EyeFlyMD

The Eye Guide

Cataract Surgery

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I would like to thank Geetha Davis MD and Sandra Johnson MD for teaching me cataract surgery and helping me share the following knowledge with others.

Proofread and edited by Ariess Gharabagi

Disclaimer: The writing, images, and graphics are my own and based on knowledge I've accumulated through various resources during my own ophthalmology training. I provide select citations and encourage every reader to consult the relevant literature/texts for their program and/or training level. Don't take my word for it. The purpose of this work is to provide a concise summary of critical topics. This work contains no medical advice and is not a substitute for formal education. Please submit errors to matt@eyeflymd.com

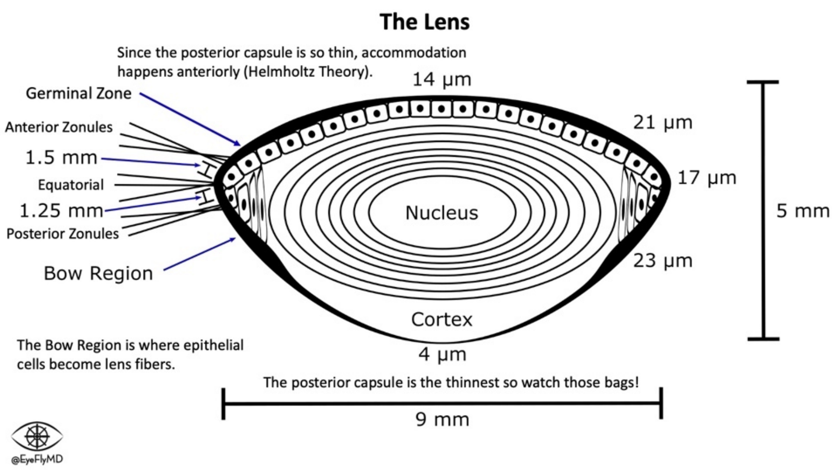
ALL PATIENT PHOTOGRAPHS AND DIAGRAMS ARE ORIGINAL

Cataracts

The Pathology of Cataracts

"Cataract" has two meanings in English. One is "large waterfall". Flowing water has a white appearance and this might explain the how it came to be used to describe whitening of the lens. The modern meaning of the eye disease most likely originates from the Greek, καταρράκτης (kataraktes), which means both large waterfall as well as *portcullis*. A Portcullis is a thatched, medieval gate. An obstruction (to vision).

A cataract, in ophthalmology, refers to the opacification of the human crystalline lens. Lenses may naturally have opacifications, but a clinically significant cataract is one that is suspected to interfere with visual acuity or daily function. Cataracts may be congenital, metabolic, age-related, or traumatic. Cataracts are mainly described based on their location within the crystalline lens, so recall the following anatomy.

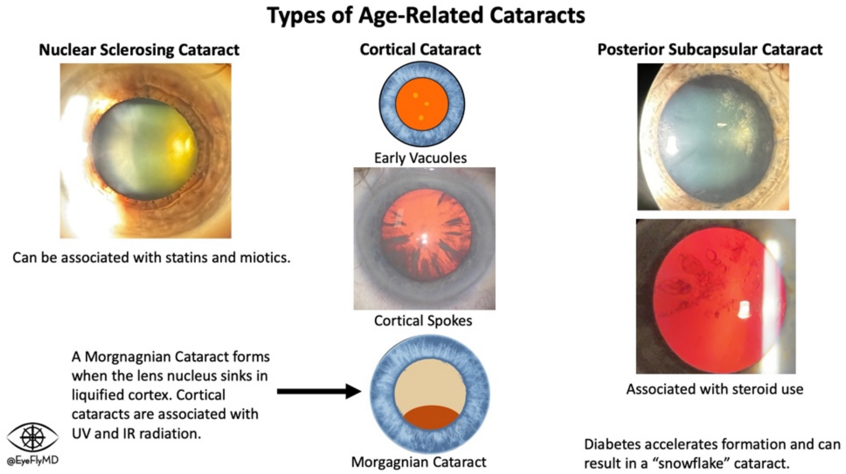


Types of Cataracts

Nuclear Cataracts affect the nucleus of the lens and presents as a hazy opacity that can particularly degrade vision at night.

Cortical Cataracts affect the lens cortex and usually presents first as vacuoles, then clefts, and eventually the entire cortex can liquify wherein the nucleus can sink within it (Morgagnian Cataract) if untreated. These are likely to cause glare and halos.

Posterior Subcapsular Cataracts are associated with steroid use and diabetes and presents as a focal collection of material toward the posterior of the lens. Patients are particularly affected in bright light as the pupil constricts and the available light must travel through the opacity.



Posterior Polar Cataracts are congenital and formed of distorted lens fibers in the central posterior part of the lens. They may represent disruption or absence of the posterior capsule in their area, so extra care of the posterior capsule must be taken during surgery.

Anterior Polar Cataracts may be congenital or acquired (e.g., associated with uveitis or glaucoma) and are analogous to Posterior Polar but involve the anterior lens/capsule.

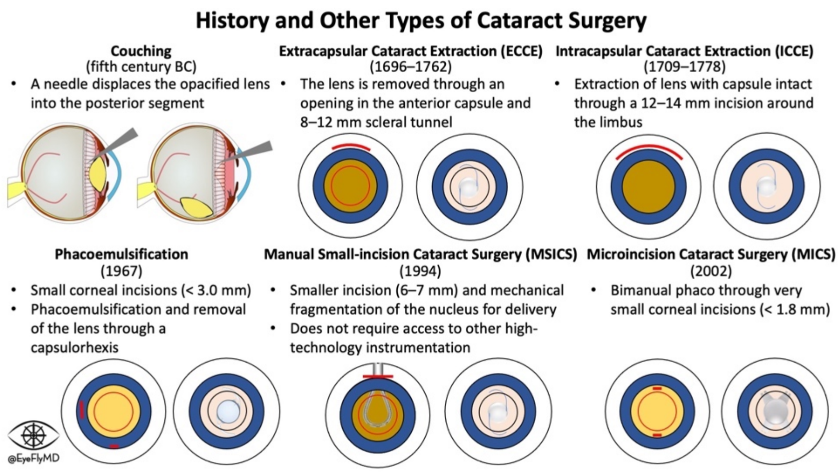
Other, rarer forms of cataracts include anterior subcapsular (common after phakic IOL surgery), traumatic, or the multicolored "Christmas Tree" variety associated with myotonic dystrophy.

History of Cataract Surgery

History of Cataract Removal

Modern cataract surgery can be thought of as “lens replacement surgery.” After removing the cataractous lens, a clear artificial lens with a selected refractive power is placed in the natural capsular bag. Common abbreviations for cataract surgery are “phaco” (for “phacoemulsification”), “phaco-IOL”, or “CE/IOL” (for “Cataract Extraction with IOL Implantation”).

Cataract surgery has a long and rich history. Its earliest form traces back to centuries BC.



Couching (5th century BC): A needle is used to simply disrupt the zonules of a dense cataract so it would fall back into the vitreous cavity. No intraocular lenses (IOLs) or even spectacles existed then but even bright, hand motion vision is advantageous compared to the near blindness of a mature lens.

Extracapsular Cataract Extraction (1696-1762): Involves opening the anterior capsule and removing the lens through a scleral incision and leaving the capsular bag largely intact.

Intracapsular Cataract Surgery (1709-1778): Involves a larger sceral wound and is essentially a more sophisticated form of couching that consists of removing the lens while still inside the capsule.

Phacoemulsification (1967): The use of ultrasound energy to liquify the lens, usually accompanied with the extracapsular technique. It's important to mention that while phacoemulsification could be accomplished through a small wound, before foldable IOLs became widespread in the 1980s, the wounds had to be enlarged to accommodate the rigid lenses of the time.

Manual Small-Incision Cataract Surgery (MSICS) (1994): This was first described in the 1990s as a solution to safely remove dense cataracts especially in resource-limited areas. A phacoemulsification machine is expensive and not all facilities around the world will have them, so this skill is especially useful for global ophthalmology. The technique involves removing the entire lens in an extracapsular fashion through a small scleral incision.

History of Intraocular Lenses (IOLs)

For a large portion of human history, the cataractous lens was removed from the eye without another lens placed. Vision may have been brighter but visual potential was limited due to the absence of a refracting element. Aphakic spectacles (sometimes called "Coke bottle" glasses due to their thickness) certainly were an improvement to the aphakia, but they were uncomfortable and caused significant distortions as they often had to be around +10.00 D.

During WWII, a Royal Air Force fighter pilot named "Mouse Cleaver" (Gordon Neil Spencer Cleaver, 04/27/1910 – 12/24/1994) was flying a Hawker Hurricane (type of fighter plane) without wearing goggles. He was shot down and sustained shards of the aircraft windscreen in his eye. An observant surgeon named Sir Harold Ridley (Sir Nicholas Harold Lloyd Ridley, 07/10/1906 – 05/25/2001) appreciated that this material caused minimal ocular inflammation and was well tolerated by the eye. He proposed and eventually placed the first acrylic lens in 1949.

IOLs have undergone an evolution throughout their history as well. Here is a summary of their evolution.

1949 – The first Successful IOL was made from Poly methyl methacrylate (PMMA) and placed by Sir Harold Ridley. Without access to biometry or IOL calculators, the postoperative refractive error of the first successful IOL was around -20.00 D.

1978 – The Mazzocco Plate-Haptic Lens was the first foldable IOL. Before this, the wounds had to be enlarged to accommodate rigid lenses.

1994 – Alcon's Acrysof® Models MA60BM and MA30BA were the first FDA-approved foldable acrylic IOLs.

1998 – STAAR® introduced the first Toric IOL. It was made from silicone with a plate haptic configuration.

1998 – Allergan AMO released the "Array" as the first presbyopia correcting, multifocal IOL.

2003 – Bausch + Lomb released the Crystalens®, the first accommodating IOL.

2005 – Alcon released the AcrySof® ReSTOR®, the first *diffractive* (more on this later), multifocal IOL. The overwhelming majority of presbyopia correcting IOLs today rely on diffractive optics.

2014 – Johnson & Johnson released the TECNIS® Symfony™, the first extended depth of focus (EDOF) IOL. Several modern presbyopia correcting IOLs use this optical concept.

2017 – RXSight® released the Light Adjustable Lens™, a silicone IOL that can be adjusted postoperative by UV light.

Modern Technique

The most common Current Procedural Terminology (CPT®) code for cataract surgery today is 66984 (Cataract surgery, extracapsular, with insertion of intraocular lens) and is usually performed with phacoemulsification. Appreciate how much history modern cataract surgery spans. Lens removal uses the 1600s and 1967 technique with ever-evolving IOL technology.

Other common CPT® codes are:

- 66984: Cataract surgery, extracapsular, with insertion of intraocular lens
- 66982: Cataract surgery with insertion of intraocular lens, complex (e.g., use of a Malyugin Ring)
- 66983: Cataract surgery, intracapsular, with insertion of intraocular lens

The Centers for Medicare and Medicaid Services (CMS) determine medical necessity for cataract surgery which is summarized here:

1. Cataract causing symptomatic impairment that is not correctable
2. Disease requiring monitoring or treatment that is prevented by the presence of cataract
3. Lens-induced disease threatening vision or ocular health (e.g., glaucoma)
4. High probability of accelerating cataract development due to subsequent procedure
5. Cataract interfering with the performance of vitreoretinal surgery
6. Intolerable anisometropia or aniseikonia after one eye

A final point worth considering is how efficient ophthalmologists have become at cataract surgery. Cataract surgery used to require overnight hospital admission. The volume surgeons can handle now are reflected in the reimbursement rates for 66984: $1,842 (adjusted for 2022 inflation) in 1996 compared to $529 in 2022.

Intraocular Lenses (IOLs)

IOL Anatomy

IOLs have a central optic portion and usually two haptics that hold the IOL in place in the capsular bag. Keeping the IOL stable in the bag is especially important for Toric lenses where rotation would cause reduction in cylinder correction. For every 1° a toric IOL rotates off axis, ~3% of the cylinder power is lost so if the lens rotates 30°, the entire effect of the lens is lost. If it rotates >30°, the lens starts adding cylinder to the system.

Optics are normally 6 mm. The most common types of IOLs are Acrylic, hydrophobic (to minimize calcifications), foldable, and square edge (to act as a physical barrier for epithelial cell migration and reduce PCO formation).

3-piece IOLs have small, filament haptics because they are typically placed in the ciliary sulcus so contact with the uveal tissues must be minimized to prevent uveal chaffing.

There are multiple types of lenses including:

Monofocal IOL – The standard lens that corrects vision at one distance. Monofocals are covered by insurance in the USA.

Toric IOL – A premium option that corrects for corneal astigmatism. A Torus is a donut shape. When you take a bite out of a donut there are two radii: the one dictating the diameter of the entire donut and the one dictating the diameter of the actual donut. These are also premium lenses that are inserted at the angle of the patient's astigmatism to correct this and provide better freedom from glasses.

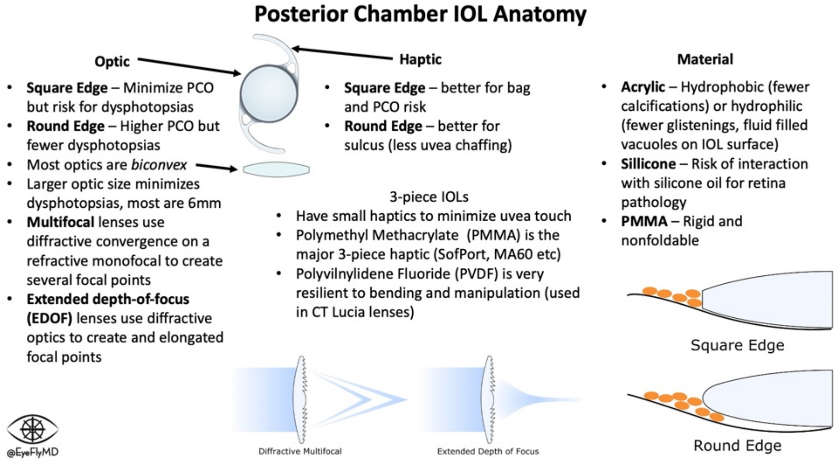
Multifocal IOL – Premium lens (usually ~$2,000 cost to the patient) that attempts to correct vision at multiple distances. There are known risks of glare and halos after surgery.

EDOF IOL – An "Extended Depth of Focus" lens is also a premium lens that uses sophisticated optics to enlarge the distance light is focused on the retina. Patients can still experience halos, glare, and loss of contrast sensitivity.

Accommodating IOL – Theoretically continues to accommodate like a natural crystalline lens.

Multifocal IOLs typically use a base monofocal and a diffractive element to create an additional focal point. EDOF lenses create an extended focal point by spreading the light. These come at the cost of contrast sensitivity because there is only so much light entering the eye, and by using it to spread the light over a larger range or multiple focal points, there is inherently a reduction in the amount of photons focusing on each point. Monofocal IOLs still provide the best contrast sensitivity because they focus all available light on a single point (remember no optical system is perfect and some light is always lost).

Most IOLs placed in the capsular bag have square edge components to minimize epithelial cell migration and reduce the risk for developing a posterior capsular opacification.



(Image of the MX60E from the BAUSCH + LOMB IOL + OVD Product Catalog 2022)

Further Reading:

Schallhorn JM, Pantanelli SM, Lin CC, Al-Mohtaseb ZN, Steigleman WA 3rd, Santhiago MR, Olsen TW, Kim SJ, Waite AM, Rose-Nussbaumer JR. Multifocal and Accommodating Intraocular Lenses for the Treatment of Presbyopia: A Report by the American Academy of Ophthalmology. Ophthalmology. 2021 Oct;128(10):1469-1482. doi: 10.1016/j.ophtha.2021.03.013. Epub 2021 Mar 17. PMID: 33741376.

IOL Options in the United States

There are *many* FDA approved IOL options and more come to market every year. Here are two links that may be helpful in staying up to date on the current market.

IOLReference.com

The EyeFlyMD IOL Cheat Sheet

Comparing IOLs

Modulation Transfer Function (MTF) charts or Defocus Curves (explained below) are a good way to compare lens performances. MTF charts also highlight the concept of "photon budget" in multifocal and EDOF lenses. The cost of multiple focal points or extended focal ranges is reduced contrast sensitivity as fewer photons form a single image. Surgeons are usually cautious to place premium (multifocal or EDOF) IOLs in eyes with existing or the potential for retinal/other pathology (e.g., AMD or glaucoma). Complicating the optical system further will risk suboptimal vision in the setting of disease.

Modulation Transfer Function (MTF) Charts and IOL Performance

There are multiple ways to objectively compare IOL performances. These are called Modulation Transfer Function (MTF) Charts (sometimes Defocus Curves or Performance Charts). There can be different values on the X and Y axes so it's important to know how to read and interpret the data.

Y-Axis

- **Modulation Transfer –** The ability of an optical system to transfer contrast to its image; MTF=Mi/Mo (image/object)
- **LogMar VA –** Visual acuity is scored with reference to the log of the minimum angle of resolution; 20/20 is LogMar 0

X-Axis

- **Spatial Frequency** - measured in line pairs per mm
- **Defocus** - measured in either D or distance

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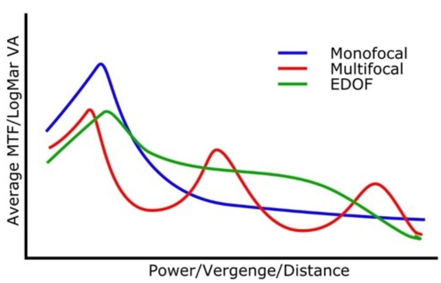
Spatial Frequency:



Here are hypothetical performance charts for the different IOL concepts. Notice there's no free lunch and only so much light entering the eye, to achieve multiple focal points or extended ranges there is typically a division of available light and a reduction in contrast.

IOL Calculations

Principles

Recall that in 1949, the first IOL had a postoperative refractive error of -20.00 D. That counts as a “refractive miss” which is usually defined by a postoperative uncorrected refraction greater than ± 0.50 D of the predicted or intended refractive outcome. Sir Harold Ridley did not have the advantage of modern day IOL formulas which minimize the risk of these kind of outcomes.

The first major formula was the Sanders-Retzlaff-Kraff (SRK). It is now mostly of historical significance but underscores the importance of accurate preoperative measurements. Appreciate that a 1 mm error in axial length equates to an average of ~2.5 D error for the lens!

Principles of IOL Calculations

The SRK formula is a first-generation formula for calculating lens power and now mostly only of historical significance.

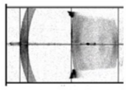
We have moved to more sophisticated calculations but the principles behind this formula underscore the importance of accurate axial length which is considered the most important variable in Biometry.

$$P = A - 2.5\,L - 0.9\,K$$

P = Lens Power for Emmetropia (D)
A = Specific IOL Constant (usually ~118)
L = Axial Length (mm)
K = Average corneal Power (D)

There are many IOL calculations now and improvements to accuracy are due to improved estimation of “**Effective Lens Position**”, the distance between the cornea the principle optical plane of the IOL.

Notice an incorrect axial length of just 1 mm will result in a 2.5 D lens error!


Biometry of my eye!

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Recall the total refracting power of the eye is ~60 D, 43 D of which is from the cornea. Thus, expect IOL powers ~20 D.

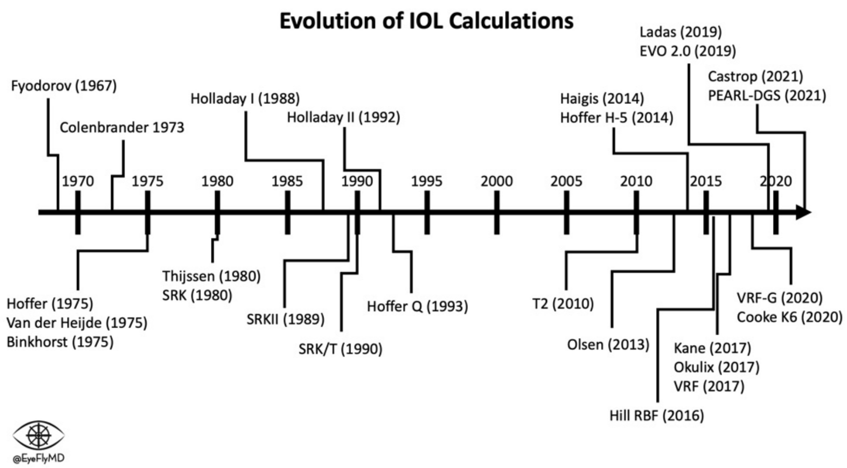
Before cataract surgery, it’s important to obtain accurate measurements of the eye (biometry) to accurately calculate the power of lens to use. Lenses are most often placed in the capsular bag but can also be placed in the ciliary sulcus or anterior chamber. The most important measurements for IOL calculations are axial length and corneal power. Extremes on either end of axial length or corneal power can also impact the accuracy of calculations.

We can calculate the power needed for an eye. Let's use MX60E as an example. It has an A-constant of 119.1. Let's also use L = 24.23 mm and K = 42.25 D. This eye would need:

P = 119.1 – 2.5(24.23) – 0.9(42.25) = +20.50 D

Remember, "P" is the power required for emmetropia so additional considerations are needed if the patient desires near or blended vision (the new term for "monovision": one eye set for distance and one eye set for intermediate-near, ~-1.50 D).

The key to a successful refractive outcome is an accurate formula and accurate measurements and as mentioned the SRK and all its variants were simply too inaccurate. Formulas have evolved over the years to better estimate "**Effective Lens Position**" (**ELP**), or where the IOL will sit postoperatively. There have been *many* IOL formulas over the years.



Here is some important language that is helpful when navigating the world of IOL formulas:

- **Empirical Formulas**: Linear regression of refractive data
- **Theoretical Formulas**: Based on optics of model eyes
- **Ray-Tracing**: Calculates the exact path of paraxial rays to calculate postoperative ELP
- **Vergence**: Theoretical refractive vergence
- **Thin Lens**: Approximate the IOL as a thin lens
- **Thick Lens**: ELP(T) (T for "thick"); differentiates between the IOL's physical and optical position

Empirical Formulas

Sanders-Retzlaff-Kraff (SRK) (1980): $P = A - 2.5L - 0.9K$

- Benefits: Most accurate at the time; best for axial lengths (L) between 22.00-24.50 mm
- Limitations: Inaccurate; doesn't consider ELP

SRKII (~1989) $P = A - 2.5L - 0.9K + C$

- Benefits: Better than SRK for longer and shorter eyes (A-constant correction factors added)
- Limitations: Still too inaccurate; doesn't consider ELP

SRK II Correction Values for *C*	
If $L \leq 20$	3
If $L \geq 20$ and < 21	2
If $L \geq 21$ and < 22	1
If $L \geq 22$ and < 24.5	0
If $L \geq 24.5$	-0.5

VFR (2017)

- Benefits: Better than the other empirical formulas; considers AL, Ks, ACD, and K diameter to estimate ELP

Theoretical Formulas

1st Generation Theoretical

Fyodorov (1967), Colenbrander (1973), Van der Heijde (1975), Thijssen (1980)

- Benefits: Accounted for ELP; reduced to:

$$P = \frac{n}{L - c} - \frac{nK}{n - cK}$$

- Limitations: Assumed ELP was always 4.0 mm; mainly for ACIOLs

2nd Generation Theoretical

Binkhorst (1975), Hoffer (1975

- Benefits: Adjusted ELP based on Axial length
- Limitations: Still limited accuracy vs. newer formulas

3rd Generation Theoretical

SRK/T (T=theoretical) (1990), Holladay I (1988), Hoffer Q (~1993), T2 (~2010)

- Benefits: Measures both L and Ks to estimate ELP
- Limitations: Best for "normal" ALs between ~22-~26 and "normal" Ks between ~41D-~46D

4th Generation Theoretical

Holladay II (1992), Barrett II Universal (2010), Haigis (~2014)

- Benefits: Measure ACD and other variables to estimate ELP; better for "abnormal" Ls and Ks; Haigis has an added benefit of not relying on Ks (good for post-LASIK)
- $\mathrm{ELP} = a_0 + a_1 AC + a_2 AL$

5th Generation Theoretical

Hoffer H-5 (2014)

- Benefits: Incorporates race and gender data

AI/Machine Learning

Kane (2017), Hill RBF (2016), PEARL-DGS (2021)

- Benefits: Uses a combination of theoretical/empirical optics and/or components of AI/machine learning

Ray Tracing

Olsen (2013), Okulix (2017), Naeser 2 (2019), VRF-G (2020)

- Benefits: Simulates whole pseudophakic eye and accounts for aberrations

Combination

Ladas Super Formula (2019)

- Benefits: Combines the most accurate portions of other formulas to make a "super formula" based on patient measurements; also uses AI

Other Vergence-Based Formulas

- Emmetropia Verifying Optical (EVO) 2.0 (2019) – Thick lens formula, considers geometry of IOL
- Cooke K6 (2020) – Uses multiple refractive indices for various media in the eye
- Castrop (2021) - Pseudophakic eye model with 4 refractive surfaces and 3 formula constants

IOL Formula Adjustments

- Wayne-Koch Adjustment – Applied to some third- and fourth-generation IOL formulas to optimize the calculation for AL >25 mm; great for Holladay II

IOL Calculation Summary

The important takeaways are that the first formulas were **empirical** (used linear regression of refractive data). The newer formulas are **theoretical** (based on formal optics and model eye). There are several generations of theoretical formulas but the most common is probably Barrett II Universal. The most accurate today appears to be the Kane formula which is based on both empirical and theoretical optics as well as AI/Machine Learning. Barrett II was previously accepted as the most accurate in general.

The formulas also have different uses depending on the circumstance. For example, the Haigis formula does not use Ks to calculate ELP, so it is exceptional for use in those with a history of corneal refractive surgery.

Further Reading:

Ryu S, Jun I, Kim TI, Kim EK, Seo KY. Accuracy of the Kane Formula for Intraocular Lens Power Calculation in Comparison with Existing Formulas: A Retrospective Review. Yonsei Med J. 2021 Dec;62(12):1117-1124. doi: 10.3349/ymj.2021.62.12.1117. PMID: 34816642; PMCID: PMC8612861.

Charters L. Haigis-TK power calculation formula provides best error prediction after LASIK. Ophthalmology Times. https://www.ophthalmologytimes.com/view/haigis-tk-power-calculation-formula-provides-best-error-prediction-after-lasik. Published December 20, 2020. Accessed November 22, 2022.

Understanding Biometry Printouts

I believe it's important to understand all aspects of how the machines and formulas function, so we'll take a small detour to understand all aspects of biometry (specifically that of the ZEISS IOLMaster® 700 below).

OD right	IOL calculation	OS left

Eye status

OD				OS			
LS:	Phakic	VS:	Vitreous body	LS:	Phakic	VS:	Vitreous body
Ref:	---	VA:	---	Ref:	---	VA:	---
LVC:	Untreated	LVC mode:	-	LVC:	Untreated	LVC mode:	-
Target ref.:	plano	SIA:	+0.00 D @ 0°	Target ref.:	plano	SIA:	+0.00 D @ 0°

Biometric values

OD						OS					
AL:	26.55 mm	SD:	6 µm			AL:	26.59 mm	SD:	10 µm		
ACD:	3.97 mm	SD:	6 µm			ACD:	4.16 mm	SD:	5 µm		
LT:	3.63 mm	SD:	7 µm			LT:	3.55 mm	SD:	10 µm		
WTW:	12.6 mm					WTW:	12.6 mm				
SE:	42.34 D	SD: 0.01 D		K1: 42.14 D	@150°	SE:	42.44 D	SD: 0.01 D		K1: 42.20 D	@ 16°
ΔK:	+0.42 D	@ 60°		K2: 42.55 D	@ 60°	ΔK:	+0.50 D	@106°		K2: 42.69 D	@106°
TSE:	42.47 D	SD: 0.03 D		TK1: 42.28 D	@144°	TSE:	42.63 D	SD: 0.03 D		TK1: 42.37 D	@ 22°
ΔTK:	+0.39 D	@ 54°		TK2: 42.67 D	@ 54°	ΔTK:	+0.52 D	@112°		TK2: 42.90 D	@112°

TK Bausch + Lomb enVista		TK Johnson & Johnson Vision DI B00		TK Bausch + Lomb enVista		TK Johnson & Johnson Vision DI B00	
- Barrett TK Universal II -		- Barrett TK Universal II -		- Barrett TK Universal II -		- Barrett TK Universal II -	
LF: +2.10 DF: Default		LF: +2.04 DF: Default		LF: +2.10 DF: Default		LF: +2.04 DF: Default	
IOL (D)	Ref (D)	IOL (D)	Ref (D)	IOL (D)	Ref (D)	IOL (D)	Ref (D)
+14.50	-0.53	+14.50	-0.58	+14.50	-0.73	+14.50	-0.78
+14.00	-0.20	+14.00	-0.24	+14.00	-0.39	+14.00	-0.44
+13.50	**+0.13**	**+13.50**	**+0.09**	**+13.50**	**-0.07**	**+13.50**	**-0.11**
+13.00	+0.46	+13.00	+0.41	+13.00	+0.26	+13.00	+0.21
+12.50	+0.78	+12.50	+0.74	+12.50	+0.58	+12.50	+0.54
+13.71	Emmetropia	+13.63	Emmetropia	+13.40	Emmetropia	+13.33	Emmetropia

TK Alcon Clareon CNA0T0		TK Alcon AcrySof MA60AC		TK Alcon Clareon CNA0T0		TK Alcon AcrySof MA60AC	
- Barrett TK Universal II -		- Barrett TK Universal II -		- Barrett TK Universal II -		- Barrett TK Universal II -	
LF: +2.02 DF: Default		LF: +1.99 DF: Default		LF: +2.02 DF: Default		LF: +1.99 DF: Default	
IOL (D)	Ref (D)	IOL (D)	Ref (D)	IOL (D)	Ref (D)	IOL (D)	Ref (D)
+14.50	-0.60	+14.50	-0.62	+14.50	-0.79	+14.50	-0.82
+14.00	-0.26	+14.00	-0.28	+14.00	-0.46	+14.00	-0.48
+13.50	**+0.07**	**+13.50**	**+0.05**	**+13.50**	**-0.13**	**+13.50**	**-0.15**
+13.00	+0.40	+13.00	+0.38	+13.00	+0.20	+13.00	+0.18
+12.50	+0.72	+12.50	+0.70	+12.50	+0.52	+12.50	+0.50
+13.61	Emmetropia	+13.57	Emmetropia	+13.31	Emmetropia	+13.27	Emmetropia

Let's take a look at some of the sections.

LS:	Phakic	VS:	Vitreous body
Ref:	---	VA:	---
LVC:	Untreated	LVC mode:	-
Target ref.:	plano	SIA:	+0.00 D @ 0°

- LS: "Lens Status", whether the patient is phakic
- VS: "Vitreous Status", if the patient had a vitrectomy
- Ref and VA are current refraction and visual acuity
- LVC: Laser vision correction, e.g., LASIK
- Target Ref: Postoperative refractive target
- SIA: Surgeon's Surgically Induced Astigmatism

AL:	26.55 mm		SD:	6 µm		
ACD:	3.97 mm		SD:	6 µm		
LT:	3.63 mm		SD:	7 µm		
WTW:	12.6 mm					
SE:	42.34 D		SD: 0.01 D	K1:	42.14 D	@150°
ΔK:	+0.42 D	@ 60°		K2:	42.55 D	@ 60°
TSE:	42.47 D		SD: 0.03 D	TK1:	42.28 D	@144°
ΔTK:	+0.39 D	@ 54°		TK2:	42.67 D	@ 54°

- AL: Axial Length and SD (standard deviation)
- ACD: Anterior chamber depth and SD
- LT: Lens thickness and SD
- WTW: White-to-White (horizontal corneal dimeter)
- SE: Spherical equivalent of the cornea and SD
- K1: Flat keratometry and axis
- K2 Steep keratometry and axis

Total Keratometry vs. Standard Keratometry

You'll notice there is a "TK" value. This stands for "Total Keratometry". It uses swept-source OCT to measure the posterior cornea to theoretically give a more accurate picture of the keratometry.

Equations like the Barrett II have been calibrated for TK and the research so far has shown a higher prediction accuracy using the TK vs standard keratometry in *post-refractive* cases. This is denoted by the black "TK".

TK Bausch + Lomb enVista

- Barrett TK Universal II -

LF: +2.10 DF: Default

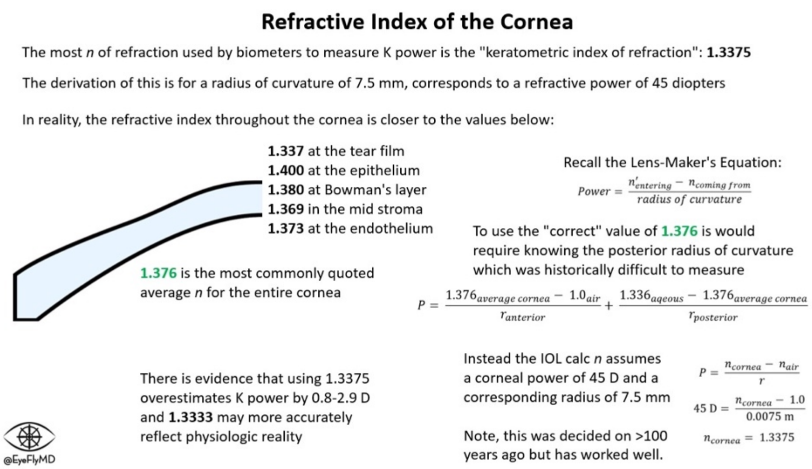
IOL (D)	Ref (D)
+14.50	-0.53
+14.00	-0.20
+13.50	**+0.13**
+13.00	+0.46
+12.50	+0.78
+13.71	Emmetropia

Further Reading:

Fabian E, Wehner W. Prediction Accuracy of Total Keratometry Compared to Standard Keratometry Using Different Intraocular Lens Power Formulas. J Refract Surg. 2019 Jun 1;35(6):362-368. doi: 10.3928/1081597X-20190422-02. PMID: 31185101.

The Refractive Index of the Cornea

You'll also notice in most biometry printouts the refractive index of the cornea (n) is set as 1.3375. In reality, the average refractive index for the cornea is closer to 1.376 but varies from anterior (1.400) to posterior (1.373). The reason the IOL calculations use 1.3375 is because to calculate the power of the cornea requires knowing both the anterior and posterior central radii of curvature (see the Lens-Maker's Equation below). Measuring the posterior radius of curvature was difficult historically, especially before tools like the Pentacam®. The workaround (decided more than 100 years ago by the way) was to assume the corneal power is 45 D with a central radius of curvature of 7.5 mm. Again, using the Lens-Maker's Equation this gives an n of 1.3375. There is evidence that this n overestimates corneal power by 0.8 to 2.9 D and 1.3333 may be closer to the physiologic reality.

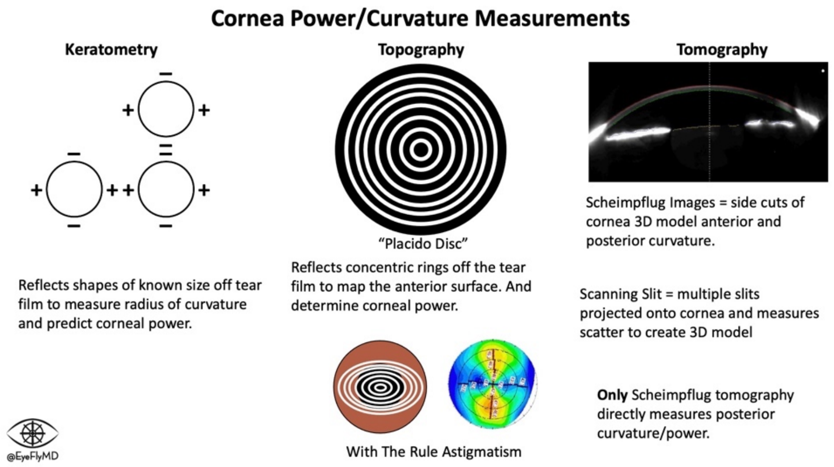


Further Reading:

Piñero DP, Camps VJ, Caravaca-Arens E, de Fez D, Blanes-Mompó FJ. Algorithm for Correcting the Keratometric Error in the Estimation of the Corneal Power in Keratoconus Eyes after Accelerated Corneal Collagen Crosslinking. J Ophthalmol. 2017;2017:8529489. doi: 10.1155/2017/8529489. Epub 2017 Oct 22. PMID: 29201459; PMCID: PMC5672131.

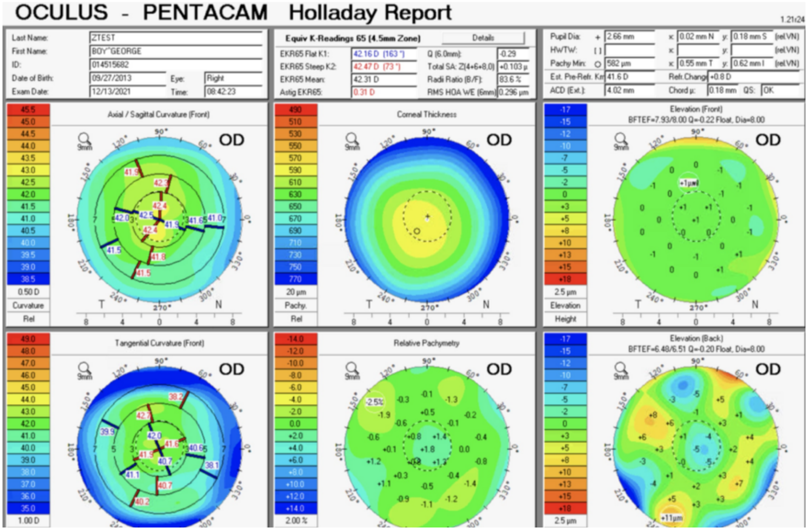
Selecting Toric IOLs

A Toric IOL can be an expensive decision for patients so proper pre-op planning is essential. Most Biometers (e.g., ZEISS IOLMaster® 700, LENSTAR®, etc.) will provide power and axis recommendations for Toric IOLs but it's important to check that the astigmatism is regular and thus correctable. One way to check this is to evaluate the surface of the cornea with tomography or topography. These are not the same thing. Topography (e.g., ZEISS Atlas) only measures the anterior cornea while Tomography (e.g., OCULUS Pentacam®) measures both the anterior and posterior cornea. Think of "topography" like the surface elevations of a state park and "tomography" as in "computed tomography". The difference between them is illustrated below.



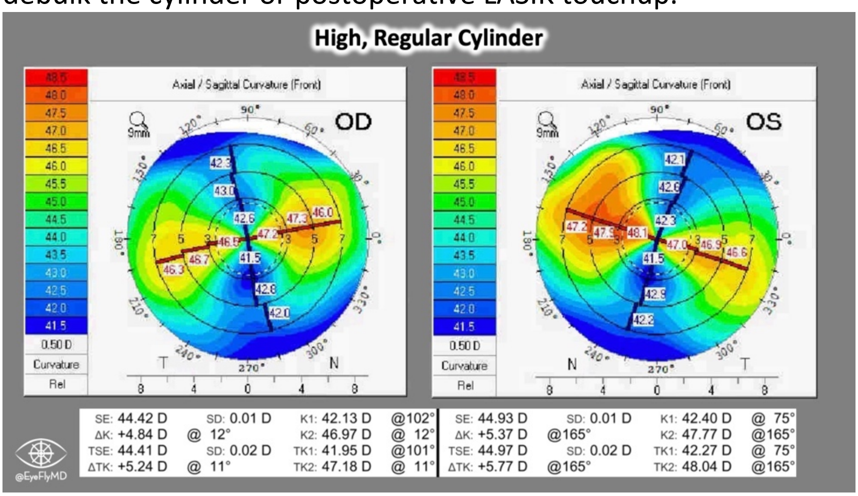
A common way to assess Toric candidacy is to look at the Holladay Report of the OCULUS Pentacam®. This is a module developed by OCULUS with Dr. Jack T. Holladay. It gives measurements of corneal power and keratometry.

The following is an example Holladay Report from an OCULUS Pentacam®.



You can appreciate that I don't have much astigmatism but what I do have is a fairly symmetric bowtie near 90°. Good Toric candidates typically have a symmetric bowtie with astigmatism that matches the biometry (and refraction).

Here is an example from a patient with high, regular cylinder. The refraction, Biometry, and Pentacam® all agree so they are a good Toric candidate. Their astigmatism exceeds even the maximum cylinder correction by most manufacturers so additional interventions may be needed to fully resolve the cylinder. Examples include femtosecond arcuate incisions to debulk the cylinder or postoperative LASIK touchup.



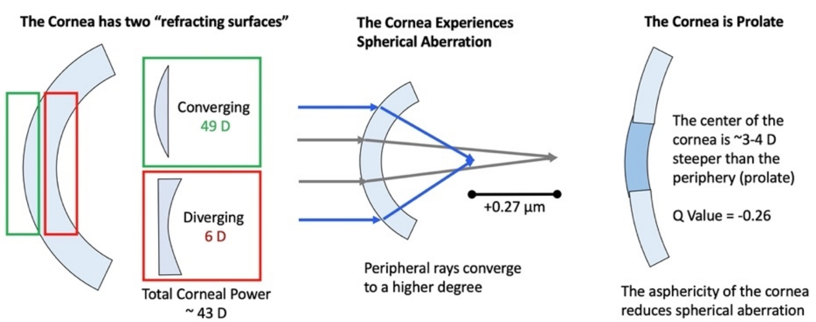
A closer look at the (my) Holladay Report also gives these Equivalent K readings:

Equiv K-Readings 65 (4.5mm Zone)		Details	
EKR65 Flat K1:	42.16 D (163 °)	Q (6.0mm):	-0.29
EKR65 Steep K2:	42.47 D (73 °)	Total SA: Z(4+6+8,0)	+0.103 µ
EKR65 Mean:	42.31 D	Radii Ratio (B/F):	83.6 %
Astig EKR65:	0.31 D	RMS HOA WE (6mm)	0.296 µm

The "65" in the numbers means the Equivalent K Reading is the "weighted mean where 65% of the values are represented using the smallest range of points" (from the Pentacam® Manual). This method of data sampling improves the accuracy of these readings in abnormal corneal situations (e.g., post-LASIK, KCN, post-RK, e.g.). The values in this box also consider the posterior cornea. The left side is self-explanatory but here is a brief explanation of the other values.

Q (6.0mm) – This is the Q-Value of the cornea at the 6.0 mm zone. Remember, to counteract the effect of spherical aberration (discussed next), the cornea is prolate (steeper centrally) by several diopters. The measure for corneal asphericity is called Q-Value. This is a dimensionless number that Pentacam® calculates using the following equation: $Q = -E^2$. The variable "E" represents corneal eccentricity which is the rate of corneal flattening from the center to the periphery. Prolate corneas are represented by a negative Q-Value and a perfect sphere has a Q-Value of 0. Oblate corneas have a positive Q-Value.

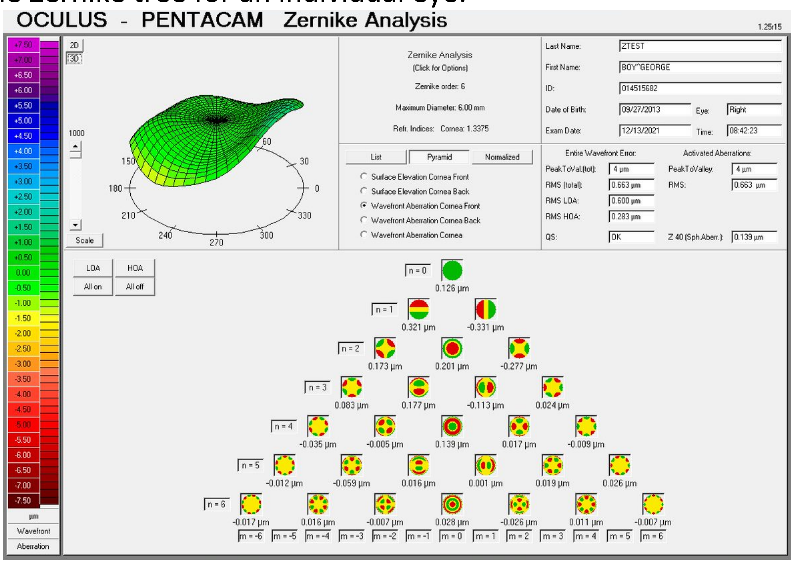
Optics of the Cornea



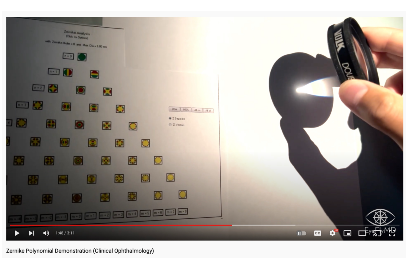
- To eliminate the effect of spherical aberration the cornea would require a Q Value of -0.52.
- When we're young, the lens has a Q value of -0.25 so we actually get pretty close eliminating spherical aberration.
- The Q Value of the lens becomes less negative with age, but the pupil also becomes more miotic, eliminating the contribution of the peripheral rays to spherical aberration.

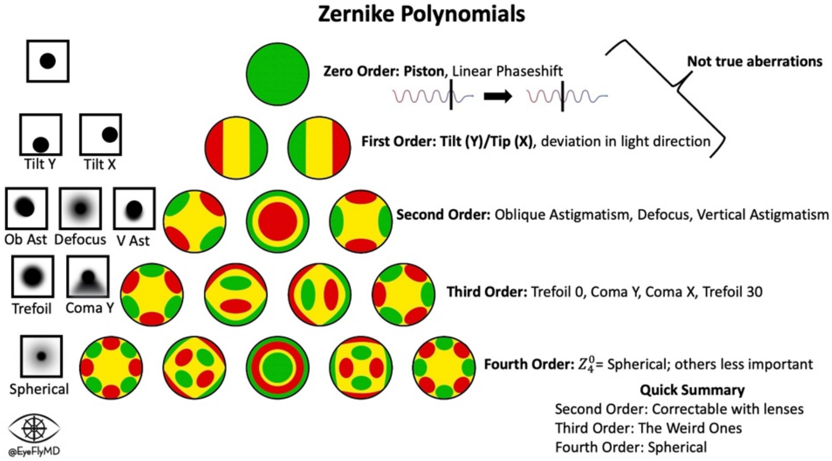
@EyeFlyMD

Total SA: Z(4+6+8,0) – This describes the spherical aberration (SA) of the cornea which is the result of peripheral light rays in spherical lenses being refracted more than central rays (they hit the lens at a greater angle). It is measured in microns (µm), the distance between the peripheral and central rays. The human cornea typically has positive SA with the peripheral rays anterior to the central. It is considered a higher order aberration (HOA). The Zernike Polynomials are a numerical system to break down the aberrations of the cornea. Spherical aberration is a fourth order aberration (Z4) but is also a sixth and eighth order aberration. The Pentacam® can display the Zernike tree for an individual eye:



This is a very complex and advanced topic, so it is easier to watch this video where I physically demonstrate the aberrations.

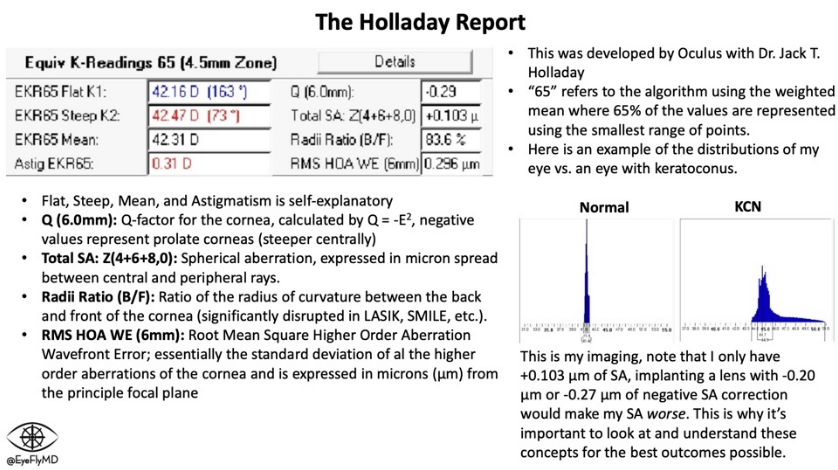




Radii Ratio (B/F) – This is the ratio of back to front Radii of the cornea. This relationship is significantly disrupted after many refractive surgeries.

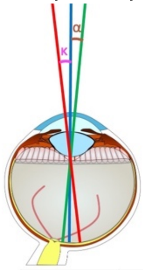
RMS HOA WE (6mm) – This is the Root Mean Square Higher Order Aberration Wavefront Error at the 6.0 mm zone. Root mean square error is expressed by the following equation where W represents wavefront deviation. It is essentially the standard deviation of all higher order aberrations of the cornea and is expressed in microns (µm) from the principle focal plane.

$$\mathrm{RMS} = \sqrt{\overline{W^2} - \overline{W}^2}$$



Selecting Premium IOLs

There are many things to think about when considering premium IOLs. The patient should have a healthy macula since light is likely to be split and the optical system should generally be in really good shape (e.g., no severe dry eye). The image should also travel straight through the center of the optic to land on the fovea so the mechanisms that allow the lens to provide presbyopia or multifocal correction work properly.



Eye Angles (Not That One)

Pupillary Axis – The line through the midpoint of the entrance pupil, perpendicular to the corneal surface
Visual Axis – The line connecting the fovea to the fixation target
Optical Axis – The line connecting the optical center of the cornea and optical center of the crystalline lens

(don't worry about this one too much)

Angle	Angle Kappa (κ)	Angle Alpha (α)	Angle Gamma
Definition	angle between the pupillary axis and the visual axis	angle between the pupillary axis and the optical axis	angle between the fixation axis* and the optical axis
Mnemonic	KVP	APO	G(t)FO
Causes	Anatomy, Macular Drag (FEVR)	Anatomy/Trauma/Surgery	Anatomy/Trauma/Surgery
Significance	Decentered LASIK ablations; positive angle simulates EXOtropia, negative angle simulates ESOtropia	A big angle makes a poor candidate for premium lenses due to misalignment with optical elements	Minimally significant *line connecting fixation target and center of eye rotation

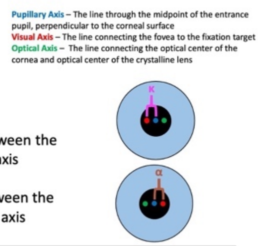
A practical way to evaluate this is on the IOLMaster® 700. The Chang-Waring (CW) Chord refers to the position of the Purkinje reflex relative to the corneal center (this is a practical measurement and similar in principle to Kappa).

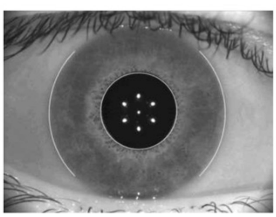
C-W Chord

The CW-Chord (Chang-Waring) – The position of the Purkinje reflex relative to the corneal center (this is a practical measurement by the biometer and very similar in principle to angle Kappa)

Ix and Iy refer to the shift of the corneal apex towards iris center

Large CW-Chords (or alpha or kappa angles) are known to negatively effect the performance of EDOF or multifocal IOLs





Angle Kappa is the angle between the pupillary axis and the visual axis

Angle Alpha is the angle between the pupillary axis and the optical axis

CCT: 592 µm		SD: 4 µm	
WTW: 12.6 mm		Ix: +0.1 mm	Iy: +0.1 mm
P: 5.4 mm		CW-Chord: 0.1 mm @ 82°	

Here are a few suggestions some experts suggest as guidelines with the CW Chord.

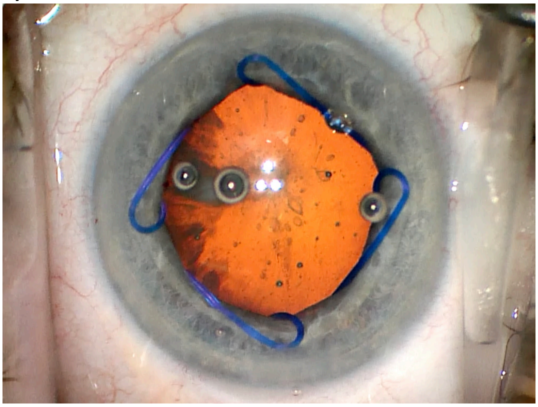
CW Cord	Lens Consideration
0.0 mm – 0.4 mm	Okay for almost all IOLs acceptable
0.4 mm – 0.6 mm	Okay for EDOF IOLs, maybe not Multifocals
> 0.7 mm	Even SA-correcting lenses may be suboptimal, consider aberration free IOLs (e.g., MX60E)

Pre-Operative Considerations

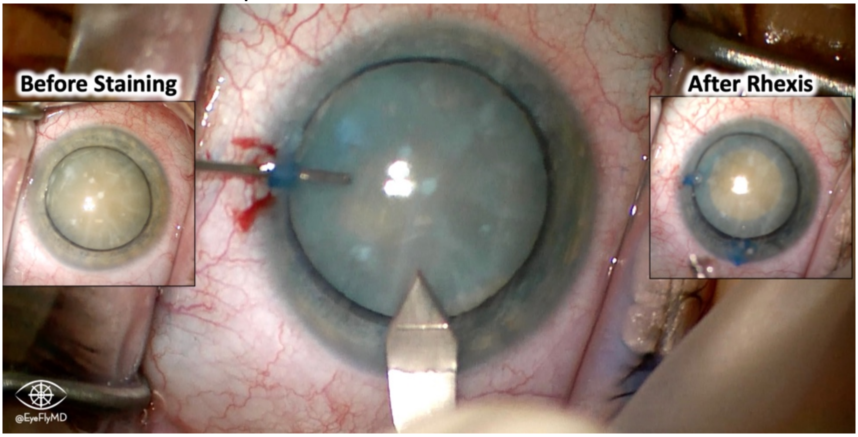
In addition to reliable measurements and an accurate formula, there are several important things to consider before operating to ensure the best possible outcome. These include but are not limited to:

- **Refractive Target/Premium Lens** – Does the patient desire distance vision, near vision, blended, or a premium/Toric lens? It's important to have clear goals and discuss expectations.
- **Ocular History/Worse Eye** – Is one eye more symptomatic? It may be beneficial to do the worse eye first to alleviate symptoms. It's also important to consider other ocular history. For example, patients with retina pathology may not be good candidates for premium or silicone lenses. This is another chance to manage expectations. Clearing the media cannot improve AMD, for example, so not every eye has the potential for 20/20. Silicone lenses may react with silicone oil if the patient ever requires certain retina procedures.

- **Dilation** – Does the eye dilate well? Will a Malyugin Ring (pictured below), Iris Hooks, or the new Visitec® I-Ring® be necessary?



- **Red Reflex** – Is the red reflex bright? Will Trypan Blue be needed to better visualize the anterior capsule for the rhexis? Trypan blue is the most common method of staining the anterior capsule to better visualize it.



- **Pseudoexfoliation/Iridodonesis/Phacodonesis** – These can all be associated with or signs of zonular weakness. Even lightly pounding your fist on the slit lamp can induce iridodonesis (shaking/wobbling of the iris) and provide clues of what to expect for the surgery. Weak zonules can be a risk factor for posterior capsular rupture so extra care should be taken.

- **Tamsulosin Exposure** – There are several medications that increase the risk of Intraoperative Floppy Iris Syndrome (IFIS) and tamsulosin is the most common. IFIS is a problem because a floppy iris is prone to prolapse through the wound.
- **Patient Fixation/Cooperation** – Is the patient nervous? Squeezing? While topical anesthesia with monitored anesthesia care is typically sufficient there may be circumstances where blocks or even general anesthesia is necessary. The van Lint facial nerve block involves injecting lidocaine ~1 cm lateral to the outer edge of the orbit to alleviate eyelid squeezing.
- **Guttae** – This may indicate the presence of Fuch's Corneal Dystrophy. Cataract surgery can lead to decompensation of Fuch's due to the phacoemulsification ultrasound energy near the endothelium so extra care must be taken (and OVD used). Patients can be counseled recovery may be prolonged.
- **Posterior Vitreous Detachment (PVD)** – A PVD is thought to be protective against retinal detachments after cataract surgery. There are many pressure changes during surgery. If the vitreous is still attached to the retina, all the anterior chamber ups and downs are translated to the retina.
- **History of Refractive Surgery** – The IOL formulas make assumptions about the relationship between anterior and posterior cornea curvature. This relationship is interrupted when only the anterior surface is changed (e.g., after LASIK or SMILE). If this was a hyperopic ablation the anterior cornea was made steeper and more *prolate* so extra consideration should be taken in the use of spherical aberration correcting IOLs.
- **First Eye** – If it is the second eye, check to see the refractive result of the other eye. If the first eye was a refractive miss, there is evidence that correcting 50% of the first eye error can improve outcomes for the second eye. This remains somewhat controversial.

Further Reading:

Naumann GO, Schlötzer-Schrehardt U, Küchle M. Pseudoexfoliation syndrome for the comprehensive ophthalmologist. Intraocular and systemic manifestations. Ophthalmology. 1998 Jun;105(6):951-68. doi: 10.1016/S0161-6420(98)96020-1. PMID: 9627642.

Seitzman GD. Cataract surgery in Fuchs' dystrophy. Curr Opin Ophthalmol. 2005 Aug;16(4):241-5. doi: 10.1097/01.icu.0000172828.39608.7c. PMID: 16000897.

Erie JC, Raecker ME, Baratz KH, Schleck CD, Robertson DM. Risk of retinal detachment after cataract extraction, 1980-2004: a population-based study. Trans Am Ophthalmol Soc. 2006;104:167-75. PMID: 17471337; PMCID: PMC1809901.

Zhang J, Ning XN, Yan H. Adjustment of IOL power for the second eye based on refractive error of the first-operated eye. Int J Ophthalmol. 2019 Aug 18;12(8):1348-1350. doi: 10.18240/ijo.2019.08.18. PMID: 31456928; PMCID: PMC6694055.

I find it helpful to have a premade sheet with important case information readily available on surgery day (in addition to the IOL calculations). An example can be found below:

Date							
Name	**Date of Birth**	**Eye**	**Procedure**	**Lens/Power**	**Ocular History**	**MRx OU/Second Eye?**	**Refractive Target**

Phacodynamics

The introduction of phacoemulsification in 1967 has made cataract surgery safer and allowed for the small wounds that are possible today. Understanding the details of using “ultrasound” to remove a lens is critical to maximize efficiency during catract surgery. The phaco needle moves at ultrasonic speeds and has intricate interactions within the eye. Phacodynamics is a massive and complex topic, but here we will review general concepts and the basics.

Inflow

The eye is kept at pressure during cataract surgery to maintain structure of the anterior chamber (which is also accomplished with viscoelastic which are discussed shortly). To sustain this pressure, modern phacoemulsification machines use a constant inflow and outflow of fluid (typically BSS with some optional additives) through the handpiece.

Inflow was traditionally achieved through use of gravity. The BSS bag was suspended at a certain height above the patient’s eye level. Every 6 inches above eye level equates to about 11 mmHg. Newer machines use forced pressure to provide finer control over intraoperative pressure and improved anterior chamber stability.

Outflow

Fluid (and other material) must be removed from the anterior chamber. The most common mechanisms are by use of peristaltic or venturi pumps. Some machines use both.

Peristaltic pumps move rollers over a flexible tubing to move fluid (like a dialysis machine). They directly control aspiration rate as well as vacuum. Vacuum is achieved by occluding the phaco tip while the rollers continue to move fluid through the tubing which builds up vacuum.

Venturi pumps use the venturi effect to move fluid through the tubing. They can only directly control vacuum level. Aspiration depends on the amount of vacuum.

Rise time refers to the time it takes to reach the preset vacuum setting (assuming tip occlusion) and is typically faster with Venturi pumps.

Phacoemulsification

The Phaco needle moving at ultrasonic speeds has two mechanical effects on the lens material. **Jackhammer** is the consequence of the phaco needle striking the lens. Many believe this is the only contributor to the process of phacoemulsification. Because the needle moves so fast, there are also pressure-related consequences. When the needle moves backwards, low pressure is induced which pulls gasses out of solution creating microbubbles. When the needle moves forward, high pressure is induced which compresses the microbubbles until they explode. This process is called **cavitation**. Cavitation can cause tissue damage and is not thought to largely contribute to the phacoemulsification process.

The delivery of energy is controlled by a foot pedal. The foot pedal has multiple positions. In addition to accessing the positions by depressing the pedal, many other settings can be controlled by various buttons on the foot pedal. It's critical to understand the settings of the phaco foot pedal as well as the microscope foot pedal.

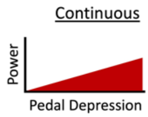
Position 1 activates irrigation, or the continuous washing of BSS through the anterior chamber. This does not engage aspiration or deliver any ultrasound energy.

Position 2 activates aspiration and draws material through the phaco tip.

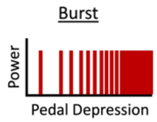
Position 3 engages ultrasound energy and this energy can be applied in different ways.

The different "modes" describe the manner in which phaco energy is applied.

Continuous mode relates the amount of phaco power to pedal depression in Position 3. The further the pedal is depressed, the greater the power delivery.

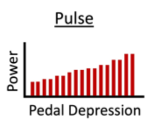


Burst mode allows intervals between application of ultrasound energy. In burst mode, the further the pedal is depressed in Position 3, the shorter the interval between bursts. Phaco energy pushes the lens material *away* from the tip so having interruptions in energy delivery allow the aspiration to pull the material back *towards* the tip.



The bouncing of lens material off the phaco tip due to the repulsive force of the phaco energy is called **chatter**.

Pulse mode is similar to continuous but employs *duty cycle*. This is the most efficient mode because it reduces overall energy delivery by provide "off time" in between phaco bursts which allows the tip to cool.



Phacodynamics and the Phases of Surgery

There are numerous ways to disassemble a nucleus during cataract surgery but "divide and conquer" is extremely common in the US and among the most often first taught so that will be the focus of this work in the next chapter.

During grooving (also called "sculpting"), high ultrasound energy is used with *low* aspiration and *low* vacuum setting. This makes sense as the use of high phaco power to initially carve into the lens creates a dangerous situation of aspirating the iris or capsule if there is too much aspiration or vacuum.

Contrast this with quadrant removal which uses a high aspiration and vacuum setting with low ultrasound energy. Good purchase on the quadrants is essential to "pull" them from the capsule. Care must be taken not to engage Position 3 when within the capsule though. The combination of higher aspiration and phaco energy can get sporty.

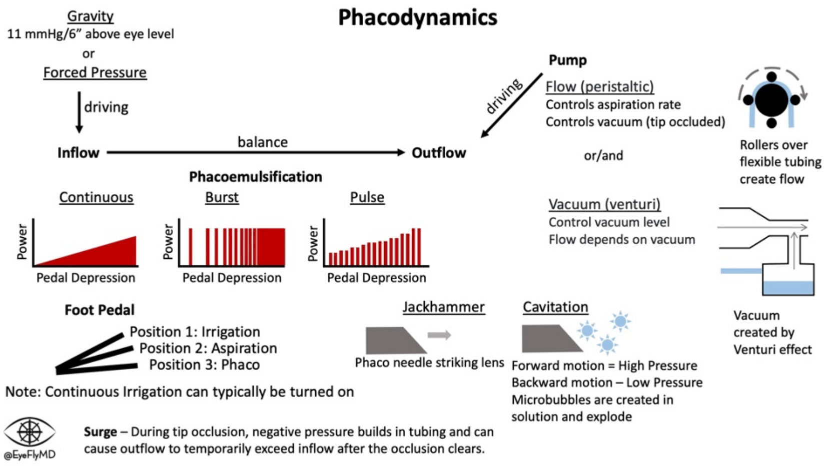
Surge

It is also important to be aware of the phenomenon of **surge**. Consider occluding the phaco tip with a peristaltic pump. The tubing is *compliant* meaning it is flexible and compressible. As continued peristaltic action creates negative pressure within the tube (vacuum) during tip occlusion the tubing can collapse. When occlusion is interrupted, the tubing can return to its normal shape and creates an additional vacuum force which pulls fluid from the anterior chamber. This means that things (like the capsule) can move towards the tip so be aware of this phenomenon. It's less common with newer machines.

Phaco Needles

Lastly, it's critical to know details of your instruments. Phaco needles can be beveled from 0-60°. Higher levels are harder to occlude as the opening is more ellipsoid but are more favorable for sculpting/grooving. The speed of the needle movement varies by manufacturer but is typically 35,000 - 45,000 Hz. For very dense lenses, *torsional* mode can be used which introduces a circular motion to the phaco tip in addition to the typical forward/backward action.

A (brief) summary of phacodynamics is below:



The Steps of Cataract Surgery

Ophthalmic Viscosurgical Devices (OVDs)

Before discussing the steps of cataract surgery, it's essential to understand the concept of Ophthalmic Viscosurgical Devices (OVD, also called "viscoelastic" or "visco"). These space-filling agents have made cataract surgery much safer since 1979. They are generally divided between "cohesive" and dispersive" OVDs. The different characteristics of the OVDs are achieved by different concentrations of sodium hyaluronate, chondroitin sulfate, and/or hydroxy-propyl-methylcellulose.

Cohesive OVDs have a high viscosity and stick to themselves. They fill the anterior chamber and provide some pressure which is helpful for portions of surgery like the IOL insertion. They are sometimes compared to spaghetti with long molecular compounds that tangle on themselves and are relatively easy to scoop out (remove from the eye).

Dispersive OVDs have low viscosity and stick to ocular structures. They are good at protecting structures like the endothelium from ultrasound phacoemulsification energy. They are analogous to macaroni with shorter molecular compounds that spread easily but are more difficult to remove (they require more "scoops" to clear the "bowl"). This means it's possible to clog the trabecular meshwork and raise IOP after surgery. These are often used first in the case so there's plenty of time for them to be completely removed.

OVD Examples		
Cohesive	**Dispersive**	**Combination**
Alcon	**Alcon**	**Alcon**
ProVisc®	Viscoat®	DisCoVisc®
BAUSCH + LOMB	**BAUSCH + LOMB**	**BAUSCH + LOMB**
Amvisc®	ClearVisc™	Amvisc® Plus
J&J	OcuCoat®	
HEALON®	**J&J**	
HEALON GV®	Healon® EndoCoat	

The Alcon DuoVisc® Viscoelastic System is a package with both ProVisc® and Viscoat®.

Basic Steps of Cataract Surgery

As mentioned earlier, most cataract surgery is in the extracapsular fashion using phacoemulsification.
Here is a basic summary of the steps.

1. A 1mm paracentesis is made.
2. Phenylephrine with Lidocaine is injected into the anterior chamber (AC).
3. Viscoelastic is injected into the eye to preserve the AC.
4. A 2.4mm (sizes vary) clear (cornea) or near-clear (some limbal vessels) corneal incision is made temporally using a keratome. Most studies have shown incisions < 2.6mm do not result in surgically induced astigmatism.
5. Continuous curvilinear capsulorhexis is achieved using different tools, creating a ~5.5mm opening in the anterior capsule.
6. Hydrodissection is achieved by injecting BSS via Chang (or other) cannula immediately underneath the anterior capsule. This will facilitate lens rotation and cortical removal.
7. The lens is rotated to ensure complete separation from the capsule.
8. Phacoemulsification – Liquification and aspiration of the lens nucleus.
9. The remaining cortical material is removed using I/A handpiece.
10. Cohesive viscoelastic is injected into the capsule prior to pulling out the I/A handpiece.
11. The foldable IOL is injected into the capsule.
12. The viscoelastic is removed and BSS is injected to reform the chamber.
13. Hydration of both wounds ensure watertight seal.

The final refractive outcome is dependent on the correct IOL orientation producing the expected optics. An IOL should form a BACKWARDS "S" when in the bag. If you see a normal "S", STOP and THINK.

Detailed Steps of Cataract Surgery

The following is a detailed narrative through a case of very routine cataract surgery with the reasoning behind certain steps. This is not medical advice or intended for surgical training. It is only one of many ways to perform cataract surgery. There are numerous techniques to accomplish every step and even I don't do things exactly the same way every time either. This is a fairly representative case of how most residents are likely to learn the procedure so hopefully it provides a helpful look into cataract surgery.

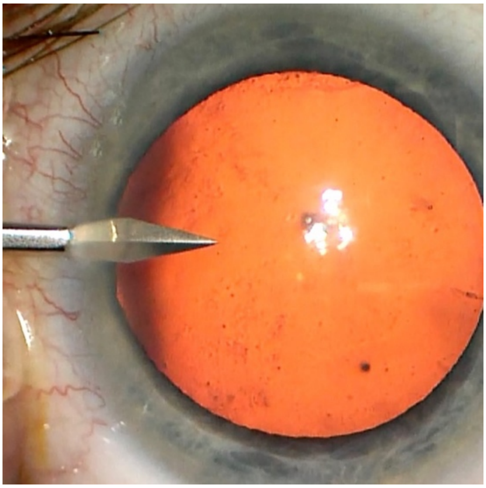
This case uses the "Divide and Conquer" method of nuclear disassembly. The phacoemulsification machine used was an Alcon Centurion® which uses a peristaltic fluidic pump. Contrast this with a BAUSCH + LOMB Stellaris® which uses a Venturi pump. Without getting into phacodynamics, these are just two different ways to create aspiration.

One other point worth mentioning is an old aviation saying: "A perfect landing starts with a perfect pattern". The "pattern" refers to the traffic pattern, or square lap pilots fly around a runway before landing. This allows time to configure the aircraft and prepare for landing. Everyone wants to have a perfect landing, but the traffic pattern can often become tedious since it essentially involves flying circles in the sky. The traffic pattern is where energy is dissipated, and the aircraft is put into the correct configuration to land though. The landing starts here, and a poorly flown traffic pattern is an easy path to a bad landing. A pilot must set themselves up for a good landing. Cataract surgery is similar. Every early step counts. If the draping is obstructive or the wounds aren't placed well, the manipulation of instruments in the eye may feel awkward. If the rhexis is too small, it may be damaged and cause a rent. Every step builds on the next so don't underestimate the value of perfecting the paracentesis!

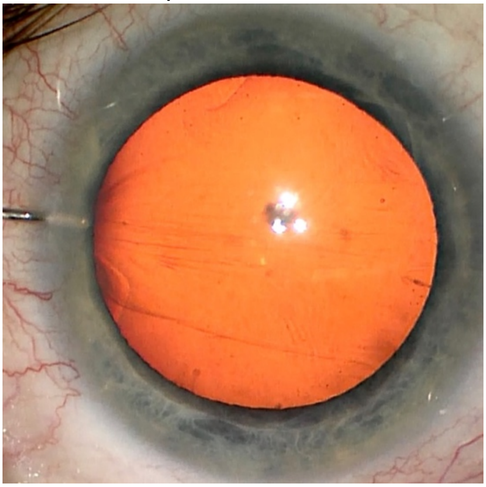
Also, the microscope is a tool and should never be a limitations be *extremely* familiar with the functions before ever sitting as primary surgeon!

WOUNDS

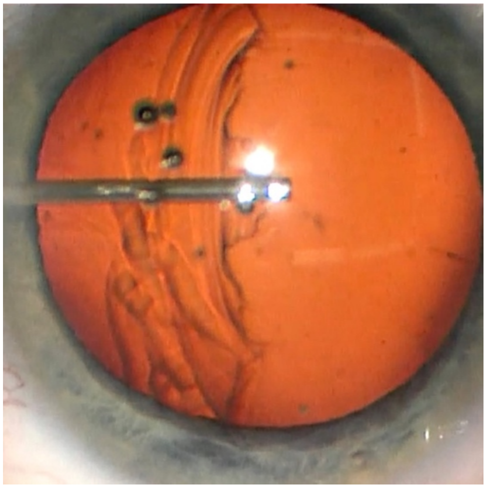
Counter pressure is applied to the eye in some fashion so a paracentesis can be created using a Sideport Blade around 9 o'clock from the surgeon's perspective. I like to use a cut Weck-Cel® Cellulose Eye Spear for counter pressure. The widest part of the blades are passed through the endothelium to ensure an even and complete wound.



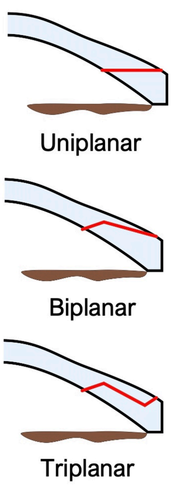
Phenylephrine with lidocaine is injected into the paracentesis. This is to provide additional anesthesia as well as dilation. When entering the eye with a cannula, "wiggling" is sometimes more effective than trying to shove. This solution can also be sprayed over the ocular surface to provide additional anesthesia.

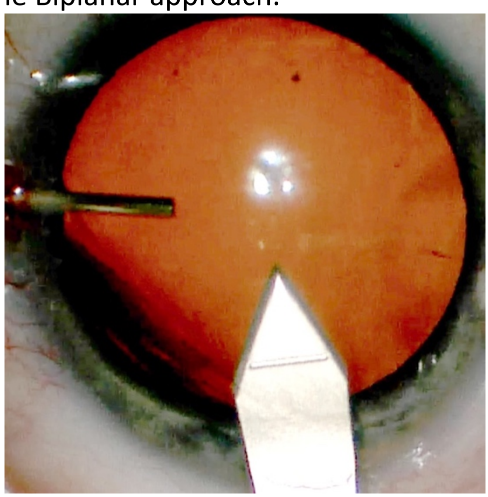


A dispersive OVD is injected into the anterior chamber. Upon entering the eye, it’s good to immediately begin injecting to protect any structures from the cannula. I start in the angle across from the paracentesis to push the fluid out of the eye. This forms the anterior chamber and coats the endothelium.



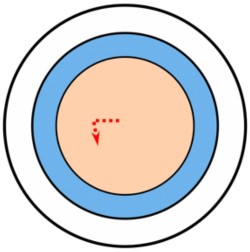
A main wound is created using a Microkeratome, the cannula from the dispersive OVD is left in the paracentesis to further stabilize the eye. Most wounds are <2.6 mm as the research has shown wounds of this size have minimal effect on surgically induced astigmatism. There are multiple ways to construct a main wound. I favor the Biplanar approach.

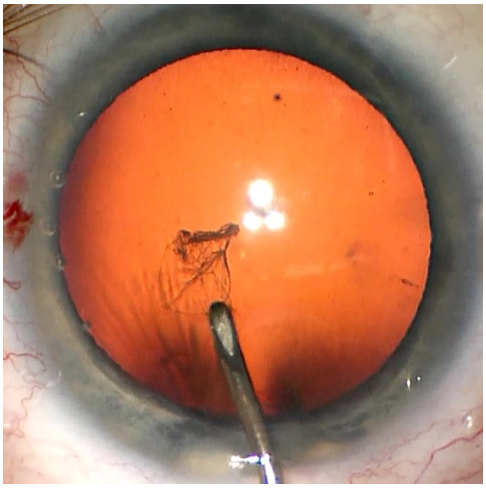




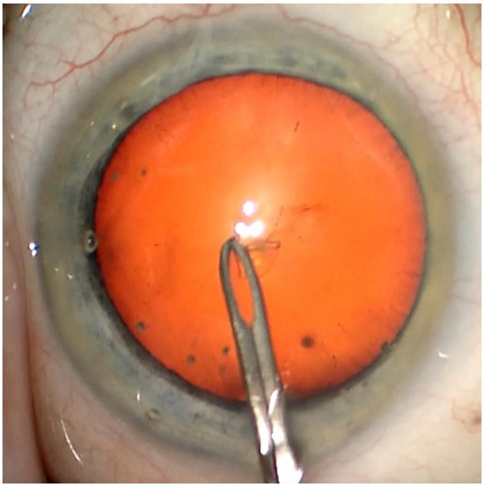
CONTINUOUS CURVILINEAR CAPSULORHEXIS

A cystotome needle is used to create a flap just left of center in a “reverse 7” pattern. This is to provide something to grasp with the forceps. This method of flap creation is among the most common for beginning surgeons.

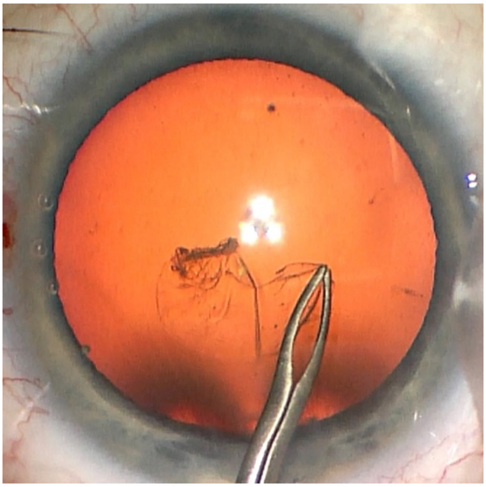




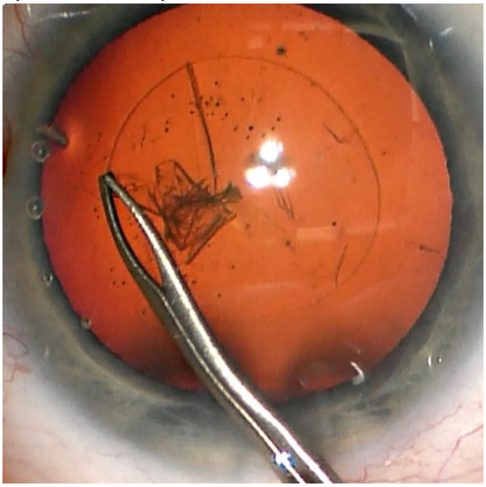
The rehxis flap can be started several ways. Some pierce the capsule with the paracentesis blade. Others pierce it with the Utrata or Giannetti forceps and immediately grab the flap as below.



The flap is grasped with Giannetti Forceps. The way the flap is laying tends to predict the shape of the rhexis. Getting the feel for the way to apply force to minimize the chance for runout and accomplish a circular rhexis is difficult and takes time. It's reasonable to grasp the flap once per quadrant, "backing it up" and folding it over itself before letting go to provide an edge to regrasp 2-3 mm from the tear.



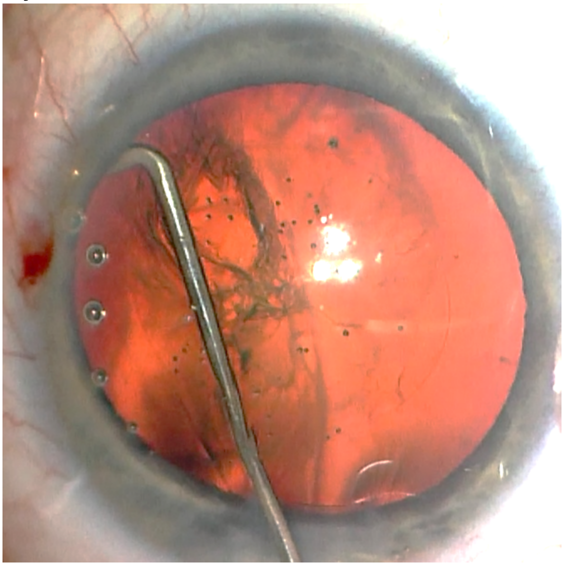
The goal is to create a rhexis of 5.0-5.5 mm since this will cover the edge of the optic to hold it in place and minimize the risk for capsular phimosis. A lot of problems can arise from the rhexis, so this is an important step to master.



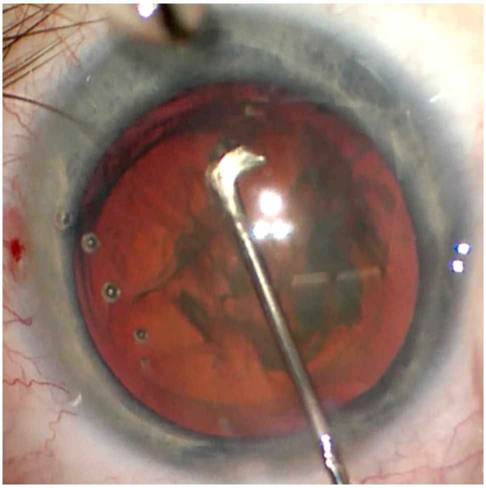
I sometimes imagine leading the tear by 90° (3 clock hours) and applying force in ~45° to the angle formed by a tangent line on the tear.

HYDRODISSECTION

A Chang cannula on BSS is inserted, applying a little downward pressure to the wound to relieve some OVD (to avoid over-pressuring the eye). The tip of the Chang cannula is placed under the rhexis ~10 o'clock, tenting the anterior capsule a little and BSS is injected. Notice the fluid wave behind the lens.

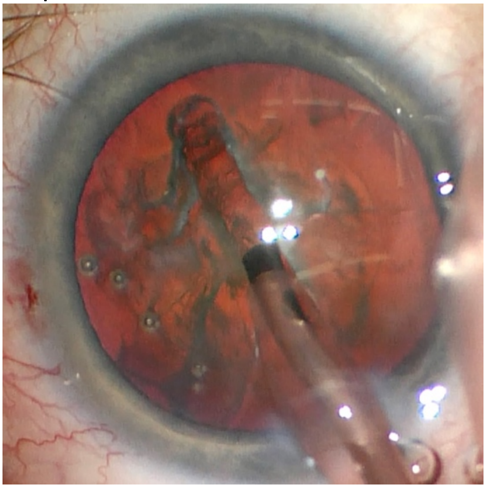


The lens can also be rocked to allow propagation of the fluid wave behind the lens and ensure the lens will spin and is free in the capsule.

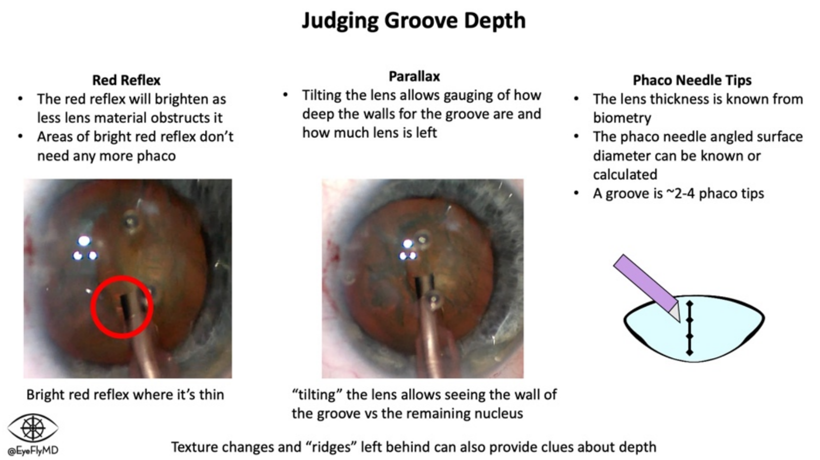


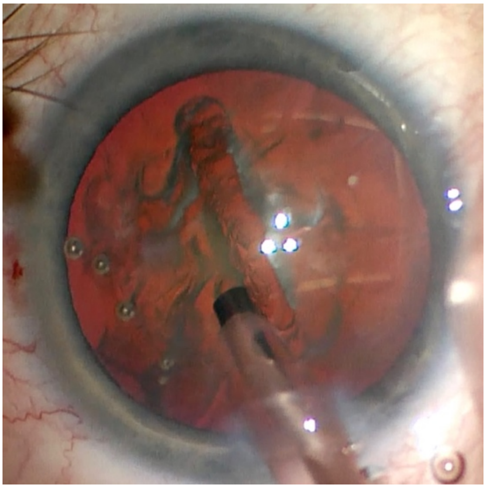
GROOVING AND CRACKING

On “Sculpt” mode for the Alcon Centurion®, ~ 2 full thickness “phaco tip” passes are made through the center of the nucleus. It's a good habit to be careful and only use the minimum amount of energy necessary to make it through the nucleus, otherwise the “walls” of the groove may fray and that makes it more difficult to position the instruments for a successful crack.

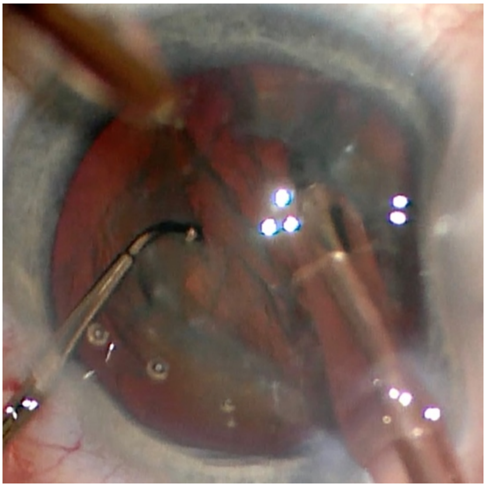


There are multiple ways to judge depth of the phaco needle. The red reflex will brighten as the nucleus becomes thinner. Additionally, parallax can be used by rocking the lens back and forth to look at the walls of the groove and how much nucleus is left. Lastly, the phaco needle is ~1mm so most lenses can tolerate 2 full thickness passes. Another "aviationism" is the concept of "sight picture." There are ways some things are supposed to look (e.g., landings), and it takes time to develop a "sight picture" for groove depth.

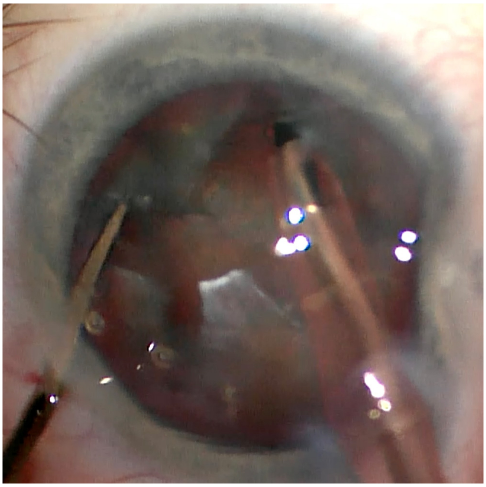




The second instrument and phaco needle are inserted DEEP into the groove for maximal traction. The lens is cracked using a rotational motion of the second instrument (in this case Angled Connor Wand) and a small amount of downward traction. After the lens is cracked in a "V" shape, it can be cracked in an "A" shape to crack it all the way through. It's sometimes necessary to rotate the lens 180° and possibly phaco some more to achieve a complete crack.

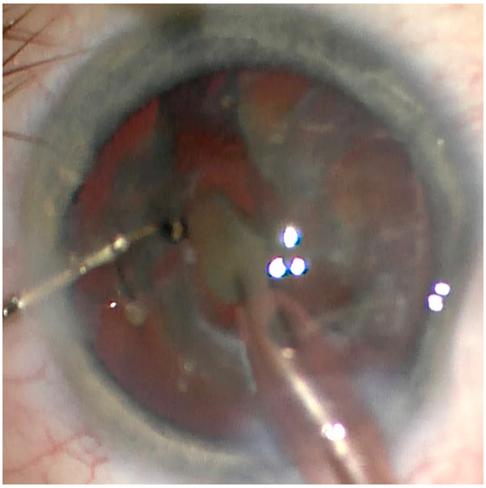


The lens is rotated 90° and the hemipiece is grooved and cracked in a similar manner.

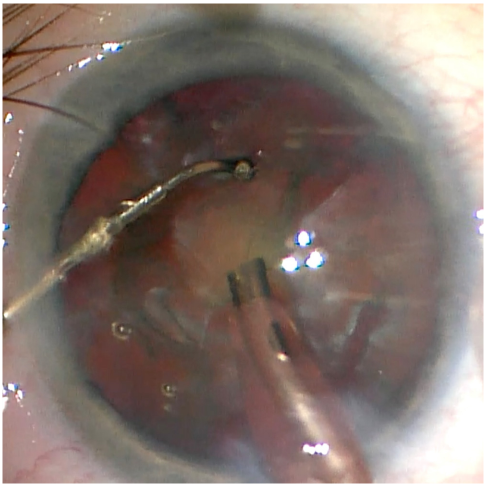


PHACOEMULSIFICATION OF THE LENS

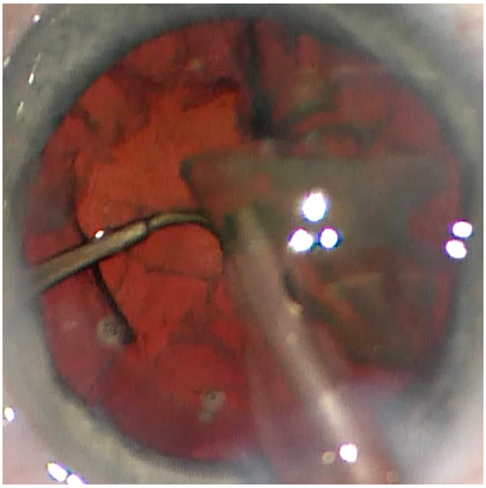
On “Chop” or “Quadrant Removal” mode on the Alcon Centurion®, a piece of the lens is aspirated and brought to the iris plane.



On “Quadrant Removal” mode on the Alcon Centurion®, the segment is emulsified. The posterior capsule at this point is protected by the remaining lens. The other quadrant is removed similarly. The remaining hemisphere is rotated to the nasal area and grooved and cracked.

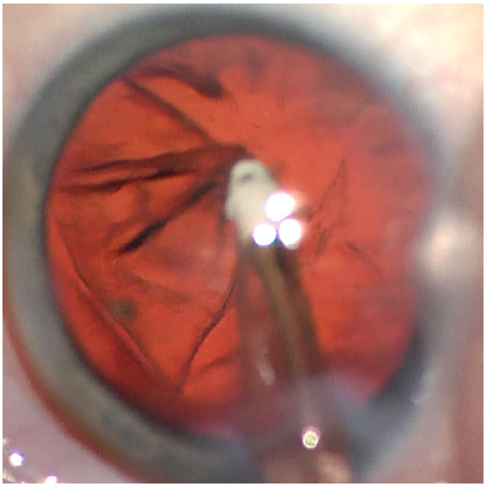


The last two quadrants are removed taking great care to protect the posterior capsule (I.e., keep it away from the phaco needle) using the second instrument.

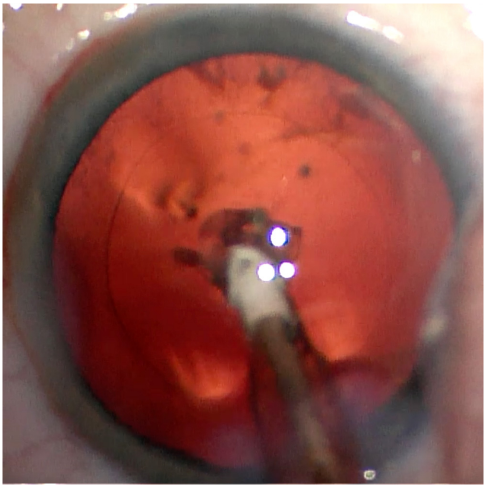


CORTEX REMOVAL

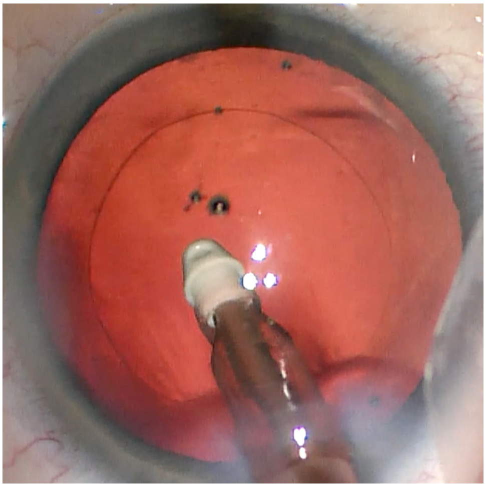
With the I/A handpiece, it's sometimes easier to remove subincisional cortex first since it's typically the most difficult. The port is occluded with cortex and the cortex is "peeled" off the capsule.



The port is always lifted to face up before more aspiration is applied to avoid inadvertently aspirating the capsule.
This process is repeated for the entire capsule. Circular motions are sometimes safer as opposed to “peeling” toward the center to minimize stress on the zonules.

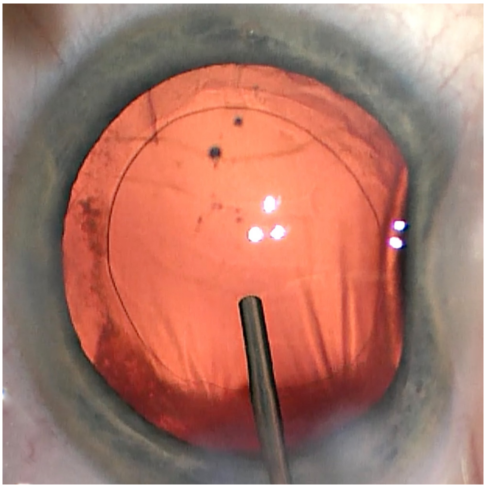


In “Polish” mode on the Alcon Centurion®, any sticky spots of cortex are removed from the posterior and anterior capsule

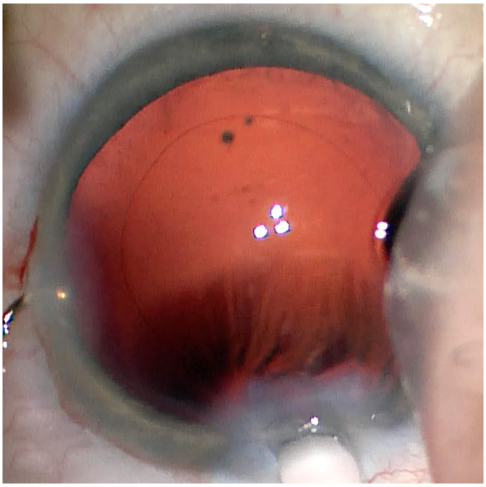


LENS INSERTION

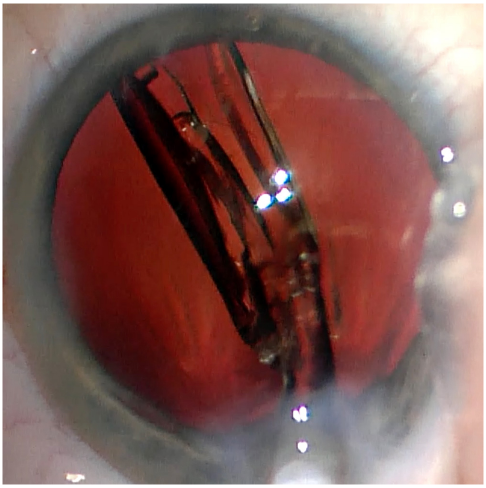
Cohesive OVD is injected into the AC and capsule to form them for receiving the lens.



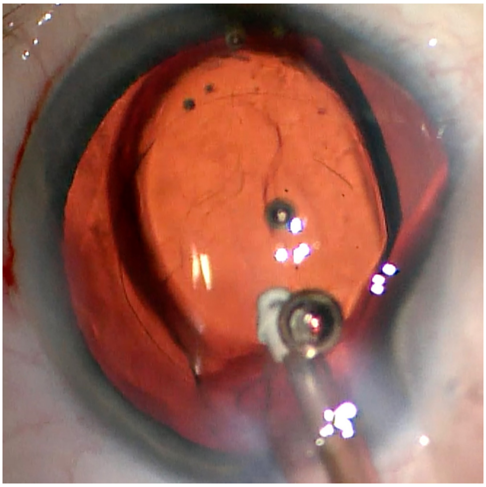
The second instrument is used to stabilize the eye by the paracentesis.



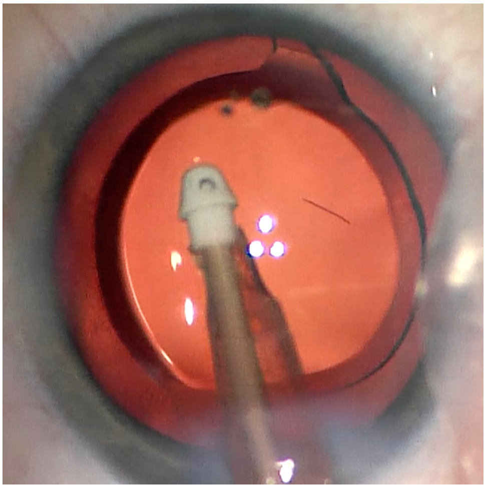
The injector is twisted, and the lens is inserted into the capsular bag. The injector is removed when the lens reaches the capsular fornix to avoid stressing the capsule.



The I/A handpiece is used to sink the temporal haptic into the capsular bag.



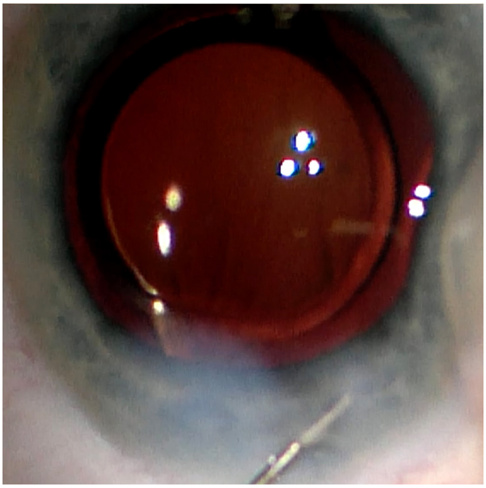
The OVD is aspirated in “Visco” mode; care is directed toward the angle and endothelium to remove all the OVD.



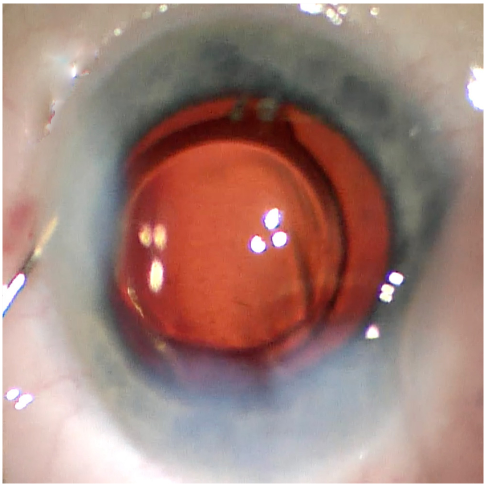
The lens is dialed (rotated) with the I/A handpiece to ensure the haptics are inside the bag. During this, watching the rhexis for peaking can provide clues if a haptic is in the sulcus.

WOUND CLOSURE

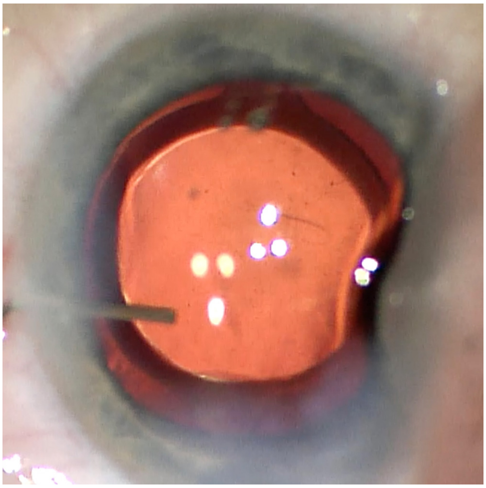
BSS is injected into the corner and along the length of the main wound taking care not to harm Descemet's Membrane.



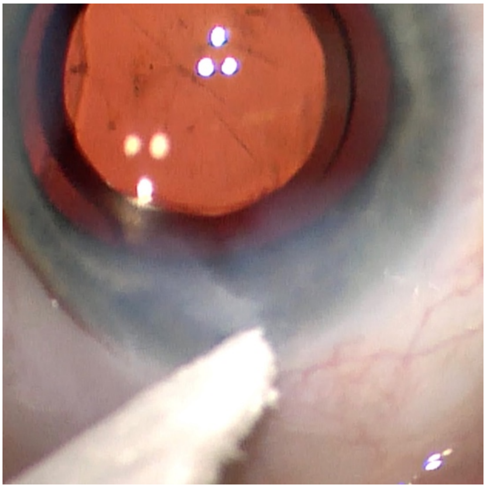
BSS is injected into the corner of the paracentesis wound to achieve a watertight seal.



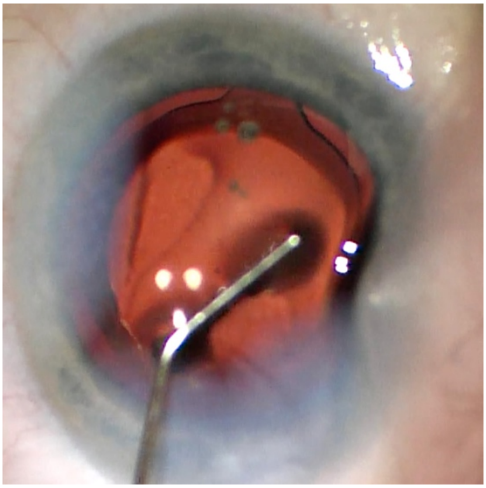
Vigamox is injected into the AC via the paracentesis.



The integrity of the wounds is confirmed with a Weck-Cel® Cellulose Eye Spear.



The cornea is tapped to ensure normal IOP. This takes some time to get a feel for.



Lens Loading

A step that was not mentioned above is loading the IOL for insertion. Many IOLs are preloaded now and those that aren't are typically loaded by the scrub tech. All surgeons and residents should know how to load IOLs just in case. This is also a common way for new surgeons and medical students to become involved in the OR. It's not immediately intuitive, but knowing how to do it well and reliably will provide a great advantage in your training. Here are videos on how to load a single and 3-piece IOL.

Single Piece **3-Piece**

Complications

Intraoperative Complications

Complications and their management could (and likely will) be a separate piece since it's a vast topic. This section will be brief as the focus of this book was on typical, straightforward cataract surgery. We will still review select complications.

One of the most dreaded complications is Posterior Capsular Rupture (PCR). This is when the posterior capsule is violated, and a passage is created for the vitreous to enter the AC. Visual outcome depends on this being handled carefully.

There are plenty of resources on managing PCRs but the most important thing is to not immediately exit the eye. This will cause the AC to shallow and allow vitreous to come forward. Leave the infusion handpiece in the eye, remove the second instrument, and stabilize the AC with OVD.

PCRs are much more common in novice surgeons. Visual outcomes can still be excellent. If the anterior rhexis remains intact a 3-piece IOL can be placed in the sulcus with or without "optic capture". Optic capture refers to "tucking" the optic portion behind the rhexis, so it is sitting in the approximate position it was intended. If there is a problem with the rhexis the IOL can be placed in the sulcus without optic capture. If the entire capsule is compromised and there is limited support for an IOL an anterior chamber IOL can be placed.

Posterior Capsule Rupture

Risk Factors

- Increasing Age
- Corneal opacities (poor view)
- Advanced cataract (poor view)
- Post-Vitrectomy (no support)
- Pseudoexfoliation (zonular weakness)
- Shallow AC (crowded chamber)
- High myopia (thin capsule)
- Inexperience

Incidence: 0.45-3.6 %, up to 9% for resident cases

Management

- DO NOT immediately withdrawal instruments, stabilize the AC
- Carefully withdrawal the second instrument
- Inject OVD through the sideport
- Switch machine settings to Low Fluidics
- If vitreous prolapses, perform and anterior vitrectomy
    - The optimal settings are CUT first, then I/A; you don't want to be aspirating vitreous that may still be attached to retina
- A PPV may be necessary to remove lens material lost in the posterior segment

Beware...

- The CCC, don't let the rhexis run out, use the Little technique if you have to
- Know lens thickness and how deep the grooves are, don't phaco through the peripheral bag
- Protect the posterior capsule with the second instrument during nucleus removal, don't ever phaco near the bag
- Be gentle with I/A, circular motions put less stress on the zonules
- When it happens, don't panic; focus on stabilizing the anterior chamber and preventing parts from falling into the posterior segment

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If pieces of nucleus or cortex are lost in the posterior segment a pars plana vitrectomy may be necessary. Patients are typically monitored closely. One of the greatest pieces of wisdom I have received regarding PCRs is “if it’s hasn’t happened to you, you haven’t done enough surgery.”

If a 3-piece IOL is placed in the sulcus, a correction must be applied to the power as the lens will be sitting further anterior than anticipated. Below is a common correction table based on the work of Jack T. Holladay, MD and Warren E. Hill, MD.

IOL Power	Sulcus Adjustment
+25.50 D – +30.00 D	-1.50 D
+15.50 D – +25.00 D	**-1.00 D**
+8.50 D – 15.00 D	-0.50 D
+1.00 D – 8.00 D	NO CHANGE
Based on the work of Dr. Holladay and Dr. Hill	

A suprachoroidal hemorrhage is another dreaded complication that typically presents as loss of red reflex and anterior chamber shallowing. This describes when the long or short ciliary arteries fill the space between the choroid and the sclera with blood. This can be *expulsive* and cause extraocular contents to exit through the wounds. Thankfully this is rare.

Postoperative Complications

Suprachoroidal hemorrhage can also occur in the immediate postoperative period. It typically presents with eye pain. Management typically involves beta blockers and steroids.

Toxic Anterior Segment Syndrome (TASS) usually occurs in the first 24 hours following cataract as profound corneal edema, inflammation, and reduced vision. It is a sterile inflammation typically due to a contaminant during some step of the procedure. Treatment usually consists of aggressive steroids.

Endophthalmitis refers to purulent inflammation of the anterior and posterior segment. This typically presents 1-2 weeks after surgery and is usually caused by *Staphylococcus*. More chronic forms can be caused by more indolent organisms.

Cystoid Macular Edema typically occurs around 4-6 weeks after surgery and is more common in diabetics. It is sometimes prudent to start diabetic patients on a topical non-steroidal anti-inflammatory agent before and after surgery.

Retinal Tears or Detachment can occur months to years after surgery.

The most common "complication" is proliferation of remaining posterior lens epithelium. This is called Posterior Capsular Opacification (PCO) or secondary cataract and occurs about 20% of the time after surgery. The cataract can never recur because the lens has been removed but the capsule that is holding the lens can opacify and the patient can experience recurrence of cataract symptoms. An Nd:YAG laser is used to break the fibrous bands causing the symptoms.

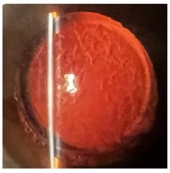
Another very common "complication" after cataract surgery is worsening symptoms of dry eye. This can be temporary. The new term for this is Surgical Temporary Ocular Discomfort Syndrome (STODS) which refers to the temporary worsening of ocular surface symptoms after any refractive surgery.

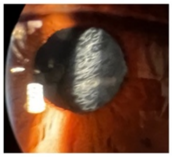
Further Reading:

Ursell PG, Dhariwal M, O'Boyle D, Khan J, Venerus A. 5 year incidence of YAG capsulotomy and PCO after cataract surgery with single-piece monofocal intraocular lenses: a real-world evidence study of 20,763 eyes. Eye (Lond). 2020 May;34(5):960-968. doi: 10.1038/s41433-019-0630-9. Epub 2019 Oct 15. PMID: 31616057; PMCID: PMC7182577.

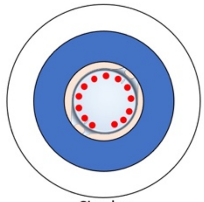
Posterior Capsular Opacification

- "Secondary cataract"; the most common postoperative complication of cataract surgery
- Residual lens epithelial cells from the anterior capsule undergo proliferation, migration toward the posterior capsule, and normal and abnormal differentiation
- Can feature Elchsnig Pearls (of swollen Bladder/Wedl cells), Soemmering Rings (where anterior and posterior capsule meet), or Capsular WRINKLING
- Occurs in 20-50% of patients within 2 to 5 years of cataract surgery


Elschnig Pearls


Dense PCO


Cruciate


Circular

The 1064 nm Nd:YAG "YAG" laser uses photodisruption to open the posterior capsule using most commonly a cruciate or circular pattern (sometimes spiraling if lens dislocation is a concern) with a typical power between 0.8 – 3.0 mJ and between 10-20 shots

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Since YAG is such a common laser medium, it's worth discussing a little further. Yttrium-Aluminum-Garnet (YAG) is a clear, synthetic gemstone that used to be common as a synthetic diamond before cubic zirconia became widespread. When doped with Neodymium, it becomes purple, and the crystal serves as the laser medium for the YAG lasers in clinic.

Ophthalmology Lasers and Wavelengths

Increasing Intensity ↓

Tissue Interaction	Mechanism	Example	Relevant Wavelength
Photochemical	Photocatalysis	PDT, Corneal Crosslinking	CXL = UVA
Thermal	Increase in Temperature	PRP	513 nm (Argon Green)
Photoablation	UV Dissociation	LASIK, PRK	193 nm (Excimer)
Plasma-Induced Ablation	Plasma Ionization	SMILE	1053 nm (Femtosecond)
Photodisruption	Shock-Wave Generation	YAG	1064 nm (Nd:YAG)

LASER

Light **A**mplification by **S**timulated **E**mission of **R**adiation

Other Notable Wavelengths

- The visible spectrum is ~400-700 nm
- Rhodopsin is most sensitive to 510 nm
- Melanin, hemoglobin, and xanthophyll strongly absorb 400 nm - 580 nm
  - Because of this the retina is especially sensitive to blue light
- The natural Crystalline Lens blocks UV-A light (315–400 nm)
- The cornea blocks:
  - UV-B (280–315 nm)
  - UV-C (280 nm and below)
  - IR-B and IR-C (1400 nm to 1 mm)

$$Power = \frac{Energy}{Time}$$

$$Fluence = \frac{Energy}{Area}$$

$$\textbf{Intensity}\ (Power\ Density) = \frac{Power}{Area\ (cm^2)} = \frac{Energy}{Time \times Area}$$

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Notes:

Watch a case!

https://youtu.be/osVvjEt9AlM

This book series is dedicated to my first teachers:
Raymond & Helen Holderle

I would also like to thank the patients whose images were used throughout for helping further ophthalmology education.

All images are original and released after obtaining a HIPAA authorization. All graphics and diagrams are original.

Thank you for reading! Please submit any errors, feedback, questions, or inquiries to matt@eyeflymd.com.

The Eye Guide: Cataract Surgery

This short book is a summary of high-yield topics in cataract surgery that provides significant detail from preoperative planning to surgical technique of a typical procedure. Starting with the history of cataract surgery, I focus on concepts that constitute a reasonable "baseline" of knowledge for new residents and eager medical students. Special attention and detail is given to areas that have relatively limited resources or I found confusing. Hopefully this will be a helpful reference guide.

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