalcemia, Wilson Disease, and myotonic dystrophy can also lead to cataract formation.

Epidemiology of Cataracts

Cataract is the #1 cause of blindness worldwide. Cataracts cause reversible blindness in 17 million people worldwide; this is projected to reach 40 million by the year 2020. In the US, cataracts affect 1 out of every 6 people over the age of 40.

Cataract surgery is the single biggest expense of Medicare, with 1.6 million cataract procedures performed on Medicare beneficiaries in 2000 costing $3.4 billion. Related office visits and tests contribute further to the financial impact of cataracts.

Evaluation and Management of Cataracts

The following questions need to be answered during cataract evaluation:

1. Does the lens opacity correspond to the degree of visual impairment?
2. Will lens removal provide sufficient functional improvement to warrant surgery?
3. Is the patient sufficiently healthy to tolerate surgery?
4. Is the patient or another responsible person capable of participating in postoperative care?
5. Is the lens opacity secondary to a systemic or ocular condition that must be taken into consideration when planning surgery?

The most common indication for cataract surgery is the patient's desire for better vision. Functional vision complaints need to be documented prior to surgery.

- Trouble seeing street signs
- Trouble with night driving/night vision
- Trouble recognizing faces
- Trouble reading
- Trouble seeing the golf ball
- Glare in bright sunlight
- Haloes around lights at night
- Double vision that does not go away with covering one eye

Traditionally, Medicare and most insurance companies require a documented best-corrected visual acuity of 20/40 or less prior to surgery. Because many patients have significant visual problems prior to reaching this point, additional testing may help demonstrate a patient's difficulties. We generally measure visual acuity under ideal circumstances (dark room, high contrast). Brightness acuity testing (BAT) was developed to demonstrate glare. It consists of a small handheld light that helps simulate a sunny day. Another alternative is to measure visual acuity with the room lights on. If a patient who reads 20/25 with the lights off can only read 20/40 with the lights on, cataract surgery may be indicated.

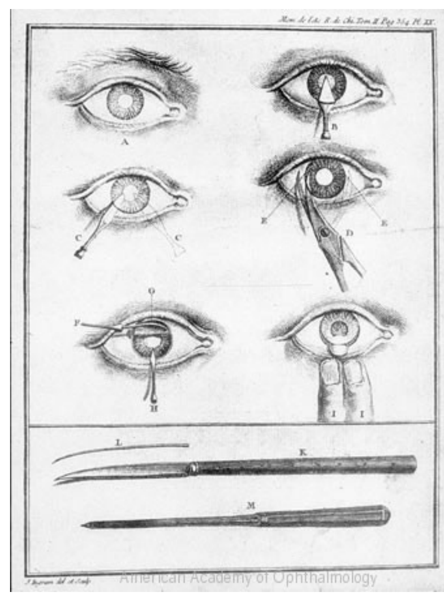
Cataract surgery is an elective procedure and need not be done until the patient requires it. Symptoms are dependent on visual requirements. An 80-year old patient living in a nursing home does not have the same visual needs as a 50-year old airline pilot or an active 90-year old playing golf every day. An asymptomatic cataract may need to be removed if it obstructs a clear view of the fundus in a patient who has a condition that requires monitoring (i.e. diabetics).

Surgery for Cataracts

<u>History of Cataract Surgery</u>

No one knows for sure exactly when the first cataract procedure was performed, but we know that surgeons in India were performing ***couching*** procedures in 800 B.C. Couching involves the use of a long needle which was placed through the sclera or clear cornea and used to dislocate the opaque cataract. A hollow version of a couching needle was described by Galen in the 2^{nd} century A.D. Ammar, an Iraqi ocularist, described the suction of a soft cataract through a hollow needle, a technique which gained popularity in the 12^{th} and 13^{th} centuries. In the middle ages, couching was looked down upon by physicians, as it was usually performed by itinerant couchers who left town before unhappy patients could complain. A couching procedure was considered a success if the patient was able to ambulate without assistance.

The first modern cataract procedure was performed by Jacques Daviel in 1751. He advocated the extraction of the cataract rather than dislodging it, and described the first ***extracapsular cataract extraction***. It was slow to be accepted due to the high rate of complications, inflammation, infection and blindness. It worked best when the cortex had already liquefied, thus starting the concept of a cataract being "ripe".

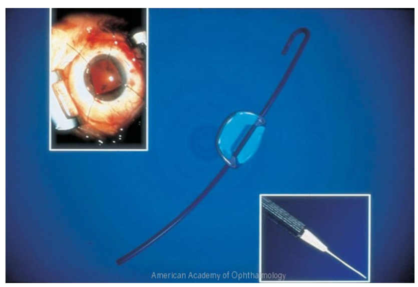


Because of the limited success of extracapsular techniques (removing the lens from within the capsule), **intracapsular cataract extraction** was developed. This involved removing the lens with the capsule intact. The chief problem with intracapsular techniques was how to break all of the zonules to remove the lens without causing secondary trauma. This was achieved a number of ways: mechanically breaking them with a muscle hook (Smith-Indian Operation), broken using gentle traction (Verhoeff and Kalt), using suction-cup like devices (Stoewer and Barraquer), using a cryoprobe to fixate the lens, or dissolving the zonules chemically (alpha-chymotrypsin). Intracapsular techniques had a high rate of success, but still had a 5% risk of potentially blinding complications. The development of the intraocular lens led to the end of intracapsular cataract extraction, as a method for lens fixation was needed.

Preoperative Considerations

Patients need to be able to lie flat without difficulty breathing. This can be an issue for patients with back pain or restrictive lung disease. Claustrophobic patients may need extra support and reassurance during surgery. Clear drapes and blowing air across the patients face during surgery may also be helpful. Patients who dilate poorly in the office may need additional dilating drops preoperatively or may need mechanical stretching of the iris during surgery. Patients on blood thinners generally do not need to stop them prior to cataract surgery.

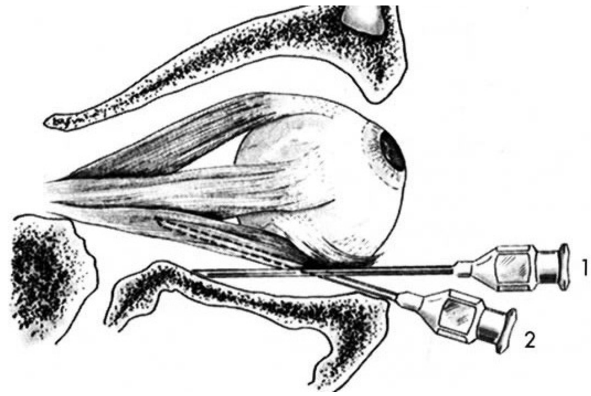
Patients on Flomax may develop Intraoperative Floppy Iris Syndrome (IFIS). During surgery, the pupil may not dilate well and may constrict. In addition, the iris has a tendency to exit through the wound, making visualization difficult. A number of pupil-fiaxating devices have been developed to assist.



Anesthesia for Cataracts

Most cataract surgery is performed with the patient awake, although general anesthesia may be used occasionally, especially on younger patients. Intravenous or oral sedation is often used in conjunction with retrobulbar, peribulbar, or topical anesthesia.

Retrobulbar blocks are given with a 1 ¼ to 1 ½ inch 25 gauge needle. A combination of lidocaine and marcaine is often used. The needle is passed through the lower eyelid, around the globe, with the goal of placing the needle in the retrobulbar space. This achieves both anesthesia and akinesia (inability to move the eye), but carries with it some risk of complications including retrobulbar hemorrhage, optic nerve trauma, and intradural injection.



Peribulbar blocks are given in a similar manner using either a short needle or using a blunt cannula. They are safer and give good anesthesia, but limited akinesia.

Retrobulbar and peribulbar blocks are often supplemented with eyelid blocks or facial nerve blocks to prevent eyelid squeezing during surgery.

Topical anesthesia can be achieved in a number of ways, but requires a cooperative patient. Topical proparacaine is helpful in initiating anesthesia, but is relative short-lived. Lidocaine has poor penetration into the eye on its own. Using topical 2% lidocaine jelly increases exposure time, but may block the surgical prep. Topical 4% lidocaine can also be used. Not all patients will have adequate anesthesia with topical alone. This can be supplemented by subconjunctival injection, or more commonly, intracameral 1% preservative-free lidocaine. The corneal endothelium is very sensitive to foreign substances – preservatives should never be injected into the eye. As a safety rule, solutions with preservatives should never be on the surgical field during surgery.

<u>The Day of Surgery</u>

Prior to surgery, patients start a regimen on antibiotic eye drops to reduce the risk of endophthalmitis. The goal is to reduce the number of bacteria present on the conjunctiva and eyelid. Some surgeons start antibiotics 1-3 days prior to surgery, while others start with a series of drops beginning the morning of surgery. Lid hygiene is also an important consideration. Aggressive pre-operative treatment of blepharitis combined with eyelid scrubs the morning of surgery may be useful. While these steps all make sense, no study has proved their efficacy. The only proven method to reduce the risk of endophthalmitis is a 5-minute exposure to 5% betadine solution. The bacteriocidal action of betadine is time-dependent, so the surgical prep cannot be rushed. Careful attention should be paid to the eyelashes, as this is the area of greatest bacterial density. In my opinion, the single most important step of cataract surgery is the surgical prep.

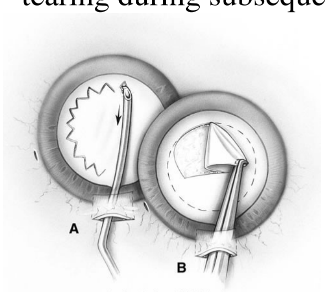
Upon the patient's arrival, the operative eye should be verified and marked. This should be verified by the surgeon and a timeout performed prior the procedure.

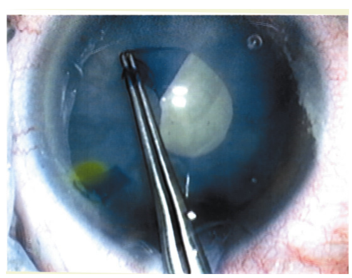
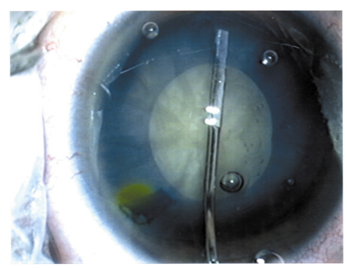
The lens chosen for surgery should be verified by the surgeon against the office chart and compared to the lens pulled for the case in the OR. In our center, we post the lens specifications for each patient at the start of the case. When the circulator opens the lens, the power and model of the lens is verified and repeated to the scrub tech. The scrub tech then repeats the power and model when handing it to the surgeon. Implanting the wrong lens can lead to costly litigation!

<u>Surgical Techniques</u>

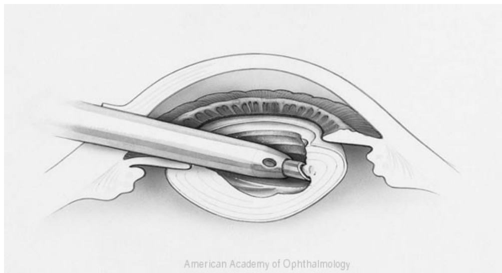
There are as many techniques for removing a cataract as there are surgeons. However, they all follow a basic pattern of steps.

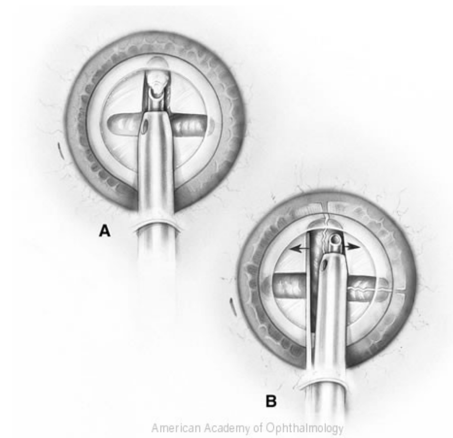
1. Paracentesis – the creation of a small incision into the cornea using a sharp blade. This is an entry port for secondary instruments and is usually made with the left hand (for right-handed surgeons).
2. Injection of Intracameral Lidocaine (if used) followed by viscoelastic to keep the eye firm.
3. Creation of the primary temporal clear cornea incision or superior scleral tunnel. This is the main incision that phacoemulsification will be performed through and the lens injected through.
4. Capsulorrhexis – tearing a circular hole in the anterior capsule using a needle and/or forceps. The continuous circular shape gives the capsule strength to resist tearing during subsequent steps of the procedure.

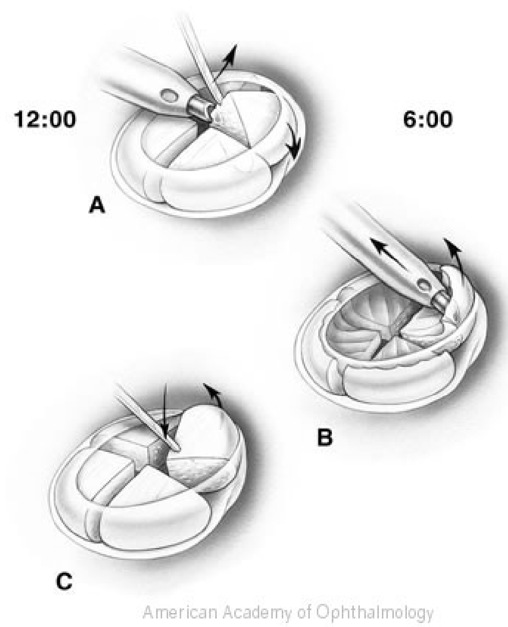


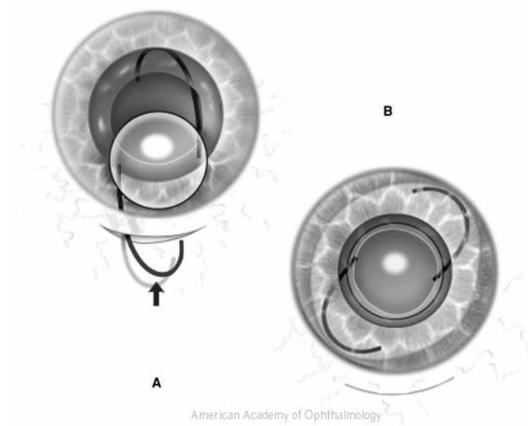
5. Hydrodissection and hydrodelineation – Injection of balanced salt solution underneath the capsule to separate the cortex from the capsule and a second injection to separate the nucleus from the cortex. A fluid wave is visible during this step.
6. Spinning the nucleus to ensure the hydrodissection step is complete.
7. Phacoemulsification of the nucleus using a variety of techniques. *Divide and conquer* refers to creating two channels in a "plus-sign" fashion and breaking the nucleus into four smaller pieces for subsequent removal. This is constrasted with *chopping*, which involves using a small instrument to break off small chunks of the nucleus, which are then removed. Most surgeons have one technique they rely on for most cases, but may use different techniques under special circumstances.







8. Irrigation and Aspiration (I&A) – removal of the soft cortex using suction alone. A second handpiece with smaller openings is used for this step to help prevent inadvertent tearing of the posterior capsule.
9. Injection of viscoelastic to help maintain the space where the lens is to be positioned (capsular bag vs. posterior sulcus).
10. Injection or insertion of the intraocular lens. Most lenses can be folded and injected or manually inserted into the eye. Some rigid lenses require the incision to be enlarged prior to insertion.



11. Removal of viscoelastic using the I&A handpiece. Viscoelastic materials can be left in the eye; however, they can cause elevated intraocular pressures post-op, so removal is generally desired.
12. Hydration of the wound and/or suture closure.
13. Testing of the wound to ensure a watertight seal.

Postoperative Care

If a patient received a block, a patch is placed to keep the eye closed until the block wears off. This prevents corneal drying from incomplete blinking and diplopia from inability to move the eye. If topical anesthesia was used, a pair of dark glasses are placed to protect the eye on the way home.

Most patients will use a combination of an antibiotic and steroid drop for the first week after surgery. After a week, the antibiotic is discontinued and the steroid is tapered off. Some surgeons also use a non-steroidal anti-inflammatory, although this is variable.

Patients should refrain from heavy-lifting following surgery for at least the first week. A shield is taped on at night to prevent accidentally rubbing the eye while asleep.

All patients should be warned about the symptoms of endophthalmitis, which are pain and decreased vision and should have instructions of how to get in contact with the surgeon should these develop.

Patients are typically seen in the office the next day, a week later and a month later. A new prescription for glasses is not given until one month appointment to allow the refraction to stabilize.

Postoperative Complications

The most common postoperative complication is **posterior capsule opacification** (PCO, after-cataract). Leftover lens epithelial cells continue to replicate after surgery and travel along the posterior capsule, causing a haze to form. Patients typically feel like their cataracts are "coming back" when this happens. It can occur anytime after surgery, but usually occurs in the first year or two. When this happens, a YAG laser can be used to cut a hole in the capsule, restoring vision. For patients who develop PCO soon after surgery, a laser capsulotomy should be delayed until 3 months post-op to allow sufficient scar tissue to fixate the lens properly. PCO occurs in up to 50% of patients.

Dry eye and foreign body sensation is common after surgery and can come and go over the first few weeks. Use of artificial tears is recommended for symptomatic relief.

Glare, haloes and light sensitivity are also common immediately after surgery, and will generally dissipate over the first few weeks to months.

Elevated intraocular pressure can occur following surgery. This is generally transient in nature and requires treatment only if severe or in the presence of a compromised optic nerve.

Wound leaks can occur leading to a low intraocular pressure. These are usually detected with the first few days after surgery. They can be treated with pressure patching, placement of a bandage contact lens, suturing, or using tissue glue.

Cystoid macular edema (CME) is swelling in the retina due to inflammation. As fluid collects, visual acuity decreases due to the additional thickness of the retina. CME manifests 4-6 weeks after surgery and is treated with anti-inflammatory drops. CME may take months to resolve, if severe.

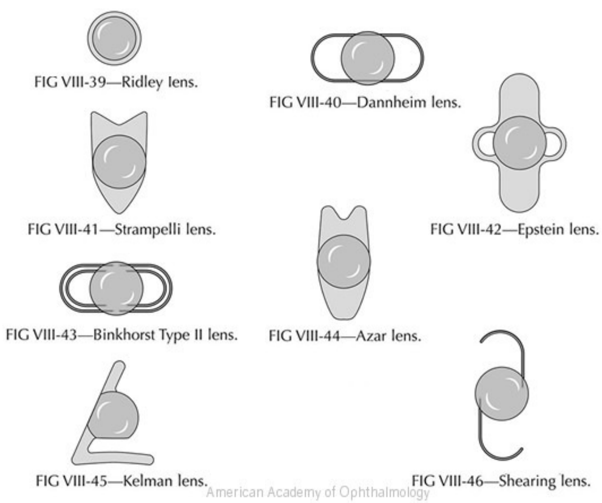
Endophthalmitis is the worst-case scenario. All patients should be aware of the warning signs of endophthalmitis, which is pain and decreased vision, and should know how to contact the doctor should these develop. The most common etiologic agents are staph and strep from the eyelashes. More virulent organisms can cause rapid vision loss. All endophthalmitis should be treated as an emergency condition, with prompt treatment. If vision is hand motion or better, an intravitreal injection of antibiotics is given. If light perception or no light perception, an emergent vitrectomy with intravitreal antibiotics is indicated. Cultures are often helpful in determining the origin. Sterile endophthalmitis can also occur. Endophthalmitis often occurs in groups and should prompt a review of sterilization techniques, instrument handling and the surgical prep.

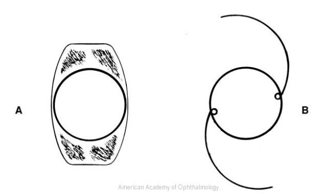
While many patients will recover from endophthalmitis, some will not recover useful vision and some will require removal of the eye. Fortunately, this is rare.

The Intraocular Lens

The first reported attempt at an intraocular lens was made by Casaamata in 1795 in Dresden. It was unsuccessful.

The modern intraocular lens was created by Sir Harold Ridley in 1949. He was a British ophthalmologist stationed in the Congo during World War II, who noticed that fragments of airplane canopies that had lodged inside the eyes of fighter pilots during crashes were relatively inert. He created a disc-shaped lens using the same material and implanted it in the posterior chamber following cataract extraction. His implant restored vision, but came with a high complication rate of glaucoma, uveitis and lens dislocation. His surgery was quite controversial among British ophthalmologists, which slowed development. A number of anterior chamber lenses were then developed over the years. It wasn't until the late 1970's/early 1980's that intraocular lenses became the standard of care.





The first IOL was made from poly-methyl-methacrylate (PMMA). Modern lenses are made from either silicone or acrylic materials.

Lenses can be divided into where they are placed inside the eye.

Anterior chamber (AC) lenses are placed in front of the iris behind the cornea. Early AC lens designs worked well, but had a high rate of complications (glaucoma, uveitis, corneal decompensation). New AC lenses have become much safer, especially if properly sized.

Posterior chamber (PC) lenses are generally preferred for their superior visual quality. Posterior chamber lenses can be placed in the posterior sulcus, the space between the iris and the anterior lens capsule, or in the capsular bag (preferred). In cases where there is inadequate capsule to fixate the lens, the lens may be fixated to the sclera or to the iris with sutures.

Refinements in IOL technology have continued over the years, resulting in a variety of lenses that may be an option. Any IOL will yield excellent postoperative vision with a good pair of glasses. The main difference between the various lenses is *uncorrected vision.*

Monofocal IOLs are currently the most commonly implanted lenses. With a monofocal IOL, patients can have good *uncorrected* distance vision OR good near vision, but not both. Most patients choose to see clearly at distance and then wear over-the-counter reading glasses to see up close. Some patients who are nearsighted choose to remain nearsighted so that they can read without their glasses, in which case, they require glasses to see clearly at distance.

For patients with astigmatism (corneal distortion), **Limbal Relaxing Incisions (LRIs)** are used to reduce the amount of astigmatism after surgery. These are extra partial-depth incisions made into the cornea to relax corneal curvature in the steep axis.

Monofocal Toric IOLs are specially designed to treat higher levels of astigmatism that are not otherwise treated by conventional lenses. For patients with significant astigmatism, these lenses may give the best *uncorrected* distance vision following surgery.

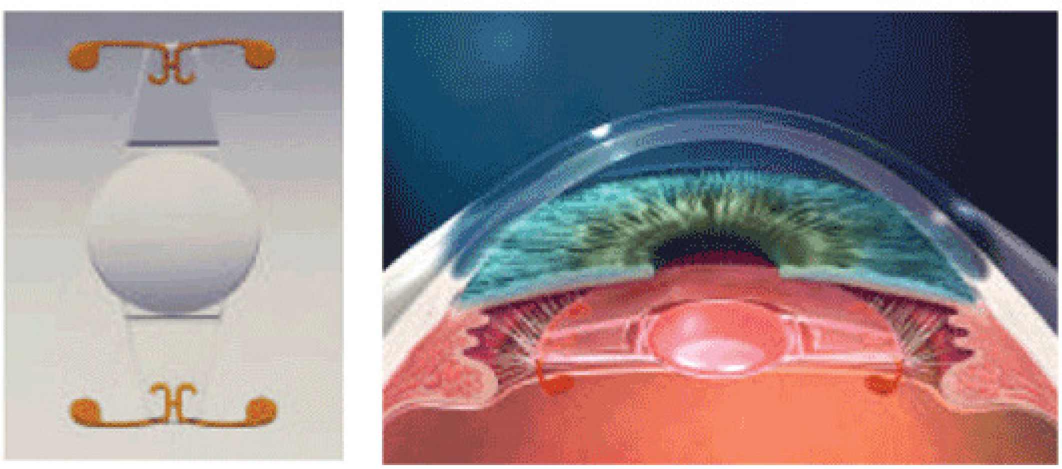
Staar Toric IOL

Alcon Acrysof Toric IOL

Multifocal and Pseudo-accommodating IOLs (ReStor, ReZoom, Crystalens) are designed to provide both distance and near vision. Rather than having a single focal point, they have a range of focus. In selecting patients for the right lens, it is helpful to divide vision into three “zones of vision”: Distance, Intermediate and Near.

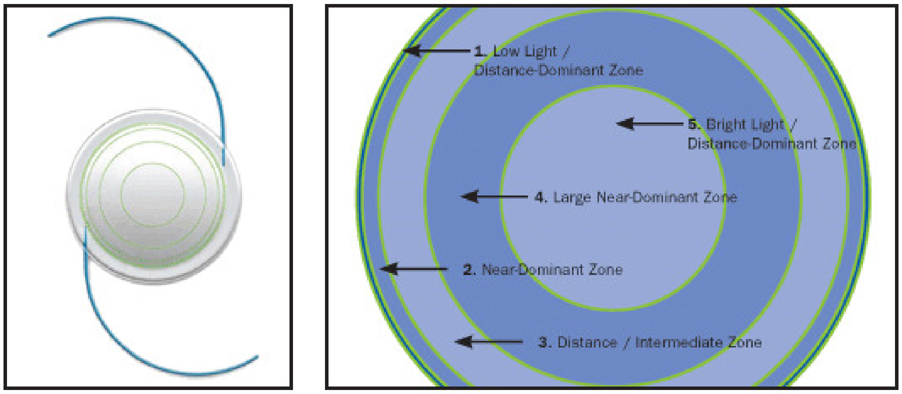
Zone of Vision:	*Used for:*
Distance	Driving Watching TV/Plays/Sporting Events
Intermediate	Using a computer Reading labels on a shelf
Near	Reading Putting on Makeup Shaving

Crystalens is a single-vision lens with built in hinges so it can move inside the eye, allowing the focal point to move in response to accommodative forces. Following implantation, the patient must do eye exercises to achieve good near vision. Patients will smaller eyes (hyperopic) generally do well.



The **Crystalens**® (L) and shown implanted (R)

ReSTOR and *ReZoom* are multifocal lenses which do not move inside the eye. Their primary difference is in the “add power” designed into the lens. ReZoom gives good distance and intermediate vision, while ReSTOR gives good distance and near vision.



The **ReZOOM™** lens (L) and magnified (R)

The **ReSTOR®** lens (L) and magnified (R)

These lenses are not perfect, and some patients still require glasses for certain tasks. Since these lenses do not correct for astigmatism, some patients require LRIs at the time of surgery or even a LASIK treatment (Laser Vision Correction) 3-6 months after surgery. Vision with these lenses improves over time, and it can take up to 6 months for best results.

A landmark decision by Medicare in May 2005 allows us to offer Toric and Multifocal IOLs to Medicare patients, even though they are not covered under the Medicare program. Generally, Medicare will cover the cost of the surgery and the cost difference for the toric or multifocal lens will be billed to the patient. Most insurance carriers do not cover the cost of these “Premium Lenses”.