Small Incision and Femtosecond Laser Cataract Surgery

5.9

Mark Packer

Definition: Innovative new techniques to make cataract surgery faster, safer and refractively more reliable.

Key features

- Incremental advances in technique and technology that occurred from the invention of phacoemulsification in the 1960s until recently are now giving way to a new era of femtosecond laser-assisted cataract surgery.
- The refinement of incision placement and architecture, as well as the reduction of final incision size occasioned by the development of foldable, injectable intraocular lenses, permits the reduction of postoperative astigmatism and enhancement of refractive cataract surgery.
- Continuous curvilinear capsulorrhexis facilitates remarkable advances in phacoemulsification (phaco) technique, beginning with sculpting techniques such as divide and conquer, trending to today's preferred horizontal and vertical chopping methods, and leading to increased precision and accuracy with femtosecond laser capsulectomy.
- The use of hydrodissection to lyse cortical-capsular connections and the use of hydrodelineation to permit phaco within the protective layer of the epinucleus has improved the safety and efficiency of phaco.
- Power modulations, such as millisecond level control of ultrasound power application, have allowed reduction of the energy required for cataract extraction, protection of the cornea from thermal injury and enhancement of the rapidity of postoperative visual rehabilitation. Femtosecond laser phacofragmentation has facilitated even further reduction in ultrasound energy delivered to the eye.
- The separation of irrigation from aspiration made possible through biaxal microincision phaco has represented an advance in control of the fluidic behavior of the intraocular environment, permitting greater versatility in every step of the cataract extraction procedure.
- Femtosecond laser-assisted cataract surgery represents a significant disruptive technology that promises to revolutionize the most frequently performed operation in the world.

INTRODUCTION

The principal technical features of phaco include:

- The construction of watertight, self-sealing corneal incisions;
- The successful completion of an intact, round, centered capsulorrhexis with a diameter smaller than that of the intended intraocular lens (IOL) optic;
- Gentle and efficient ultrasound power modulation to protect the capsule, iris, and cornea;
- Fastidious cortical cleanup resulting in a clean capsular bag; and
- Atraumatic IOL insertion through an incision of 1.5–2.4 mm.

Phaco has thus come to refer to all of the techniques and technology required for the fragmentation and extraction of the crystalline lens through a small corneal incision and the implantation of an intraocular lens, resulting in immediate visual rehabilitation and reduced need for optical correction. The first three steps, including corneal incisions, capsulectomy and phacofragmentation, may today be performed by either blade, forceps, ultrasound, or by femtosecond laser.

Since the time of its introduction in the late 1960s, phaco has evolved into a highly effective method of cataract extraction. Incremental advances in surgical technique and the simultaneous redesign and modification of technology have permitted increased safety and efficiency. Among the advances that have shaped modern phaco are incision construction, continuous curvilinear capsulorrhexis, cortical cleaving hydrodissection and hydrodelineation, and nucleofractis techniques.

United States patent 3 589 363, filed July 25, 1967, lists Anton Banko and Charles D. Kelman as inventors of:

> *'an instrument for breaking apart and removal of unwanted material, especially suitable for surgical operations such (as) cataract removal, including a handheld instrument having an operative tip vibrating at a frequency in the ultrasonic range with an amplitude controllable up to several thousandths of an inch.'*[1]

Even recently, the fundamental mechanisms by which the system known as phaco operates remained controversial. While some authors have described the surgical advantages of a unique type of cavitational energy, others have denied any role for cavitational energy in phaco.[2]

INCISION CONSTRUCTION AND ARCHITECTURE

Since 1992, when Fine described the self-sealing temporal clear corneal incision, the availability of foldable IOLs has furthered the trend away from scleral tunnel incisions to clear corneal incisions.[3] Rosen demonstrated by topographical analysis that clear corneal incisions 3 mm or less in width do not induce significant astigmatism.[4] This finding led to increasing interest in T-cuts, arcuate cuts, and limbal relaxing incisions for managing pre-existing astigmatism at the time of cataract surgery. Surgeons recognized many other advantages of the temporal clear corneal incision, including better preservation of pre-existing filtering blebs and options for future filtering surgery, increased stability of refractive results because of decreased effects from lid blink and gravity, ease of approach, elimination of the bridle suture and iatrogenic ptosis, and improved drainage from the surgical field via the lateral canthal angle.

Surgeons originally adopted single-plane incisions utilizing a 3.0 mm diamond knife. After pressurizing the eye with viscoelastic through a paracentesis, the surgeon placed the blade on the eye so that it completely applanated the eye with the point of the blade positioned at the leading edge of the anterior vascular arcade. The knife was advanced in the plane of the cornea until the shoulders, 2 mm posterior to the point of the knife, touched the external edge of the incision. Then the point of the blade was directed posteriorly to initiate the cut through Descemet's membrane in a maneuver known as the dimple-down technique. After the tip entered the anterior chamber, the initial plane of the incision was re-established to cut through Descemet's in a straight-line configuration.

Williamson was the first to utilize a shallow 300–400 µm grooved clear corneal incision.[5] Langerman later described the single hinge incision, in which the initial groove measured 90% of the depth of the cornea anterior to the edge of the conjunctiva.[6] Surgeons employed adjunctive techniques to combine incisional keratorefractive surgery with clear corneal cataract incisions. Osher described the construction of arcuate keratotomy incisions at the time of cataract surgery for the correction of pre-existing corneal astigmatism. Kershner used the temporal incision by starting with a nearly full-thickness T-cut through which he then made his corneal tunnel incision.[7] Finally, the recommendation of limbal relaxing incisions by Gills and Nichamin advanced the ultimately most popular means of reducing pre-existing astigmatism.[8,9]

Following phaco, lens implantation, and removal of residual viscoelastic, stromal hydration may be performed in order to seal the incisions by gently irrigating balanced salt solution into the stroma at both edges of the incision with a 26- or 27-gauge cannula. An intraoperative Seidel test may be used to ensure sealing. Studies of sequential optical coherence tomography of postoperative clear corneal incisions have demonstrated that the edema from stromal hydration lasts up to one week.[10]

Clear corneal incisions, by nature of their architecture and location, are associated with unique complications. Chemotic ballooning of the conjunctiva may occur due to irrigating fluid streaming into an inadvertent conjunctival incision. In this case, the conjunctiva may be snipped to permit decompression. Incisions that are too short can result in an increased tendency for iris prolapse and poor sealability. A single suture may be required in order to secure the wound. On the other hand, a long incision may result in striae in the cornea that compromised the surgeon's view during phaco. Coarse manipulation of the phaco tip may result in epithelial abrasions or tears in Descemet's membrane, compromising self-sealability. Of greater concern has been the potential for incisional burns.[11] When incisional burns develop in clear corneal incisions there may be rapid contraction of tissue and loss of self-sealability. Suture closure of the wound may induce excessive astigmatism.

Literature supports the view that suboptimal construction of clear corneal incisions may lead to poor coaptation, inadequate sealing and ingress of bacteria, thereby increasing the risk of acute postoperative bacterial endophthalmitis.[12] However, four large published series have found no greater likelihood of infection with corneal versus other types of incisions.[13–16] Regardless of the type of incision, the principle remains that appropriate incision construction and watertight closure are obligatory. Besides poor wound closure, other significant findings have been associated with higher risk of postoperative infection, including posterior capsule rupture, vitreous loss, older age, prolonged surgery, immunodeficiency, active blepharitis, lacrimal duct obstruction, inferior incision location, and male gender.[17]

CONTINUOUS CURVILINEAR CAPSULORRHEXIS

Implantation of the IOL in an intact capsular bag facilitates the permanent rehabilitative benefit of cataract surgery. For many years, surgeons considered a 'can-opener' capsulectomy to be satisfactory for both planned extracapsular cataract extraction and phaco. However, in 1991, Wasserman and associates performed a postmortem study that showed that the extension of one or more V-shaped tears toward the equator of the capsule produced instability of the IOL and resulted in IOL malposition.[18] Gimbel and Neuhann popularized continuous curvilinear capsulorrhexis (CCC) in the later 1980s.[19–21]

The basic principles of manual CCC include the following:

1. The continuous capsular tear should be performed in a stable anterior chamber under viscoelastic pressurization.
2. The tear should be initiated at the center of the capsule so that the origin is included within the circle of the tear.
3. The continuous tear may proceed either clockwise or counterclockwise in a controlled and deliberate fashion, the surgeon regrasping with the forceps or repositioning the point of the cystotome/bent needle on the inverted flap to control the vector of the tear.

A tear that begins moving peripherally or radially is a signal that a condition exists that requires immediate attention. Further progress of the tear should be stopped and the depth of the anterior chamber assessed. Frequently, the cause of the peripheral course of the tear is shallowing of the anterior chamber. Adding more viscoelastic to deepen the anterior chamber opposes the posterior pressure, making the lens capsule taut, widening the pupil, and permitting inspection of the capsule.

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One important technique for redirection of the capsulorrhexis has been described by Little.[22] In this technique, in order to rescue the capsulorrhexis from a peripheral tear-out, the force applied to the capsular flap is reversed but maintained in the plane of the anterior capsule. It is necessary to first unfold the capsular flap so that it lies flat against the lens cortex as it did prior to being torn. Force can then be applied with the capsule forceps holding the capsular flap as near to the root of the tear as possible and pulling backwards, in a retrograde direction along the circumferential path of the completed portion of the capsulorrhexis. Traction should be applied in the horizontal plane of the capsule and not upward. The initial pull should be circumferentially backward, and then, while holding the flap under tension, directed more centrally to initiate the tear. The forward progress of the capsulorrhexis will uniformly and predictably redirect toward the center of the capsule (Fig. 5-9-1). In the event that the capsule will not tear easily and the entire lens is being pulled centrally, this rescue maneuver should be abandoned to avoid a wrap-around capsular tear or zonular dialysis. Alternate rescue techniques such as completing the capsulorrhexis from the opposite direction or making a relieving cut in the flap edge and continuing in the same direction represent reasonable alternatives.

The use of trypan blue to stain the anterior capsule in the absence of a good red reflex constitutes an important adjunctive technique for capsulorrhexis construction. The dye may be injected into the chamber through a paracentesis under air. The air and residual dye are then exchanged for viscoelastic. Despite the absence of a red reflex the capsule is easy to see.

The technique of CCC has provided important advantages both for cataract surgery and IOL implantation. Because endolenticular or in situ phaco must be performed in the presence of an intact continuous capsulectomy opening, capsulorrhexis has served as a stimulus for modification of phaco techniques. Because the edge of a well-constructed rhexis completely overlaps the edge of the IOL, it insures positional stability and enhances refractive predictability.

HYDRODISSECTION AND HYDRODELINEATION

Hydrodissection has traditionally meant the injection of fluid into the cortical layer of the lens to separate the nucleus from the cortex and capsule. Following the adoption of capsulorrhexis, hydrodissection became a critical step to mobilize, disassemble and remove the nucleus. Fine first described cortical cleaving hydrodissection, which is designed to cleave the cortex from the capsule and leave the cortex attached to the epinucleus.[23] Cortical cleaving hydrodissection often eliminates the need for cortical cleanup as a separate step in cataract surgery.

In this technique, the anterior capsular flap is initially elevated with a 26-gauge blunt cannula. Firm and gentle continuous irrigation results in a fluid wave that cleaves the cortex from the posterior capsule. The lens bulges forward because fluid is trapped by equatorial cortical-capsular connections. Depressing the central portion of the lens with the side of the cannula forces fluid around the equator and lyses the cortical-capsular connections. Adequate hydrodissection is demonstrated by rotation of the nuclear-cortical complex. The demonstration of free rotation of the lens within the capsule represents a critical step in phaco.

Hydrodelineation describes separation of the epinuclear shell from the endonucleus by the irrigation. The epinucleus acts as a protective cushion within which phaco forces can be confined. Further, the epinucleus keeps the bag on stretch throughout the procedure, making capsule rupture less likely.

To peform hydrodelineation, a 26-gauge cannula is placed in the nucleus, off center to either side, and directed at an angle downward and forward toward the central plane of the nucleus. When the nucleus starts to move, the endonucleus has been reached. At this point, the cannula is directed tangentially to the endonucleus, and a to-and-fro movement of the cannula is used to create a tunnel within the epinucleus. The cannula is backed out of the tunnel approximately halfway, and gentle but steady pressure on the syringe allows fluid to enter the distal tunnel without resistance. A circumferential golden or dark ring will outline the endonucleus.

Occasionally, an arc will result and surround approximately one quadrant of the endonucleus. In this instance, the procedure can be repeated in multiple quadrants until a golden or dark ring verifies complete circumferential separation of the nucleus.

NUCLEOFRACTIS TECHNIQUES

The recognition that the lens nucleus could be divided and removed from within the protective layer of the epinucleus while preserving

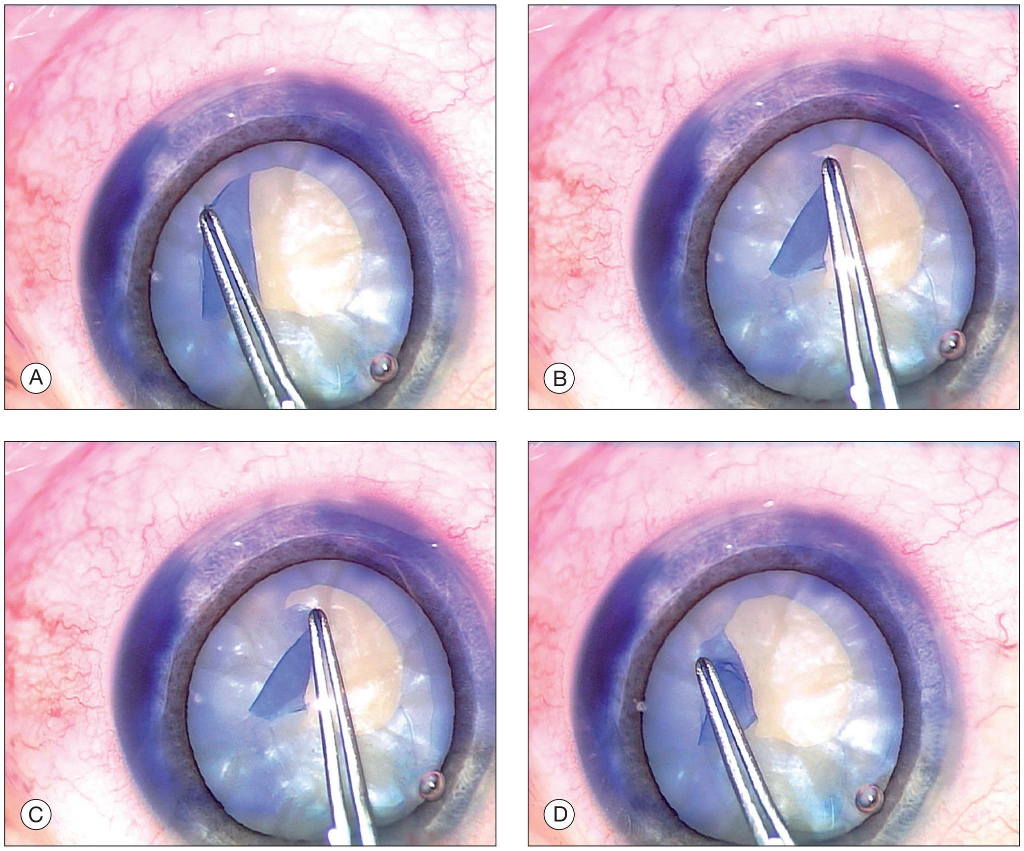

Fig. 5-9-1 Backwards traction on the capsular flap forms the basis of a predictable technique for rescuing the capsulorrhexis from a radial tear-out. As shown here in the case of an opaque cataract with trypan blue capsule stain, the tear has extended too far to the periphery (A). Therefore the flap is unfolded and laid back in the plane of the capsulorrhexis from where it was torn (B). The flap is then pulled with reverse tangential force until the capsule tears back towards the center (C). Construction of the capsulorrhexis may then continue (D).

the capsulorrhexis influenced the development of a plethora of phaco techniques.

Divide and Conquer

In the divide and conquer technique originally described by Gimbel,[24] a deep crater is sculpted into the center of the nucleus including the posterior plate. However, phaco fracture, a technique actually described by Shepherd, is often referred to as 'divide and conquer'.[25] In this technique the surgeon sculpts a groove parallel to the incision one and a half to two times the diameter of the phaco tip, with the tip in a bevel-up position, using moderate power and low vacuum. Using the phaco handpiece and a second instrument, the surgeon then rotates the nucleus by 90°, and sculpts a second groove perpendicular to the first. Sculpting continues until the red reflex is seen at the bottom of the grooves. A bimanual cracking technique is used to create a fracture through the nuclear rim in the plane of one of the grooves. The nucleus is then rotated 90°, and additional fractures are made until four separate quadrants are isolated. A short burst of phaco power with increased vacuum is then used to embed the phaco tip into one quadrant which is pulled into the center for emulsification. The second instrument can help elevate the apex of the quadrant to facilitate its mobilization.

Phaco Chop

Nagahara first introduced the phaco chop technique by using the natural fault lines in the lens nucleus to create cracks without creating prior grooves (Presentation at the American Society of Cataract and Refractive Surgery Film Festival, 1993). The phaco tip is embedded in the center of the nucleus after the superficial cortex is aspirated. In horizontal chopping, a second instrument, the phaco chopper, is then passed to the equator of the nucleus, beneath the anterior capsule, and drawn to the phaco tip to fracture the nucleus. The two instruments are separated to widen the crack. In vertical chopping, a sharp-tipped instrument is inserted directly into the nucleus beside the embedded phaco needle and the two instruments are again separated as in horizontal chopping. The nucleus is rotated and this procedure is repeated until several small fragments are created, which are then emulsified.

POWER MODULATIONS

Fine described the 'choo-choo chop and flip' technique in 1998 and subsequently correlated the reduction of ultrasound energy made possible by power modulations with superior uncorrected visual acuity on the first postoperative day.[26,27] Effective phaco time (EPT), absolute phaco time (APT), and cumulative dissipated energy (CDE) became standard metrics for the consumption of ultrasound energy. Although EPT, APT, and CDE cannot be compared across different machines made by different manufacturers, when using the same machine they can be compared from one case to the next as a sign of surgical safety and efficiency.

In Fine's technique, a 30° straight phaco tip is used bevel down. After aspirating epinucleus uncovered by the capsulorrhexis, a horizontal chopper is placed in the golden ring by touching the top center of the nucleus with the tip and pushing the tip peripherally so that it slides beneath the capsulorrhexis. The chopper is used to stabilize the nucleus by lifting and pulling toward the incision slightly, after which the phaco tip lollipops the nucleus in either pulse mode at 2 pulses/second or 80 millisecond burst mode. Burst mode utilizes fixed power and duration with variable interval. In pulse mode, there is variable power with fixed duration and interval. These power modulations reduce total ultrasound energy and increase hold. Once the tip is buried in the center of the nucleus, vacuum is maintained in foot position 2. The nucleus is scored by bringing the chopper to the side of the phaco needle. It is chopped in half by pulling the chopper to the left and slightly down while moving the phaco needle, still in foot position 2, to the right and slightly up (Fig. 5-9-2). Then the nuclear complex is rotated by 90°. The chop instrument is again brought into the golden ring, the heminucleus is lollipopped, scored, and chopped with the resulting wedge now lollipopped on the phaco tip and evacuated. The nucleus is rotated so that wedges can be scored, chopped, and removed by high vacuum assisted by short bursts or pulses of phaco. The size of the wedges is varied according to the density of the nucleus.

After evacuation of all endonuclear material, the epinuclear rim is trimmed in each of the three quadrants, mobilizing cortex. As each quadrant of the epinuclear rim is rotated to the distal position in the capsule and trimmed, the cortex in the adjacent capsular fornix flows over the floor of the epinucleus and into the phaco tip. The floor is pushed back to keep the bag on stretch until three of the four quadrants of the epinuclear rim and cortex have been evacuated. The epinuclear rim of the fourth quadrant is then used as a handle to flip the epinucleus. As the remaining portion of the epinuclear floor and rim is evacuated from the eye, most of the time the entire cortex is evacuated with it.

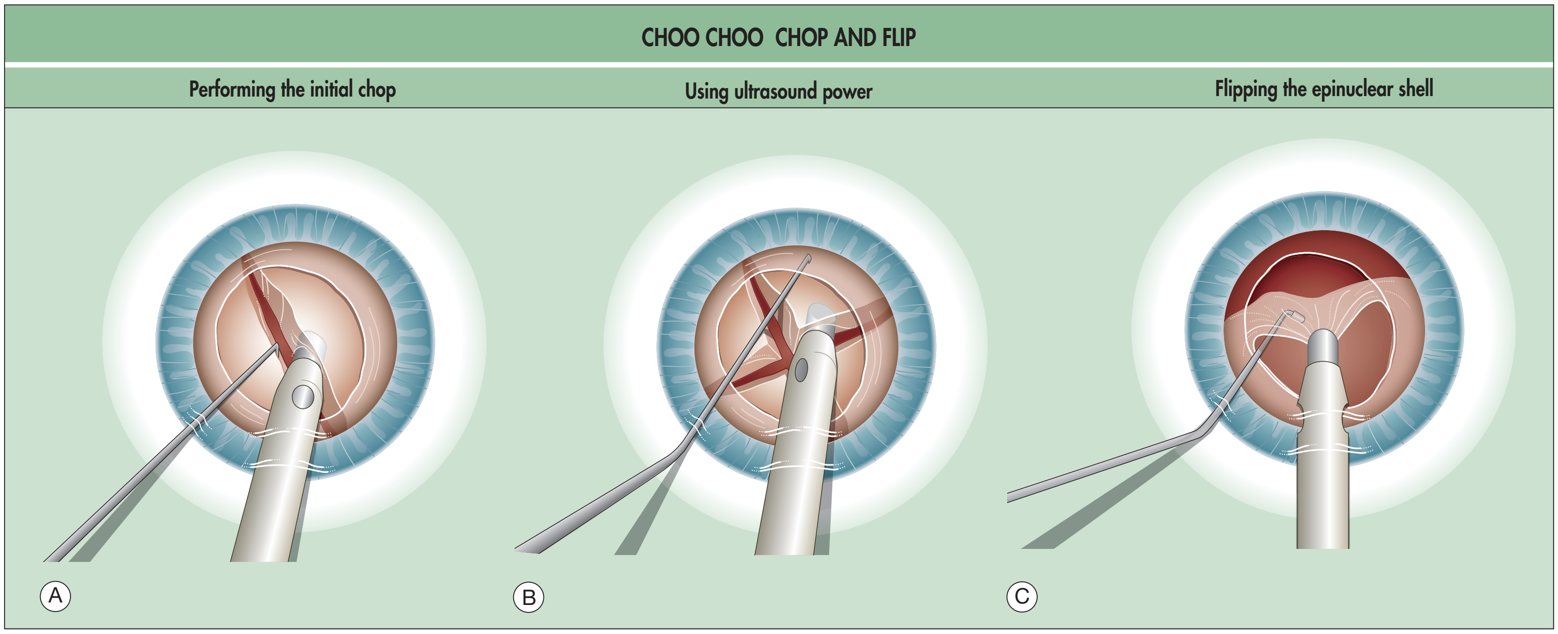

Fig. 5-9-2 The surgeon performs the initial chop of the nucleus by deeply embedding the phaco needle in the center of the nucleus using ultrasound power, and then maintaining a hold on the nucleus with high vacuum in foot pedal position 2 without ultrasound as the horizontal chopper is brought from the golden ring to the side of the phaco needle to score the nucleus. The surgeon then completes the chop by separating the instruments with a slight upward movement of the phaco tip and a slight downward movement of the chopper (A). Each quadrant of nuclear material is in turn impaled, chopped, mobilized and consumed with high vacuum and low amounts of ultrasound power (B). Finally, the epinuclear shell is flipped with a helpful push from the chopper (C).

If there is cortex remaining following removal of all the nucleus and epinucleus, there are three options. The phaco handpiece can be left high in the anterior chamber while the second handpiece strokes the cortex-filled capsular fornices. Frequently, this results in floating up of the cortical shell as a single piece and its exit through the phaco tip (in foot position 2) because cortical cleaving hydrodissection has cleaved most of the cortical-capsular adhesions.

Alternatively, if one wishes to complete cortical cleanup with the irrigation-aspiration handpiece prior to lens implantation, the residual cortex can almost always be mobilized as a separate and discrete shell and removed without turning the aspiration port down to face the posterior capsule.

The third option is to viscodissect the residual cortex by injecting a dispersive viscoelastic through the posterior cortex onto the posterior capsule. The viscoelastic material spreads horizontally, elevating the posterior cortex and draping it over the anterior capsular flap. At the same time the peripheral cortex is forced into the capsular fornix. The posterior capsule is then deepened with a cohesive viscoelastic and the IOL is implanted, leaving anterior residual cortex anterior to the IOL. Removal of residual viscoelastic material accompanies mobilization and aspiration of the residual cortex.

Non-linear delivery of ultrasonic or sonic frequencies, such as torsional and elliptical phaco, has further improved operating efficiency. Chopping techniques in combination with power modulations and nonlinear ultrasound power delivery minimize morbidity and enhance the rapidity of visual rehabilitation.

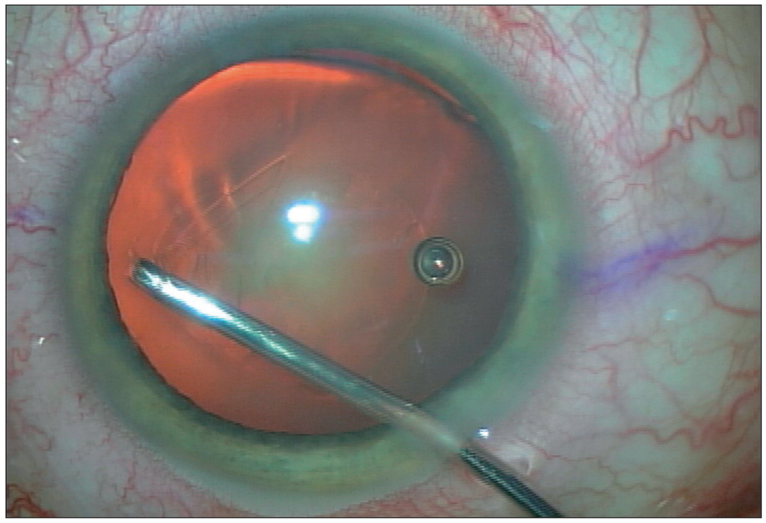

Fig. 5-9-3 The capsulorrhexis is nearly complete in this eye with a history of trauma and 90° of zonular dialysis visible temporally. The wrinkling of the capsule is a clear sign of the lack of zonular tension. Nevertheless, because of the increased control allowed by the microincisions, which prevent extrusion of viscoelastic, the capsulorrhexis will be centered, round, and smaller in diameter than the IOL as intended.

BIAXIAL MICRO-INCISION CATARACT SURGERY

Advances in ultrasound engineering during the late 1990s led to the application of millisecond-level control and variable duty cycles in phaco, vastly reducing the risk of thermal injury from the phaco needle and permitting removal of the irrigation sleeve. Separation of irrigation from aspiration during phaco came to be known as biaxial micro incision cataract surgery (B-MICS).

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The advantages of B-MICS include better followability due to separation of infusion and aspiration, access to 360° of the anterior segment with either infusion or aspiration by switching instruments from one hand to the other, the ability to use the flow of irrigation fluid as a tool to move material within the capsular bag or anterior chamber (particularly from an open-ended irrigating chopper or manipulator), prevention of iris billowing and prolapse in cases of intraoperative floppy iris syndrome, and significantly decreased chance of vitreous prolapse in the case of a posterior capsular tear, zonular dialysis, or subluxed cataract, thanks to maintenance of a pressurized stream of irrigation.

Perhaps the greatest advantage of the biaxial technique lies in its ability to remove subincisional cortex without difficulty. As originally described by Brauweiler, by switching infusion and aspiration hand pieces between two micro-incisions, 360° of the capsular fornices are easily reached and cortical cleanup can be performed quickly and safely.[28]

Since dispersive viscoelastics do not easily extrude through these small incisions, the anterior chamber is more stable during capsulorrhexis construction and there is much less likelihood of an errant tear. This added margin of safety is particularly noticeable in cases of zonular compromise, such as pseudoexfoliation and traumatic zonular dialysis (Fig. 5-9-3). The added chamber stability can also make a difference in control of the capsulorrhexis in both high myopia with an extremely deep anterior chamber and high hyperopia with a very shallow chamber.

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B-MICS VERTICAL CHOP TECHNIQUE

Following hydrodissection and hydrodelineation, the phaco needle is first embedded proximally with high vacuum and 40% power (Table 5-9-1). In the left hand is a vertical chopper which will be used to split the nucleus. As vacuum builds to occlusion a rapid rise time enables the phaco needle to quickly grasp the endonucleus. At the point occlusion is reached, the aspiration flow rate drops to zero. The surgeon then moves into foot position two so that high vacuum is maintained and the power drops to zero. The blade of the irrigating vertical chopper is brought down just distal to the phaco tip. As a full-thickness cleavage plane develops, dividing the nucleus in two, the instruments are separated to insure a complete chop (Fig. 5-9-4).

The lens is then rotated with the irrigating chopper so that the first heminucleus can be chopped. If there is a disparity in size, the larger half is moved distally. The phaco needle is now embedded to the right using high vacuum and low levels of power. A quadrant size piece is chopped off and consumed (Fig. 5-9-5). The remaining quadrant of the first heminucleus is then impaled with the phaco tip and aspirated. Total EPT to this point is zero, showing minimal usage of ultrasound.

To address the second half of the nucleus, it is first rotated with the irrigating chopper so that it is in the distal capsule. The phaco needle is embedded in the smaller heminucleus and this is subdivided with the irrigating chopper, again using high vacuum and low levels of power (Fig. 5-9-6). As the final quadrant is grasped and pulled centrally for aspiration the sharp blade of the irrigating chopper is turned sideways as a safety precaution (Fig. 5-9-7).

When addressing the epinucleus, the vacuum and aspiration flow are reduced. Once three quadrants of the epinuclear shell have been rotated and trimmed, the final quadrant is used to flip the epinuclear bowl into the phaco needle. Following aspiration of the epinucleus, the capsule is almost entirely clean of cortex (Fig. 5-9-8).

B-MICS with a vertical chop technique allows efficient lens extraction with rapid visual rehabilitation. This procedure demonstrates some of the tangible benefits of separating inflow from outflow, use of irrigation fluid as an instrument to mobilize material, and reduced effective phaco time.

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FEMTOSECOND LASER-ASSISTED CATARACT SURGERY

Femtosecond lasers have a unique ability to create discreet photodisruption of tissue with minimal collateral effects. This enables very precise cutting in ocular tissues including the cornea, lens capsule and the crystalline lens.

Femtosecond lasers are indicated for the following surgical steps:

- Anterior capsulectomy;
- Lens fragmentation;
- Partial and full thickness corneal cuts with applications for:
  - Refractive keratectomy;
  - Surgical incisions.

Anterior Capsulectomy

Laser capsulectomy brings precision and reproducibility to the process of creating a capsular opening. Studies have shown that laser capsulectomies are significantly closer to the intended diameter than manual CCCs. Differences in the deviation from the intended diameter between published papers reflect differences in the way the outcomes were measured, either attempting to measure the capsular opening where an arbitrary correction has to be made for anterior chamber depth and refractive index of the aqueous humor or BSS (balanced salt solution) present at time of measurement, or measuring the removed

TABLE 5-9-1 CAPSULECTOMY DATA BY GROUP

Differences are significant (p = 0.03).

	Capsulectomy/capsulorrhexis diameter (mm)		
Group	**Attempted**	**Measured**	**Attempted-achieved**
Laser (n=49)			
Mean	5.23	5.08	0.16
SD	0.06	0.18	0.17
CCC (n=24)			
Mean	5.36	4.95	0.42
SD	0.55	0.53	0.54

(from Naranjo Tackman, et al. Anterior capsulectomy with an ultrashort-pulse laser. J Cataract Refract Surg 2011;37:819–824)

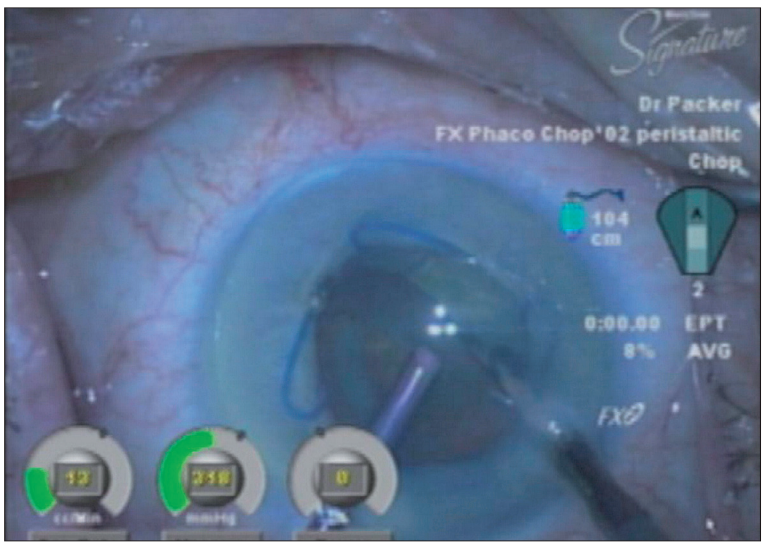

Fig. 5-9-4 The phaco tip is embedded in the proximal nucleus bevel down; the nucleus is then held with high vacuum as the irrigating chopper slices vertically downward distal to the phaco tip. The chopper and the phaco tip are then separated as shown, to divide the nucleus.

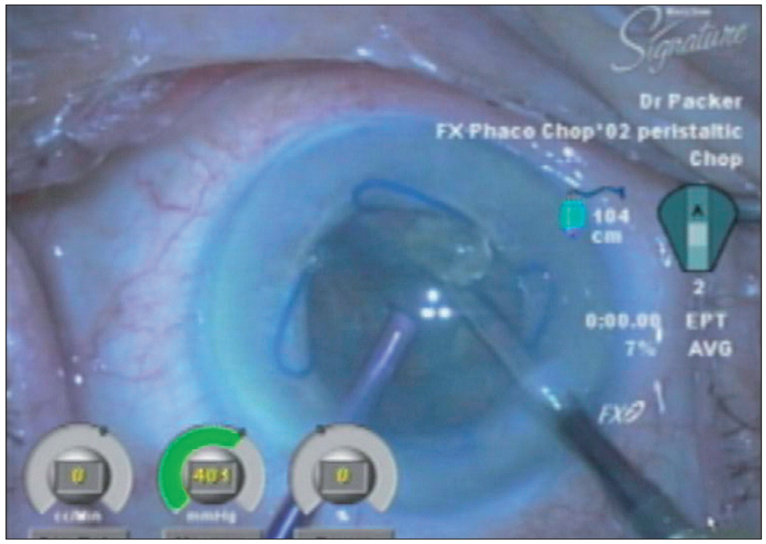

Fig. 5-9-5 A quadrant-sized piece of nucleus is chopped and brought centrally, where it will be emulsified and aspirated.

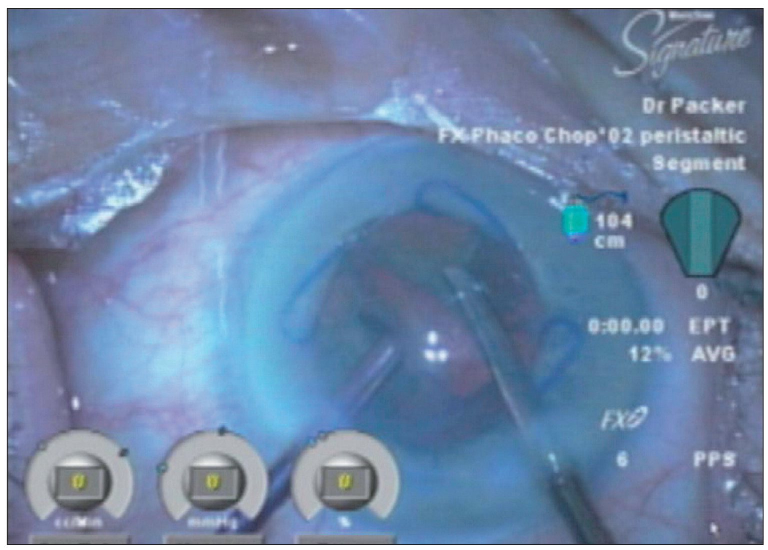

Fig. 5-9-6 A wedge of nucleus is chopped from the remaining heminucleus.

capsular button which may have undergone changes due to variations in hydration and/or mechanical changes from the cutting of the capsule fibers.

Tackman[29] reported on buttons removed from cataract patients and compared the deviation from intended capsulectomy diameter with a laser system with that obtained with a manual CCC. The laser capsulectomies were significantly closer to the intended diameter, as shown in Table 5-9-1. Friedman[30] reported on a similar series, although the analysis of button diameter was based on the mean of just four diameters across the button. They reported a mean deviation from intended diameter of 29 µm for laser capsulectomy compared with 337 µm for manual capsulorrhexis.

The capsulectomy and its relationship to the IOL implanted in the bag have a significant influence on the final resting position of the implant. The centration of the capsulectomy influences the centration of the IOL and thus the placement of the capsulectomy is of real importance. Some laser guidance systems offer the option to center the capsulectomy over the pupil center (which is typically where a manual CCC is placed) or over the optical axis of the crystalline lens. This latter option will place the optical axis of the IOL in the same position as that of the crystalline lens being removed (assuming centration of the lens within the bag) and may be least likely to cause avoidable induced optical aberrations.

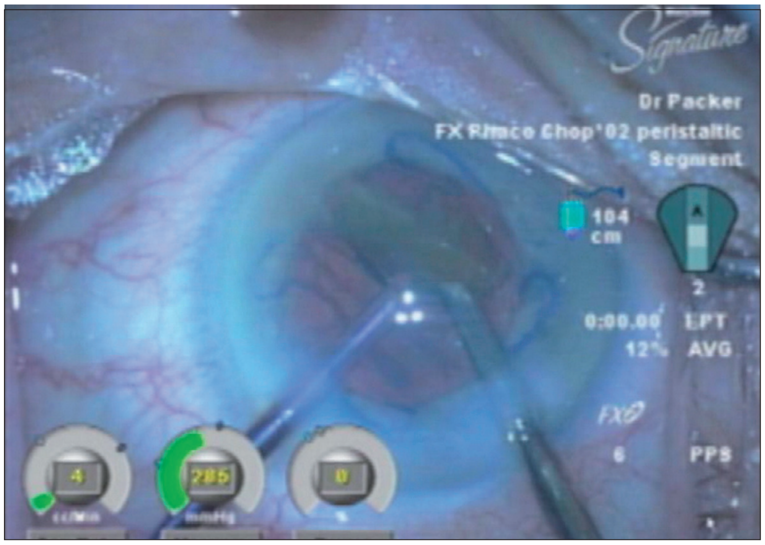

Fig. 5-9-7 The final segment of nucleus is grasped with high vacuum and brought centrally.

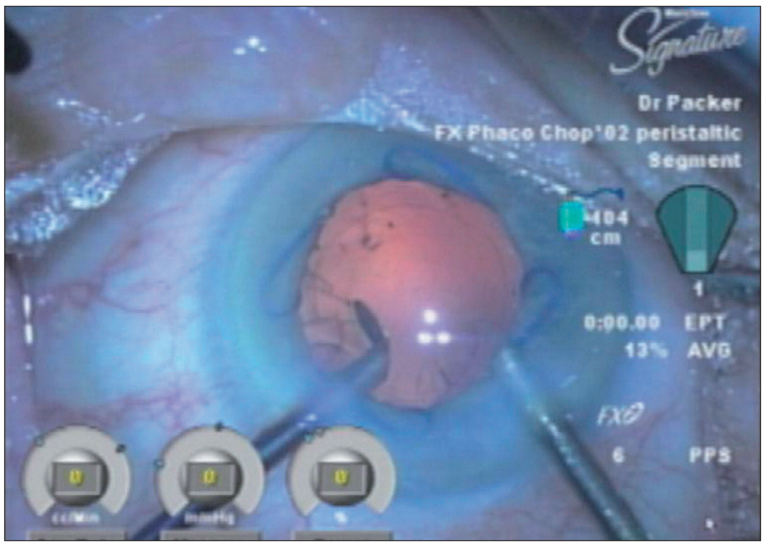

Fig. 5-9-8 At the conclusion of epinucleus aspiration the capsule is almost entirely free of cortex.

The size of the capsulectomy may influence the progression of posterior capsular opacification (PCO). Current practice requires the capsulectomy to be in contact with the optic of the IOL around its circumference. However significant variations in the extent of this contact or areas where there is no contact may cause the lens to decenter and tilt as the capsule contracts postoperatively.

Kranitz and Nagy reported improved overlap of the capsulectomy edge on the optic of the IOL and less horizontal decentration of the IOL in cases where laser capsulectomy had been used.[31,32] It has been proposed that the consistency of laser capsulectomy may increase the consistency of Effective Lens Position (ELP) and hence the ability to hit the targeted postoperative refractive result. Early data presented by Uy and Hill tend to confirm this effect.[33,34] In a study of 44 cases undergoing laser capsulectomy and 62 cases undergoing manual CCC, a significantly higher proportion produced the intended refractive outcome at 6 months by a factor of four. Table 5-9-2 shows the results which support the hypothesis that laser capsulectomy has a positive effect on consistency of ELP.

Lens Fragmentation

Fragmentation of the lens prior to cataract surgery is intended to reduce or eliminate the need for ultrasound energy during nuclear disassembly. In the ideal situation, the nucleus would simply be removed by aspiration. However it might be anticipated that harder nuclei might still require some ultrasound emulsification.

In the quest for optimal outcomes, different cutting patterns and algorithms (shot placement, energy, and pulse repetition frequency) may all influence the efficiency of the fragmentation. Nichamin has shown some of the patterns that were evaluated during an early phase of the development of lens fragmentation.[35] It was found that different patterns had different effectiveness depending on the hardness of the cataract being treated. Overall, the pie pattern proved the most effective over the range of cataract grades from 1 to 5+.

Packer and Uy have presented data on the effectiveness of phacofragmentation by comparing the total ultrasound energy required for nuclear disassembly following laser lens fragmentation with that required during conventional ultrasound phaco surgery. Their results are shown in Tables 5-9-3 and 5-9-4.[36]

The reduction in the use of ultrasound energy may lead to other benefits, such as less corneal edema, faster visual recovery and a reduction in the rate of endothelial cell loss. Packer and Uy also report that endothelial cell density changes from baseline are less following laser lens fragmentation compared with conventional ultrasound phaco. Table 5-9-5 summarizes these results.

TABLE 5-9-2 PERCENTAGE OF CASES ACHIEVING THE REQUIRED REFRACTIVE OUTCOME

Percentage achieving intended results		
	6 months post-surgery	
Deviation	**Laser**	**Manual**
0.00	13.5%	3.4%
≤0.50	81.1%	74.6%
≤1.25	100.0%	96.6%

From Uy H, Hill WE, Edwards K. Refractive results after laser anterior capsulotomy. Invest Ophthalmol Vis Sci 2011;52:5695.

TABLE 5-9-3 ANALYSIS OF MEAN (SD) CDE AS A FUNCTION OF NUCLEAR CATARACT GRADE

Treatment groups	For Grade 0 Mean (SD) N	For Grade 1 Mean (SD) N	For Grade 2 Mean (SD) N	For Grade 3 Mean (SD) N	For Grade 4 Mean (SD) N
Laser Treatments	1.9 (3.2) 3	0.0 (0.0) 4	3.0 (4.0) 29	9.3 (9.4) 25	24.0 (18.8) 27
Control Group	7.8 (—) 1	4.4 (2.4) 7	8.2 (6.1) 24	15.2 (13.0) 15	41.2 (24.7) 7
% Difference Control vs Laser	−75.6%	−100.0%	−63.4%	−38.8%	−41.7%

TABLE 5-9-4 NUMBERS OF SUBJECTS AND STATISTICAL SIGNIFICANCE BY CATARACT GRADE

Grade ≤1		Grade 1		Grade 2		Grade 3		Grade 4	
Laser	Phaco	Laser	Phaco	Laser	Phaco	Laser	Phaco	Laser	Phaco
N=7	N=8	N=4	N=7	N=29	N=24	N=25	N=15	N=27	N=7
p=0.006		p=0.006		p<0.001		p=0.069		p=0.052	

TABLE 5-9-5 CHANGES IN ENDOTHELIAL CELL DENSITY BETWEEN BASELINE AND 3 MONTHS AFTER SURGERY

	Change in Endothelial Cell Density at 3 months post-surgery							
	Grade 1		Grade 2		Grade 3		Grade 4	
	Laser	Phaco	Laser	Phaco	Laser	Phaco	Laser	Phaco
Mean % change	1.5	−7.0	0.1	−1.3	−0.1	−4.3	−2.4	−1.5
SD	14.4	9.7	14.9	11.1	10.5	8.7	11.9	8.3
P value	0.10>p>0.05		NS		0.10>p>0.05		NS	

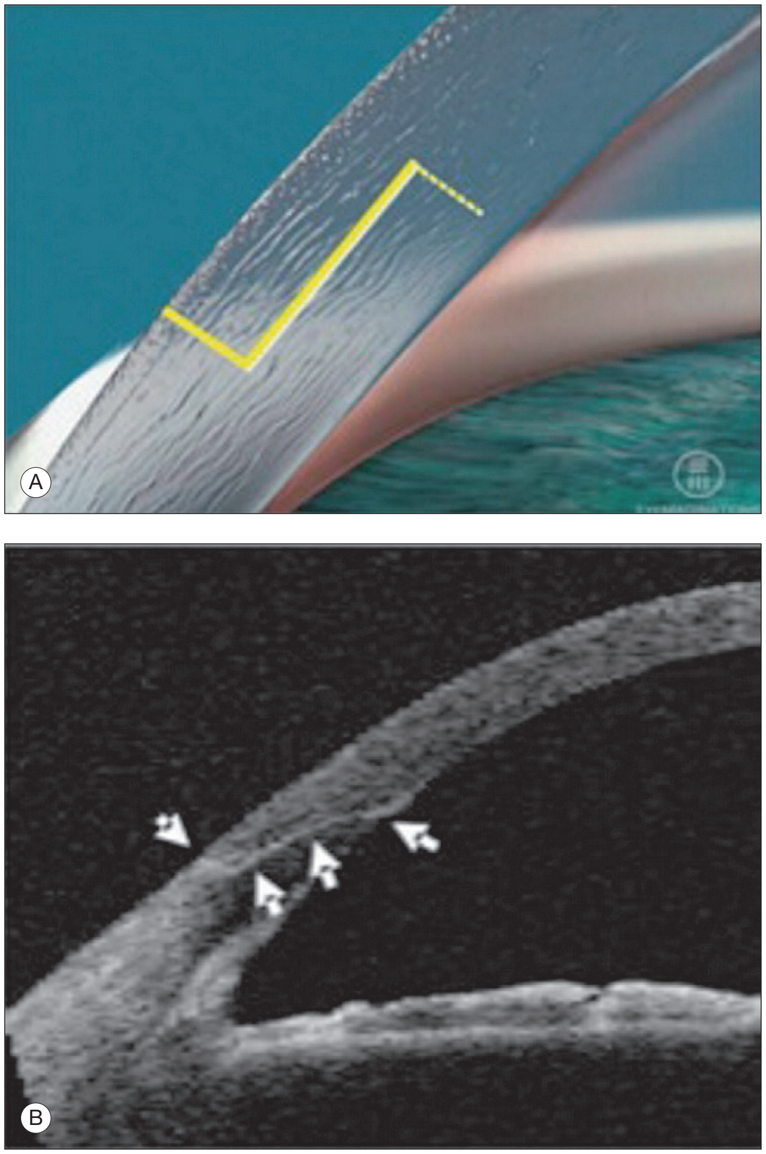

Fig. 5-9-9 Planned incision (A) with dotted line showing part to be opened at time of surgery with a surgical blade and optical coherence tomography (OCT) if incision the day after surgery (B).

Corneal Incisions

In an early study with cadaver eyes, Masket showed the ability of a single-plane laser incision to be self-sealing at significant intraocular pressures (IOP) and indentations at certain wound tunnel lengths.[37] Palanker reported that three-plane laser incisions were self-sealing and watertight at physiological IOPs.[38] It is not clear whether this applies to the incision immediately after its creation or at the end of the surgical cases, following the use of the phaco handpiece and IOL insertion. Fig. 5-9-9 shows the planned corneal incision and the optical coherence tomogram of the wound the day after surgery.

The effectiveness of laser limbal relaxing incisions or astigmatic keratotomy has yet to be established in the literature, although the precision of the laser in creating incisions of the precise length and depth required suggests that the procedure should be more reproducible and reliable than manual methods. Several authors have shown reduction of astigmatism in post-keratoplasty patients or patients with a high degree of astigmatism with femtosecond laser arcuate keratotomy.[39–42]

CONCLUSION

Since the time of Charles Kelman's inspiration in the dentist's chair (while having his teeth ultrasonically cleaned), progress in phaco technology and techniques have produced ever-increasing benefits, including more rapid visual rehabilitation and reduced dependence on contact lenses and glasses. Creative engineering and surgical ingenuity have acted synergistically to improve outcomes. Advances in technique and technology will continue to benefit our patients as we develop the exciting new future of femtosecond laser assisted cataract surgery.

KEY REFERENCES

Cataract in the Adult Eye, Preferred Practice Pattern, American Academy of Ophthalmology, 2011. http://one.aao.org/ce/practiceguidelines/ppp_content.aspx?cid=a80a87ce-9042-4677-85d7-4b876deed276. Accessed December 6, 2011.

Fine IH. Architecture and construction of a self-sealing incision for cataract surgery. J Cataract Refract Surg 1991;17: 672–6776.

Fine IH. Cortical cleaving hydrodissection. J Cataract Refract Surg 1992;18:508–12.

Fine IH, Packer M, Hoffman RS. Use of power modulations in phacoemulsification. J Cataract Refract Surg 2001;27:188–97.

Friedman NJ, Palanker DV, Schuele G, et al. Femtosecond laser capsulotomy. J Cataract Refract Surg 2011;37(3):1189–98.

Kershner RM. Clear corneal cataract surgery and the correction of myopia, hyperopia, and astigmatism. Ophthalmology 1997;104:381–9.

Masket S, Sarayba M, Ignacio T, et al. Femtosecond laser-assisted cataract incisions: Architectural stability and reproducibility. J Cataract Refract Surg 2010; 36:1048–9.

Nichamin LD, Chang DF, Johnson SH, et al. ASCRS White Paper: What is the association between clear corneal cataract incisions and postoperative endophthalmitis? J Cataract Refract Surg 2006;32:1556–9.

Nubile M, Carpineto P, Lanzini M, et al. Femtosecond laser arcuate keratotomy for the correction of high astigmatism after keratoplasty. Ophthalmology 2009;116:1083–92. Epub 2009 Apr 23. doi: 10.1016/j.ophtha.2009.01.013.

Packer M, Fishkind WJ, Fine IH, et al. The Physics of phaco: a review. J Cataract Refract Surg 2005;31(2):424–31.

Palanker DV, Blumenkranz MS, Andersen D, et al. Femtosecond laser-assisted cataract surgery with integrated optical coherence tomography. Sci Translat Med 2010;58(1):1–9.

Tackman NR, Villar Kuri J, Nichamin LD, et al. Anterior capsulotomy with an ultrashort-pulse laser. J Cataract Refract Surg 2011;37:819–24.

REFERENCES

1. Kelman CD. Phacoemulsification and aspiration: a new technique of cataract removal: a preliminary report. Am J Ophthalmol 1967;64:23.
2. Packer M, Fishkind WJ, Fine IH, et al. The physics of phaco: a review. J Cataract Refract Surg 2005;31(2):424–31.
3. Fine IH. Architecture and construction of a self-sealing incision for cataract surgery. J Cataract Refract Surg 1991;17: 672–6776.
4. Rosen ES. Clear corneal incisions: a good option for cataract patients. A Roundtable Discussion. Ocular Surgery News, 1 February, 1998.
5. Williamson CH. Cataract keratotomy surgery. In: Fine IH, Fichman RA, Grabow HB, editors. Clear-corneal cataract surgery and topical anesthesia. Thorofare, NJ: Slack, Inc.; 1993. p. 87–93.
6. Langerman DW. Architectural design of a self-sealing corneal tunnel, single-hinge incision. J Cataract Refract Surg 1994;20:84–8.
7. Kershner RM. Clear corneal cataract surgery and the correction of myopia, hyperopia, and astigmatism. Ophthalmology 1997;104:381–9.
8. Gills JP, Gayton JL. Reducing pre-existing astigmatism. In: Gills J.P., editor. Cataract surgery: The state of the art. Thorofare, NJ: Slack, Inc.; 1998. p. 53–66.
9. Nichamin L. Refining astigmatic keratotomy during cataract surgery. Ocular Surgery News, 15 April, 1993.
10. Fukuda S, Kawana K, Yasuno Y, et al. Wound architecture of clear corneal incision with or without stromal hydration observed with 3-dimensional optical coherence tomography. Am J Ophthalmol 2011;151:413–9.e1. Epub 2011 Jan 13.
11. Fine IH. Special Report to ASCRS Members: Phacoemulsification incision burns. Letter to American Society of Cataract and Refractive Surgery members, 1997.
12. Nichamin LD, Chang DF, Johnson SH, et al. ASCRS White Paper: What is the association between clear corneal cataract incisions and postoperative endophthalmitis? J Cataract Refract Surg 2006;32:1556–9.
13. Mollan SP, Gao A, Lockwood A, et al. Post-cataract endophthalmitis: incidence and microbial isolates in a United Kingdom region from 1996 through 2004. J Cataract Refract Surg 2007;33:265–8.
14. Eifrig CW, Flynn Jr HW, Scott IU, et al. Acute-onset postoperative endophthalmitis: review of incidence and visual outcomes (1995–2001). Ophthalmic Surg Lasers 2002;33:373–8.
15. Miller JJ, Scott IU, Flynn Jr HW, et al. Acute-onset endophthalmitis after cataract surgery (2000–2004): incidence, clinical settings, and visual acuity outcomes after treatment. Am J Ophthalmol 2005;139:983–7.
16. Oshika T, Hatano H, Kuwayama Y, et al. Incidence of endophthalmitis after cataract surgery in Japan. Acta Ophthalmol Scand 2007;85:848–51.
17. Cataract in the adult eye; preferred practice pattern, American Academy of Ophthalmology, 2011. http://one.aao.org/ce/practiceguidelines/ppp_content.aspx?cid=a80a87ce-9042-4677-85d7-4b876deed276. Accessed December 6, 2011.
18. Wasserman D, Apple D, Castaneda V, et al. Anterior capsular tears and loop fixation of posterior chamber intraocular lenses. Ophthalmology 1991;98:425.
19. Neuhann T. Theorie und operationstechnik der kapsulorhexis. Klin Monatsbl Augenheilkd 1987;190:542.
20. Gimbel HV, Neuhann T. Development, advantages and methods of the continuous circular capsulorrhexis technique. J Cataract Refract Surg 1990;16:31.
21. Gimbel HV, Neuhann T. Letter to the editor: Continuous curvilinear capsulorrhexis. J Cataract Refract Surg 1991;17:110.
22. Little BC, Smith JH, Packer M. Little capsulorrhexis tear-out rescue. J Cataract Refract Surg 2006;32:1420–2.
23. Fine IH. Cortical cleaving hydrodissection. J Cataract Refract Surg 1992;18:508–12.
24. Gimbel HV. Divide and conquer nucleofractis phacoemulsification. J Cataract Refract Surg 1991;17:281.
25. Shepherd JR. In situ fracture. J Cataract Refract Surg 1990;16:436.
26. Fine IH. The choo-choo chop and flip phacoemulsification technique. Operative Tech Cataract Refract Surg 1998;1:61–5.
27. Fine IH, Packer M., Hoffman RS. Use of power modulations in phacoemulsification. J Cataract Refract Surg 2001;27:188–97.
28. Brauweiler P. Bimanual irrigation/aspiration. J Cataract Refract Surg 1996;22:1013–6.
29. Tackman NR, Villar Kuri J, Nichamin LD, et al. Anterior capsulotomy with an ultrashort-pulse laser. J Cataract Refract Surg 2011;37:819–24.
30. Friedman NJ, Palanker DV, Schuele G, et al. Femtosecond laser capsulotomy. J Cataract Refract Surg 2011;37:1189–98.
31. Kranitz K, Takacs A, Mihaltz K, et al. Femtosecond laser capsulotomy and manual continuous curvilinear capsulorrhexis parameters and their effects on intraocular lens centration. J Refract Surg 2011 epub doi 10.3928/1081597X-20110623-03.
32. Nagy ZZ, Kranitz K, Takacs AI, et al. Comparison of intraocular lens decentration parameters after femtosecond and manual capsulotomies. J Refract Surg 2011 epub doi 10.3928/1081597X-20110607-01.
33. Uy H, Hill WE, Edwards K. Refractive results after laser anterior capsulotomy. Invest Ophthalmol Vis Sci 2011;52:5695.
34. Hill WE, Uy H. Effective lens position following laser anterior capsulotomy. Presentation to the Annual Meeting of the American Academy of Ophthalmology 2011; Orlando.
35. Nichamin LD, Uy H. Choice of fragmentation algorithm impacts the reduction in CDE during cataract surgery. Presentation to the Annual Meeting of the American Academy of Ophthalmology 2010; Chicago, IL. October 16-19, McCormick Place, Chicago, IL.
36. Packer M, Uy H. Endothelial changes after laser phaco-fragmentation. Presentation to the Annual Meeting of the American Academy of Ophthalmology 2011; Orlando, FL. October 22-25, Orlando Convention Center, Orlando, FL.
37. Masket S, Sarayba M, Ignacio T, et al. Femtosecond laser-assisted cataract incisions: Architectural stability and reproducibility. J Cataract Refract Surg 2010;36:1048–9.
38. Palanker DV, Blumenkranz MS, Andersen D, et al. Femtosecond laser-assisted cataract surgery with integrated optical coherence tomography. Sci Translat Med 2010;58:1–9.
39. Nubile M, Carpineto P, Lanzini M, et al. Femtosecond laser arcuate keratotomy for the correction of high astigmatism after keratoplasty. Ophthalmology 2009;116:1083–92. Epub 2009 Apr 23 doi: 10.1016/j.ophtha.2009.01.013.
40. Kumar NL, Kaiserman I, Shehadeh-Mashor R, et al. IntraLase-enabled astigmatic keratotomy for post-keratoplasty astigmatism: on-axis vector analysis. Ophthalmology 2010;117: 1228–35.
41. Abbey A, Ide T, Kymionis GD, et al. Femtosecond laser-assisted astigmatic keratotomy in naturally occurring high astigmatism. Br J Ophthalmol 2009;93:1566–9.
42. Bahar I, Levinger E, Kaiserman I, et al. IntraLase-enabled astigmatic keratotomy for postkeratoplasty astigmatism. Am J Ophthalmol 2008;146:897–90.