Cataract Surgery in the Glaucoma Patient

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Abstract

This article describes the changing treatment of co-existent cataract and glaucoma over the past 70 years. Seventy years ago, the cataract was removed using an intracapsular technique. Glaucoma was always controlled with a scleral fistulizing operation before the cataract was removed. In 1975, Charles Kelman introduced phacoemulsification. When clear corneal incisions were introduced for phacoemulsification, glaucoma surgery no longer needed to precede cataract surgery. The combined procedure of phacoemulsification/lens implantation and trabeculectomy became popular 10 years ago. Recently, non-bleb treatments for glaucoma have emerged that eliminate the problems associated with trabeculectomy. These procedures include phaco/intraocular lens (IOL) alone, trabectome, iStent®, and canaloplasty. A major cause of adult glaucoma, the enlarging crystalline lens as it ages, was recognized in 2007. Greater IOP reductions following phaco/IOL alone were discovered at this time. Phaco/IOL may emerge as the preferred treatment of co-existent cataract and glaucoma. Trabectome can be added to phaco/IOL if greater IOP reduction is needed.

Keywords

Phacoemulsification, artificial lens implantation, phaco/intraocular lens (IOL), co-existent cataract and adult glaucoma, trabecular meshwork, canal of Schlemm, trabeculectomy, combined procedure, canaloplasty, trabectome, iStent®

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According to Research to Prevent Blindness, 20.5 million US citizens have cataract, and two million are visually impaired with glaucoma. Today, we operate on approximately three million cataracts a year, and 10% of these patients have co-existing glaucoma; so, 300,000 times a year, a US surgeon must decide how to treat a patient with co-existent cataract and glaucoma.

Treatment Has Changed for Co-existent Cataract and Glaucoma During the Past 70 Years

From 1940 to 1975 the predominant method of cataract removal was intracapsular surgery. Since intracapsular surgery entailed removing the lens capsule, the lens capsule could no longer serve as a barrier between the anterior vitreous and aqueous. Without this barrier, vitreous mixed with aqueous in the anterior chamber in many aphakic eyes, and caused many fistulas of glaucoma operations to fail if glaucoma surgery was performed after the cataract was removed. Also, the limbal incision through conjunctiva and sclera made with intracapsular surgery created scleral/conjunctival scarring that increased the failure of subsequent glaucoma operations. Therefore, when patients had co-existent cataract and uncontrolled glaucoma, glaucoma surgery was always carried out before the cataract was removed.

Glaucoma Bleb Surgery

The first successful operations for open-angle glaucoma created an alternative channel for aqueous egress from the eye that bypassed the eye's failing trabecular meshwork (TM) and Schlemm's canal (SC). The operation created a fistula at the limbus through corneal–scleral tissue that drained aqueous from the anterior chamber, and created a bleb beneath Tenon's capsule and conjunctiva. The bleb drained posteriorly into the orbital lymphatics. In 1913 Elliot[1] introduced his trephine to create this fistula. Scheie[2] in the 1960s popularized thermal sclerectomy to create his fistula. Both techniques had problems. Often, the conjunctival blebs were too thin. They often failed and intraocular pressure (IOP) elevated, or the thin blebs sometimes ruptured, creating hypotony, allowing endophthalmitis to occur years later.

In 1968 Cairns[3] introduced trabeculectomy. He removed corneal/scleral tissue that contained TM and SC to create a fistula that drained under a scleral flap rather than under Tenon's capsule. This created a thicker, more durable bleb, and allowed for better control of aqueous drainage while the operative site healed. Trabeculectomy has remained the gold standard for IOP reduction when low pressures are needed to protect eyes from continued visual field loss. However, the unpredictability and complications of this operation have stimulated other ways to treat uncontrolled glaucoma.

The success of a trabeculectomy depends on maintaining the proper size of the scleral fistula and conjunctival bleb. This is affected by the amount of scarring as the operative site heals. If too much scarring

Table 1: Mean Intraocular Pressure Reductions of Phacotrabeculectomy versus Non-bleb Surgeries

n	Treatment	Authors of Study	PO Year Average	Glaucoma Drops		Intraocular Pressure				
				Before	After	Before surgery	At 1 year	1-year Change	At Final	Final Change
60	Phacotrabectomomy	Jin et al.[8]	3.0	1.6	0.2	23.1	14.5	-8.6	14.9	-8.2
17	Phaco/IOL	Poley et al.[9]	4.5	1.3	1.0	24.7	18.7	-6.0	16.3	-8.4
25	Phaco/IOL iStent	Spiegel et al.[10]	1.0	1.5	0.5	21.5	15.8	-5.7	15.8	-5.7
48	Canaloplasty	Lewis et al.[11]	1.0	1.9	0.6	23.9	15.3	-8.6	15.3	-8.6
54	Phaco/IOL Canaloplasty	Shingleton et al.[12]	1.0	1.5	0.2	24.4	13.7	-10.7	13.7	-10.7
35	Trabectome	Minckler et al.[13]	3.0	2.9	1.0	25.7	16.1	-9.6	16.4	-9.3
10	Phaco/IOL Trabectome	Ferrari et al.[14]	3.0	2.4	0.8	25.0	15.2	-9.8	15.3	-9.7

IOL = intraocular lens; PO = post-operative.

Table 2: Characteristics and Intraocular Pressure Results of Non-glaucomatous Eye when Operated with Phaco/Intraocular Lens

Group	Eyes (n)	Age (Years)	Post-operation FU (Years)	Mean IOP (mmHg)				
				At surgery	1 year Post-operation	Change at 1 Year	Final	Final Change (%)
31–23	19	69	2.4	24.5	17.8	-6.7	18.0	-6.5 (27)
22–20	62	70.9	4.6	20.9	15.8	-5.1	16.1	-4.8 (22)
19–18	86	67.4	4.9	18.3	15.5	-2.8	15.8	-2.5 (14)
17–15	223	71.2	4.7	15.9	14.6	-1.4	14.3	-1.6 (10)
14–9	198	70.5	4.2	12.7	13.1	+0.4	12.9	+0.2 (0)
p-value	—	0.57	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
All eyes	588	70.3	4.5	16.0	14.5	-1.5	14.4	-1.6 (10)

Sorted according to their pre-surgical intraocular pressure (IOP) group.[16] FU = follow-up.

occurs, the fistula's lumen and bleb fails. Repeated needlings of the bleb sometimes salvage the outflow channel. If needling is unsuccessful, elevated IOP recurs, and the operation fails. Application of mitomycin C to the sclera decreases scarring and allows more fistulas and blebs to survive. However, in the short term, this treatment can retard healing too much causing hypotony, choroidal effusion, and macular edema. Long term, bleb rupture with hypotony, and sometimes endophthalmitis, can occur years later. The National Survey of Trabeculectomy III[4] reported that of 1,240 eyes following trabeculectomy, 46% had early complications and 42% had late complications.

Unsolved problems of trabeculectomy include acceleration of cataract formation and prolonged time until vision and IOP stabilize (i.e. six to 12 post-operative visits over two to four months). Continuous attention to aqueous flow during this time sometimes requires cutting flap sutures and bleb needlings. This effort makes post-operative follow-up tedious for both patients and surgeons.

In 1997, the ExPRESS X shunt[5] was introduced to better control aqueous flow. Its purpose is to create a scleral opening whose lumen is uniform size, i.e. 50μm, and does not change over time.[6] A 2.42mm stainless steel tube is inserted through a scleral opening made with a sapphire blade (Optonol), or a 25-gauge needle, and its back plate rests under a scleral flap; the same as a flap that is made for traditional trabeculectomy. This steel shunt decreases the short-term problems of irregular aqueous flow: hypotony, or bleb failure. However, longer-term bleb problems such as bleb failure resulting in elevated IOP and bleb rupture leading to hypotony or endophthalmitis still occur, although less frequently.

Impact of Phacoemulsification/Lens Implantation on Co-existent Cataract and Glaucoma

In 1975 Charles Kelman[7] introduced phacoemulsification (phaco) for cataract removal. Today, this technique, together with artificial lens implantation, is the preferred technique for treating cataract. Since this technique leaves the lens capsule intact to separate vitreous from aqueous, and a clear corneal phaco incision now spares the conjunctiva for later filtering glaucoma surgery if needed, control of glaucoma with trabeculectomy is no longer necessary before cataract surgery with phaco/intraocular lens implantation (IOL). This new rationale led to the development of the combined procedure.

Combined Procedures

Cataract and glaucoma operations are now successively combined into one procedure, and are described as a combined procedure.[8] A combined procedure is a trabeculectomy, with or without an ExPRESS™ shunt, combined with phaco/lens implantation into one procedure. Another term for a combined procedure is phacotrabeculectomy. Patients are no longer required to endure two months of visual disability while the glaucoma operation heals before the cataract can be removed, since the two operations can be accomplished with one surgical procedure.

Non-bleb Glaucoma Surgery

Methods for non-bleb glaucoma surgery have been developed to decrease problems associated with phacotrabeculectomy, which entails a functioning conjunctival bleb. *Table 1* compares IOP reductions of non-bleb procedures with those of phaco-trabeculectomy.

Table 3: Characteristics and Intraocular Pressure Results of Glaucomatous Eyes when Operated with Phaco/Intraocular Lens

Group	Eyes (n)	Age (Years)	Post-operation FU (Years)	Mean IOP (mmHg)				
				At surgery	1 year Post-operation	Change at 1 Year	Final	Final Change (%)
29–23	17	73	5.8	24.7	18.7	-6.0	16.3	-8.4 (34)
22–20	23	72.8	5.0	20.7	17.0	-3.7	16.1	-4.6 (22)
19–18	28	75.4	4.6	18.5	15.8	-2.7	15.2	-3.3 (18)
17–15	33	78.0	3.2	16.0	14.4	-1.6	14.9	-1.1 (7)
14–5	23	76.3	4.6	11.6	12.9	+1.3	13.5	+1.9 (16)
p-value	—	.57	.210	.002	<0.001	<0.001	0.007	<0.001
All eyes	124	75.5	4.5	17.8	15.4	-2.4	15.1	-2.7 (15)

Sorted according to pre-surgical intraocular pressure (IOP) group.[9] FU = follow-up.

Table 4: Frequency of Ocular Hypertensive Eyes (≥20mmHg) Before Surgery, One Year After Surgery and at the Final Measurement

Initial Pre-operation IOP mmHg	IOP Frequency, Eyes (n)		
	Pre-operation	1 year Post-operation	Final Measurement
20	25	12	12
21	19	5	5
22	18	3	1
23	9	2	2
24	4	2	1
25	2	—	—
27	3	—	—
31	1	—	—
No. of OHT eyes	81/100%	24/30%	21/26%
No. of OHT eyes become normotensive		57/70%	60/74%

IOP = intraocular pressure; OHT = ocular hypertensive.

Ab-interno Micro Stent to Bypass Trabecular Resistance[6]

The ab-interno approach bypasses trabecular resistance by inserting one or more trabecular microbypass stents—the iStent® (Glaukos Corp.)—into the SC. The titanium Glaukos stent has a 180μm lumen, is 1mm long, and has an L shape, with the long arm for placement in SC and the short arm designed to rest in the anterior chamber.[6] The long arm's open end is angled to penetrate the trabecular tissue and inner wall of the SC. Three rearward-facing retention barbs of the long arm help retain the iStent within the canal after its placement. The Glaukos stent is typically placed after the cataract is removed. The stent is less likely to be occluded by iris in an aphakic eye than in a phakic eye since the anterior chamber is deepened with lens removal. Insertion of the iStent is under direct visualization through the gonioprism. The iStent is pre-loaded on the handle mechanism for insertion, which has a button on the handle to disengage the iStent from handle after its long arm is completely positioned in the SC.

Insertion of the iStent after phaco/IOL reduces IOP from mean 21.5 to mean 15.8mmmHg for a reduction of mean of –5.7mmHg.[10] By comparison, phacotrabeculectomy reduces IOP mean by 8.2mmHg.[8] If patients need IOP reduction to the low teens or single digits, and they have significant field loss, a trabeculectomy or combined procedure would be the procedure of choice. Patients with cataracts whose glaucoma is moderately controlled with glaucoma drops are well served by this technique. As conjunctiva is spared with phaco/IOL iStent surgery, a trabeculectomy can be performed later if lower IOP is still required.

Ab-externo Non-penetrating Schlemm's Canaloplasty[6]

Ab-externo non-penetrating Schlemm's canaloplasty expands the collapsed SC (iScience International Inc.). This procedure increases aqueous outflow through compromised trabecular tissue and SC by tightening sutures placed within SC. This maneuver mechanically opens the canal by drawing the inner wall of the canal centripetally. Conjunctiva is reflected, and a scleral flap is cut as in a trabeculectomy.[6] However, two scleral flaps are cut: the first is one-third scleral thickness; a second, deeper flap is cut 1mm inside the edge of the earlier scleral incision to within 100μm of the underlying choroid. A trabeculo-Descemet window is fashioned, and the inner scleral flap is excised. At this point, the inner wall of the SC and TM remains, and the roof of the SC has been removed and its two cut ends are exposed. A micro-catheter is inserted into one of the cut ends of the canal, and passed throughout its 360º circumference while dilating the canal with visco-elastic. The catheter's tip contains a blinking red light that allows its position to be known as it advances through the canal. After the catheter exits the opposite cut end of the canal, a double-arm 10-0 prolene suture is tied to the end of the catheter, the catheter is withdrawn, and the prolene suture remains within the canal. The prolene suture is tightened and tied. The inner wall of the canal is drawn centripetally, which expands the lumen of the SC allowing aqueous to egress the eye with less resistance, and at a lower IOP. The scleral flaps and conjunctiva are sutured closed water-tight with 10-0 vicryl suture so an external bleb rarely forms. Canaloplasty alone reduces mean IOP by 8.6mmHg in the first year.[11] Canaloplasty combined with phaco/IOL reduces mean IOP by 10.7mmHg in the first year.[12] By comparison, phacotrabeculectomy reduces mean IOP by 8.2mmHg the first year.[8] Open-angle glaucoma eyes or eyes that become open angle after cataract removal are best suited for this technique. Eyes with narrow angles may experience anterior synechiae formation, and are poorly suited for this technique unless the lens is removed.

An Ab-interno Micro-electrocautery Device, the Trabectome, Removes Trabecular Tissue to Decrease Trabecular Resistance[13,14]

This micro-electrocautery device creates direct passage of aqueous from the anterior chamber to the SC by cauterizing and removing

Table 5: Conversion Rates of Ocular Hypertensive Eyes to Glaucoma Eyes—OHTS Study (2002) versus Poley, Lindstrom, Samuelson, Schulze Study (2008)[15]

Study	Treatment	n	Follow-up (Years)	Initial IOP Range	IOP Reduction (%)	Conversion Factor	Conversion Percentage
OHTS[17]	Untreated	750	5.0	32–21mm	9.9	VF change	9.5%
OHTS[17]	Glauc Gtts	750	5.0	32–21mm	22.5	VF change	4.4%
P/L/S/S[9]	Phaco/IOL	81	4.5	31–20mm	23.8	Glauc Gtts started	1.1%

IOL = intraocular lens; IOP = intraocular pressure; OHTS = Ocular Hypertension Treatment Study; VF = visual field.

trabecular tissue and the inner wall of SC. The Trabectome device is an ab-interno foot-pedal-activated hand-piece with a 19-gauge infusion sleeve and a 25-gauge aspiration port with an electrocautery element 150μm from an insulated tapered foot plate.[6] After the cataract is removed with phaco and the IOL implanted, the device is inserted through the clear corneal cataract incision. The foot plate penetrates the TM and inner wall of the SC under direct visualization through a gonioprism. When the foot plate is situated within the canal, the trabecular tissue is cauterized and removed as the foot plate advances in the canal. The tissue is ablated in one direction until visualization is no longer possible. The device is reoriented 180º, and a similar procedure is repeated in the opposite direction. In this way, about 60º of trabecular tissue can be ablated.

Ablation of trabecular tissue with the Trabectome after phaco/IOL reduces IOP from mean 25.0mmHg to mean 15.2mmHg for a reduction of mean of 9.8mmHg.[14] By comparison, phacotrabeculectomy reduces IOP mean by 8.4mmHg.[8]

Patients should have open angles pre-operatively for this procedure, and patients with narrow angles may encounter gonio-synechiae following the procedure. Transient hyphema frequently occurs, but clears without causing complications. Other post-operative complications are rare. They include: Descemet detachment, anterior synechiae, hypotony, and uncontrolled IOP requiring additional filtering surgery. Conjunctiva is left undisturbed by this procedure, so trabeculectomy surgery is not compromised if needed at a later date.

Phaco/Intraocular Lens Alone Expands and Enhances the Function of the Trabecular Meshwork and Schlemm's Canal[9,15]

Phaco/IOL alone enhances the function of the TM and SC by removing the crystalline lens, which continuously enlarges with age. We published studies in 2008[15] and 2009[9] showing the efficacy of phaco with artificial lens implantation alone to prevent and control adult glaucoma.

We retrospectively studied IOP reduction after phaco/IOL of 588 non-glaucomatous eyes and 124 glaucomatous eyes. Post-operative follow-up was one to 10 years, average 4.5 years. IOP was recorded before surgery, one year after surgery, and at the final measurement. Eyes were stratified according to their pre-surgical IOP and divided into five groups. *Table 2* shows the results of the non-glaucomatous eyes, and *Table 3* shows the results of the glaucomatous eyes.

By stratifying eyes according to their pre-surgical IOP, we found greater IOP reductions than previously reported. IOP reduction was proportional to the pre-surgical IOP in both the non-glaucomatous eyes and glaucomatous eyes. Eyes with the highest pre-surgical IOPs that needed the greatest IOP reduction achieved the greatest reduction following phaco/IOL surgery. Non-glaucomatous eyes within a pre-surgical IOP range of 23–31mmHg had a mean 6.5mmHg/27% reduction to a mean of 18.0mmHg for the 10 years of the study. Similarly, glaucomatous eyes within a pre-surgical IOP range of 23–29mmHg had a mean 8.4mmHg/34% reduction to a mean of 16.3mmHg for the 10 years of the study. The IOPs of glaucoma eyes were as low as glaucoma drops could achieve before phaco/IOL surgery. However, significant IOP reductions occurred after phaco/IOL surgery.

Figure 1: SA Strenk's and LM Strenk's *In Vivo* Magnetic Resonance Composite Image of a 24-year-old and a 52-year-old Eye

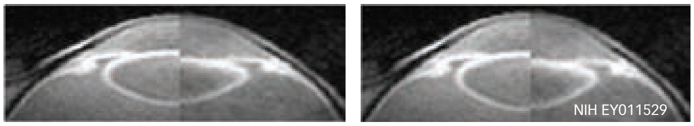
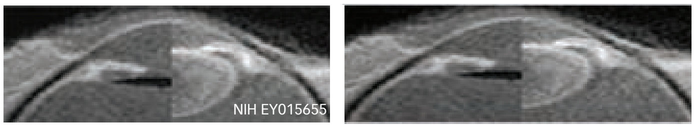


Figure 2: SA Strenk's and LM Strenk's *In Vivo* Magnetic Resonance Composite Image of a 74-year-old Pseudophakic Eye and its Fellow Phakic Eye



Surgeons operating cataractous eyes with IOPs ≥20mmHg would like to know whether the IOP after surgery would be up, down, or unchanged. Our studies showed all eyes with IOPs ≥20mmHg had IOP reductions of 2–12mmHg. No IOPs increased.

Our studies comparing mean IOP reduction one year after surgery with mean IOP reduction at the final measurement (one to 10 years, average 4.5 years) of non-glaucomatous and glaucomatous eyes showed mean IOP reduction at final measurement was as great or greater than mean IOP reduction at one year following surgery. Hence, IOP changes achieved at one year were sustained for the 10 years of the study.

Table 4 shows that 81 non-glaucomatous eyes were ocular hypertensive (OHT) with IOPs ≥20mmHg before phaco/IOL surgery. After phaco/IOL surgery, only 21 eyes remained OHT. Hence, phaco/IOL converted 60/81 (74%) OHT eyes to normotensive eyes with IOPs ≤19mmHg for one to 10 years, average 4.5 years.

Table 5 compares the conversion percentage of eyes from OHT to glaucoma from the 2002 Ocular Hypertension Treatment Study (OHTS)[16] (when treated with glaucoma drops) to those of the 2008 Poley, Lindstrom, Samuelson, Schulze (P/L/S/S) study[15] when treated with phaco/IOL. The OHTS study conversion factor was the development of visual field changes, while the P/L/S/S conversion factor was the physician starting glaucoma drops to treat elevated IOP. Phaco/IOL (conversion rate=1.1%) appears more successful in preventing OHT eyes from converting to glaucoma than observation alone (conversion rate=9.5%) or glaucoma drops (conversion rate=4.4%).

Why is phaco/IOL so effective in preventing and controlling adult glaucoma? Earlier, we proposed a hypothesis:[9,15] the crystalline lens continuously enlarges throughout life whereas the eye's anterior segment remains stable after 22 years of age. As the lens enlarges, its anterior lens surface moves forward of the SC within the anterior chamber. Zonules that extend from the anterior lens capsule to the ciliary body create anterior traction on the muscles of the ciliary muscle complex[19] whose anterior tendons form the framework of the TM.[17] TM becomes compressed, and the lumen of the SC collapses. Thus, the major cause of TM and CS failure has been identified, i.e. enlargement of the crystalline lens with age. Phaco/IOL lowers elevated IOP by replacing the enlarging crystalline lens with a thin stable artificial lens. After lens exchange, the anterior surface in the anterior lens capsule surrounding the IOL lies well behind the SC so zonules extending from the anterior capsule now exert rearward traction on the ciliary muscle complex. The TM and SC expand, their function improves, and elevated IOPs reduce to lower levels. Since thin artificial IOLs do not enlarge with time, the IOP reductions achieved by phaco/IOL surgery at one year are maintained for the 10 years as reported in our study, and are probably maintained indefinitely.

Figure 1 is Strenk's[18] composite MRI image of a 24- and a 52-year-old eye. It shows anterior displacement of the uveal tract results from growth of the lens as it ages. *Figure 2* is Strenk's[18] composite MRI image of a 74-year-old pseudophakic eye and its fellow phakic eye. It shows the uveal tract returns to an antero-posterior position of relative youth after lens exchange. These images appear to support our hypothesis that lens growth with age causes anterior displacement of the uveal tract resulting in compression of the TM and collapse of the SC. Note, the anterior lens surface is rearward of SC in the 24-year-old, and is well forward of SC in the 74-year-old. After phaco/IOL, the anterior capsule of the 74-year-old lies further behind SC than it does in a 24-year-old. Hence, the vector force of zonules emanating from the enlarged lens is reversed by lens exchange. Before lens exchange, zonules of a 74-year-old pull the ciliary muscle complex forward, which compresses the TM and SC. After lens exchange, zonules of a 74-year-old pull the ciliary muscle complex rearward, which expands the TM and SC.

Conclusion

Ten years ago, trabeculectomy was the preferred surgical option to lower IOP when glaucoma drops were no longer adequate. This operation was successful in achieving adequate IOP reductions for many eyes, but it entailed high risk, and was an unsatisfactory operation because of the high percentage of unsolvable complications associated with its scleral fistula and conjunctival bleb.

Today, non-bleb surgical procedures for reduction of elevated IOP have been developed. The complications associated with scleral fistulas and conjunctival blebs do not occur with these procedures. Non-bleb glaucoma procedures currently include canaloplasty, iStent, Trabectome and phaco/IOL alone. Only phaco/IOL and Trabectome have US Food and Drug Administration (FDA) approval at this time. Mean IOP reduction of these four procedures is essentially the same, as *Table 1* indicates.

Somewhat greater IOP reduction has been reported when canaloplasty or Trabectome are combined with phaco/IOL. Few complications have been reported with these procedures. These non-bleb surgeries have lowered the risk and increased the success for treatment of patients with co-existent glaucoma and cataract.

Phaco/IOL alone may emerge as a treatment of choice for the majority of patients with co-existent cataract and glaucoma. If target IOPs <16mmHg are needed, phaco/IOL can be combined with Trabectome during one setting, or Trabectome can be carried out after phaco/IOL alone if lower IOPs are still needed. Trabeculectomies and ExPRESS shunts will remain as valuable treatments for eyes with advanced glaucoma that need IOPs in the low teens or single digits. ■

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