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Lens and Cataracts
by Tim Root, M.D.

If you hang out with an ophthalmologist long enough, you’re going to be dragged into surgery at some point. Cataract surgery is our signature operation, so it’s worthwhile to familiarize yourself with basic lens anatomy and surgical goals.

The eye is the most amazing organ in the human body, and the lens is one of the most impressive structures within it! Not only is the lens the densest tissue in the body (highest protein content and lowest water percentage), it also remains optically clear for years despite constant bombardment by light radiation. The lens can even use it’s mighty-morphing transformer powers to change shape and thus it’s focusing power! Not bad, eh?

Some Cataract Terminology

Phakic: When you have your natural lens

Pseudophakic eye: When a cataract is replaced with an artificial lens

Aphakic eye: When a cataract is removed but isn’t replaced.

Lens Anatomy

We can’t go any further in our discussion without first describing the anatomy of the lens and how it sits in the eye. When conceptualizing the structure of the lens, you may find it useful to think of it like a yummy peanut M&M candy. Thus, there is an outer capsule like a “hard candy shell” that surrounds the lens. Inside you’ll find the chocolate layer (the lens cortex) and the inner nut (the hard lens nucleus). These three layers are clear, of course, but that’s the general layout.

Cataracts can form at different layers within the lens, and the location can give you clues to the causative insult and explain specific visual complaints. The lens layers become even more relevant during surgery – with cataract extraction, we tear a round hole through the anterior capsule, suck out the cortex and nucleus (the chocolate and the peanut), and inject a prosthetic lens into the remaining capsular bag.
Now, we know the structure of the lens and we know the lens sits behind the iris … but what keeps the lens from falling into the back of the eye? The lens is actually suspended behind the iris by zonular fibers. These zonules attach at the equator of the lens like trampoline springs and connect the lens to the surrounding ciliary body. The ciliary body is a ring of muscle sitting behind the iris. Trauma and surgical mishaps can break the zonules and cause the lens to de-center or even fall into the back of the eye.

**Accommodation**

Now, I just said that the lens is suspended by spoke-like zonules to the ciliary body. But what is this mysterious ciliary body? The ciliary body is a ring of muscle that sits directly underneath the iris. You can't see it directly by standard exam without using mirrors, but this ciliary body is important for two reasons: it produces the aqueous fluid that nourishes the eye and it controls lens focusing.

The ciliary muscle can be thought of as a camera diaphragm, or if you prefer a more entertaining description, a sphincter muscle. When this sphincter contracts, the central “hole” gets smaller causing the zonular “springs” to relax. With zonular relaxation, the lens relaxes and gets rounder. This rounding makes the lens more powerful and allows you to read close-up.
Unfortunately, as we age our lens becomes harder and does not "relax" into a sphere very well, no matter how hard the ciliary body contracts. This loss of lens accommodation is called presbyopia and explains why we need the extra power of bifocals to read after the age of 40.

**Fun Fact**

Ever wondered how those “blue blocker” sunglasses are supposed to improve vision? You know, those yellow-tinted glasses that sport enthusiasts and hunters wear?

They work because all lens systems, including the eye, suffer from some degree of chromatic aberration. This occurs because some wavelengths of light are bent more when going through a lens or prism system. Red light is bent the least, so the color red tends to focus slightly behind the retina, while blue light bends more, thus focuses in front of the retina. This creates a mild blur because not all colors can be perfectly focused at the same time.

Yellow-tinted glasses only allow certain wavelengths to pass through. This eliminates chromatic aberration and the image appears sharper.

**Cataract Types and Mechanism:**

The lens begins as a clear magnifying glass inside your eye, but with time can opacify. Most cataracts are of idiopathic etiology, though there are many associated conditions that lead to both congenital and environmentally induced lens opacities. Here is a short summary of the important cataract types:

**Nuclear sclerotic cataracts**

NSCs are the most common type of cataract and many consider them to be a normal maturation of the lens. Over time, the lens becomes larger and brunescent (yellow or brown), especially in the denser central nucleus. If this process goes on long enough the opacity eventually leads to visual obstruction and problems with glare. The lens can become so big that it pushes the iris forward, placing the patient at increased risk for angle closure glaucoma.

With far-advanced cataracts the middle cortical layer (the chocolate layer) can liquefy and become milky white and the nucleus layer (the central peanut) gets hard and falls to the bottom of the capsular bag. These end-stage “Morgagnian cataracts” are rarely seen in this country and are particularly hard to remove at surgery.
Some patients with nuclear sclerotic cataracts will develop so called “second sight” where it seems like the vision improves. This is because the round cataract lens is more powerful and offsets the coexisting presbyopia allowing older patients to read better. Their vision hasn’t really improved, it’s just that their cataracts are working like weak bifocals inside their eyes.

**Posterior Subcapsular Cataract:**
The PSC cataract forms on the back of the lens, on the surface of the posterior capsule bag. These cataracts tend to occur in patients on steroids, with diabetes, and those with history of ocular inflammation. The opacity looks like breadcrumbs or sand sprinkled onto the back of the lens. This posterior location creates significant vision difficulty despite appearing innocuous on slit-lamp exam. PSC cataracts are quite common, and often occur in conjunction with some degree of NSC.

**Location is Everything!**

Posterior cataracts cause more visual complaints than anterior cataracts. This is because of the optics of the eye. Advanced optics are beyond the scope of this book. Keep in mind, though, that the eye has an overall refractive power of approximately 60 diopters (40 from the cornea, and 20 from the lens). If you simplify the eye to a single 60-diopter lens system, the important “nodal point” of this system is near the back of the lens.

The closer you get to this nodal point, a greater number of light rays will be affected. Thus, small posterior cataracts are more significant than larger anterior cataracts.

**Congenital Cataracts:**
Lens opacities in children are of concern because they can mask deadly disease (remember the differential for leukocoria from the pediatric chapter?), and because they have devastating effects on long term vision.

Cataracts in the newborn can be idiopathic or inherited. If small or anteriorly located, they may be visually insignificant. However, when approaching a leukocoric pupil, you should first rule out potentially deadly disease. This
includes cataract masqueraders like retinoblastoma, and deadly causes of cataract like the TORCH infections and galactosemia.

A true cataract needs to be removed quickly, usually within the first two months of life, because they are highly amblyogenic. Cataract surgery is challenging in this age-group as children have impressive inflammatory responses and are not easy to examine pre- and post-operatively. After taking the cataract out, you usually don’t implant a prosthetic implant in newborns, but wait a few years because their eyes are still growing. The family must deal with powerful aphakic glasses or contact lens placement until the child is old enough for the secondary lens implantation.

**Traumatic Cataract:**

A cataract can form after blunt or penetrating injuries to the eye. These traumatic cataracts are more common in young men. When the outer lens capsule breaks, the inner lens swells with water and turns white. The lenses are very soft and easy to suck out, but removal and implant placement can be complicated as the blunt force often tears the zonular support. If the lens is barely hanging in position, it may be safer to consult a retina specialist to remove the cataract from behind (a pars plana approach) to keep the lens from falling back into the eye.

**Lens-Swelling**

The cells that make up the adult lens have no innervation or blood supply, and thus derive their nutrition entirely from the surrounding aqueous fluid. Because of this low O2 tension, these lens cells survive almost entirely on glycolysis.

Poorly controlled diabetics can have very high levels of glucose. If high enough, the lens metabolism can shunt down a sorbitol pathway. Sorbitol buildup in the lens can then create an osmotic swelling of the lens with resulting refractive changes!

If a diabetic patient complains of episodic blurring vision, find out what their glucose has been running. If it has been high recently, don’t prescribe glasses, as their prescription may still be changing from lens swelling.

**Posterior Capsular Opacification (PCO):**

A posterior capsule opacification isn’t a true cataract, but an “after cataract” that forms after a cataract surgery. I’ll be talking about the cataract surgery technique shortly, but basically we suck out the cortex and nucleus (the chocolate and the peanut) and inject a new lens into the remaining capsule (the hard candy shell).
Residual lens epithelial cells are left behind after surgery. These orphaned epithelial cells get confused (and lonely) and can migrate along the back surface of the implant and opacify the posterior capsular bag.

This is a common occurrence and fortunately is easily treated in clinic with a laser. The YAG laser is used to blast a hole in the posterior capsule. We don’t break a large hole, as you don’t want the implant to fall into the back of the eye, but one big enough to clear the visual access. This procedure is known as a YAG capsulotomy.

One more topic ... Lens Dislocations
As already mentioned, a lens can dislocate from traumatic force (such as a punch to the eye). It can also dislocate because of inherited diseases that affect zonular strength. The two major causes of hereditary lens dislocation are Marfan's syndrome and homocystinurea.

Marfan’s disease is an autosomal dominant disease of fibrillin. These patients have tall body habitus, arachnodactyly and can have lens subluxation with the lens dislocating upwards. This can create large astigmatism as the patient is looking through the edge of the lens, and may eventually require cataract extraction.

Homocystinurea is an autosomally recessive hereditary disorder that results in an absence of cystathionine B-synthetase. This enzyme causes the conversion of homocysteine to cystathionine. These patients have a marfanoid habitus, arachnodactyly, and there is a 50% incidence of mental retardation. The lens zonules are largely composed of cysteine, and without good cysteine, the zonules become brittle and can break. The majority of these patients develop downward lens dislocations. They also have poor peripheral circulation and are subject to thromboembolic events under general anesthesia.

Some historians believe that Abraham Lincoln may have had Marfan's syndrome.
Is your patient “ripe” for surgery?

Most people over 50 have some degree of cataract in their lens. The question then becomes “should you have surgery or not.” This is not always a clear-cut choice: you will be amazed at the dense cataracts that patients are still able to see through, and conversely, the seemingly “wimpy cataract” that causes major visual complaints.

There is a saying in ophthalmology, "If you can see in, than the patient can see out." That is to say, if you can see the retina clearly with your ophthalmoscope, it is likely that the patient can see clearly through their lens. More objectively, we generally use 20/50 as a guideline for surgery as this is the minimal driving acuity in most states, but patients have different visual needs. A visual acuity of 20/30 is not acceptable for a young commercial airline pilot. Conversely, potentially life-threatening anesthesia might not be necessary for a 20/70 nursing home patient who likes jazz music and is happy with his vision.

Acuity isn’t everything:

One big complaint that people have is glare. In the dark a patient may see fine. But have them drive into the sun or at night with car headlights coming at them, and they become blinded by the scattering of light through their hazy lens. Many patients tell us that they no longer drive at night. We can test glare in the clinic by checking vision while shining a light in the eye. Also, you can formally test glare with the BAT (brightness acuity tester) device. This is a light-bulb illuminated hemisphere with a view hole that induces glare.

Another indication for surgery is the presence of underlying retinal disease such as advanced diabetic retinopathy. If a cataract interferes with careful fundus examination or laser treatment, the lens needs to come out.

Who decides?

Ultimately, it’s our patient’s decision whether to have surgery. In an ideal world without operative complications everyone should have cataract surgery as soon as the vision drops to 20/25. Unfortunately, bad things can happen in surgery, and patients have to decide if their vision is affecting their life enough to take the risk of surgery. Our job is to educate and inform our patients about these risks and their surgical options.
Cataract surgery – a historical prospective:

In Egyptian times, cataract surgery was a primitive affair. Eye “surgeons” would take a sharp needle and shove it into the eye to rip the lens from it’s zonular support and allow it to fall into the back of the eye. This technique, called “couching,” clears the visual axis, because the lens is now bouncing around in the bottom of the eye. Patients had terrible vision after this (with approximately 20 diopters of hyperopia) but back in those days of ultra-dense cataracts, this was an improvement allowing these early patients to see basic shapes, such as the outline of the pyramids and perhaps their camel.

During World War 2, British fighter pilots suffered from penetrating eye injuries when fragments of their Plexiglas cockpits exploded. Eye doctors of that era found that the eye seems to tolerate plastic, thus spawning the idea of using plastics to create intraocular lens implants to replace the natural lens.

Cataract implants have evolved since then. Now we have lenses made of PMMA plastic, acrylic, and silicone. These implants can be folded through smaller incisions and placed in different positions inside the eye - in the capsule, behind the iris in the “sulcus,” or even sitting on top of the iris in the anterior chamber. We can also perform cataract surgery through much smaller incisions, allowing faster recovery times and lower complication rates.

Preoperative measurements: how to choose your implant power?

Our goal in cataract surgery is to put the ideal power intraocular lens into the eye so that the patient won’t need additional glasses for viewing distant objects. This is not always an easy task, as everyone's eyes are different and minor anterior-posterior shifts in the lens placement will severely affect the end refraction. There are many formulas designed from both lens theory and regression analysis to help you choose the correct power lens. We won’t be going over these formulas, but keep in mind that we need to measure two things to come up with the right prescription for the implant:

a. The corneal curvature: Remember that the cornea-air interface actually performs the majority of the refractive power of the eye. The cornea performs approximately 40-diopters of refraction, while the lens makes up the last 20-diopters. A person with a powerful cornea will need a less powerful lens. We measure the curvature of the cornea with a keratometer.
b. The length of the eye: The shorter the eye, the more powerful lens you'll need to focus images onto the retina. We measure this with the A-scan mode of a hand-held ultrasound.

Cataract Surgery – How to Do it!

Cataract surgery is easy in concept, but actually performing this surgery is challenging as you’re working under a surgical microscope with delicate ocular structures.

There are many steps to cataract extraction, and many ways to go about it – everyone has their own combination of machine settings, viscoelastics, irrigating fluids, and preferred instruments. Essentially, you can break down the cataract surgery into a few steps:

1. Anesthesia

Dilate the pupil, prep, and anesthetize the eye. Anesthetic can be given with simple topical eyedrops like tetracaine and I perform the majority of my cases with topical anesthesia. We can also perform a retrobulbar block by injecting lidocaine/bupivicane into the retrobulbar muscle cone to knock out sensation through V1, and eye movement by knocking out CN3 and CN6. The trochlear nerve (CN4) actually runs outside the muscle cone, so you can see some residual eye torsion movement after the block. If you’ve never seen a retrobulbar block, you’re in for a treat (it can look gruesome the first time).
2. Enter the eye
The main surgical entry site can be performed several ways. You can enter
the eye by cutting through the cornea, or you can spend more time tunneling
in from the sclera. A clear-cornea incision is fastest, while the scleral tunnel
takes longer but is easier to extend if you run into surgical complications.

3. Capsulorhexis
To get the lens out you need to tear a hole in the anterior capsule (hard
candy shell) of the lens. This step is important to get right, because if the
rhexis is too small, it will make cortex and nucleus removal harder. Also, the
outer capsule you are tearing is finicky and can tear incorrectly, with a rip
extending radially outwards to the equator (not good). If you lose your
capsule, you can lose pieces of lens into the back of the eye. Poor capsular
support also makes implant placement that much harder.
4. Phacoemulsify
We use an instrument called the phaco handpiece to carve up the lens nucleus. This machine oscillates at ultrasonic speeds and allows us to groove ridges into the lens. After grooving, the lens can be broken into pie-pieces and eaten up one-by-one.

5. Cortical removal
After removing the inner nucleus, we can remove the residual cortex (the middle chocolate layer) of the lens. This cortex is soft but wants to stick to the capsular bag. You don’t want to leave too much, as it will cause inflammation and can cause “after cataracts” (posterior capsule opacification). We strip this with suction and vacuum it out.
You need to be careful with your posterior capsule during this cleanup. The surgeon tries to maintain the posterior capsule for a couple of reasons – not only does it create a support structure for the new lens, but it maintains the barrier between the anterior and posterior chambers, keeping the jelly-like vitreous from squeezing into the anterior chamber.

6. Insert the lens

We usually use a foldable lens that can be injected directly into the bag. If we’ve lost capsular support (for example, we managed to break the posterior capsule during phaco or cortex removal), the lens can be placed on top of the entire capsular bag, right behind the iris. If support for this sulcus placement is questionable (i.e., you’ve had a LOT of complications with the case), a lens can be placed in the anterior chamber on top of the iris, or sutured to the back surface of the iris (tricky).

7. Close up

You now close the eye. Many small incision corneal wounds are self-sealing, but some require closure with 10-0 nylon suture that will eventually biodegrade.

8. Postop care

Immediately after surgery, antibiotics are dropped and a shield is placed over the eye. The patient is then seen the next day and will use antibiotic drops and a steroid drop to decrease inflammation.
Conclusion: Cataract surgery is not easy

Almost every ophthalmologist performs cataract surgery, so there is a tendency to view this as a simple procedure that only takes a few minutes. Some cataract cowboys are able to perform an extraction in ten minutes and may even downplay the risk.

The reality is that cataract surgery is very difficult. The lens is mostly clear, floating in clear aqueous, supported by a microns-thin clear capsule that wants to tear. The patient is usually awake, so any small movement such as a cough or simple head adjustment looks like an earthquake under the microscope. Cataract extraction involves many steps, and early mishaps at the beginning of the case cascade and make the later steps that much more difficult.

Look at it this way: any surgery that takes over 100 operations to develop basic proficiency has got to be tough. Cataract surgery is like flying an airplane … it takes many years of training, screening, certification, accreditation to be an accomplished pilot, and most flights are uneventful. But you want a qualified person behind the wheel when you hit turbulence. Fortunately, most of the time things go just fine.

Would you prefer speed or accuracy?
1: What does it mean to have a phakic eye or an aphakic eye?
Phakic means that the patient has their original lens. Pseudophakic means that they have an intraocular lens implant. Aphakic means that their lens was removed, but no replacement lens was placed.

2. What are the layers of the lens?
There are three layers to the lens. The outer capsule, the inner nucleus, and a middle cortex … in a configuration like a peanut M&M candy.

3. When you accommodate (look at near objects) do the zonules relax or tighten?
The zonules relax. With accommodation, the spincter-like ciliary body contracts, the zonules relax, and the lens relaxes and becomes rounder (thus more powerful). You’re going to have to think that one out a few times and look at the drawing in this chapter.

4. What are the two functions of the ciliary body?
The ciliary body changes lens shape, allowing fine focusing and accommodation. It also produces aqueous fluid that inflates the anterior chamber and nourishes the avascular lens and cornea.

5. By what mechanism can a diabetic patient have a temporary refractive error?
Too much glucose will switch the lens metabolism from anaerobic glycolosis to a sorbitol pathway. Sorbitol buildup in the lens creates an osmotic swelling that changes the lens power (the round, swollen lens makes images focus in front of the retina, thus the patient is temporarily near-sighted).

6. Why do yellow sunglasses make images seem sharper?
All lens systems have chromatic aberration because the different colors of light bend differently. This means that images don’t focus perfectly on the retina – the blue component focuses slightly in front of the retina, while the red component slightly behind. Tinted glasses limit the spectrum of color that hits the retina, and makes images appear sharper.
7. How soon should a child with a cataract go to surgery?
Soon, as cataracts create a visual deprivation that quickly leads to amblyopia. Some practitioners recommend surgery prior to two months.

8. How can a cataract cause glaucoma?
Many cataracts are large, and this bulk can push the iris forward and predispose to angle closure glaucoma. Also, end-stage cataracts can leak proteins into the aqueous fluid and the resulting inflammatory cells (macrophages) can clog the trabecular meshwork.

9. What measurements must you have to calculate a lens implant power?
You need to know the cornea curvature (because the cornea performs the majority of the eye’s refractive power) and the length of the eye.

10. How much of the lens is removed in typical cataract surgery?
With eye surgery, we create a hole in the anterior capsule and suck out the inner nucleus and cortex. The outer capsule is left behind to serve as a pocket to put the new implant into.

11. What’s the difference between a PCO and a PSC cataract?
PCO: posterior capsular opacification. This is an “after cataract” that forms on the back surface of the posterior capsule after successful cataract surgery. This opacity can be cleared with a YAG laser.
PSC: posterior subcapsular cataract. This is a cataract that forms on the back portion of the lens. These tend to occur more often in diabetics and those on steroids, and tend to be visually significant because of their posterior position.

12. What does it mean to place a lens “in the sulcus?”
The sulcus is the space between the lens capsule and the back of the iris. If the posterior capsule is torn and can’t support the lens, you can often place a lens on TOP of the entire capsule in this potential space.

13. What drops are given after a cataract surgery?
Usually an antibiotic, such as ciprofloxacin or vigamox. Also, a steroid is given to decrease inflammation.