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PREVENTION OF POSTERIOR SEGMENT COMPLICATIONS OF PHACOEMULSIFICATION

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Optimal prevention of posterior segment complications of phacoemulsification depends upon achieving, at the completion of surgery, placement of an intraocular lens within an intact capsular bag that is supported by an intact zonular apparatus. Studies have suggested that the risks of retinal detachment,[1,4,24,26,33,35,36,41] endophthalmitis,[5,25,34] and cystoid macular edema[27] increase when the capsule is not intact. The incidence of capsular rupture and vitreous loss increases in the presence of a small pupil, hard nucleus, traumatic cataract, deep-set eyes, patient movement during surgery, and pseudoexfoliation.[2,23,29,39] Techniques that minimize the risk of damage to the zonule and capsule, therefore, offer the best alternatives for the prevention of posterior segment complications of phacoemulsification.

If the capsular apparatus does become compromised intraoperatively, correct management may reduce the risk of further complications. Capsular rupture and zonular dehiscence occur most often during lens emulsification and cortical clean up.[22,28,40] Rapid recognition of a break in the posterior capsule or a loss of zonular integrity may enable the surgeon to prevent extension of the tear, prolapse of vitreous, and posterior dislocation of lens material. Viscoelastic devices enable maintenance of the anterior chamber and prevent anterior vitreous migration. Anterior vitrectomy is recommended if vitreous presents at the wound or entangles lens fragments in the anterior chamber.[30] Aggressive attempts at removing posterior intravitreal lens fragments are not recommended because of increased risk of vitreous hemorrhage, retinal tear and retinal detachment.[6,9,19,37] Once the anterior segment is free of lens material and vitreous, an intraocular lens should be positioned in the anterior chamber or, in the presence of adequate capsular support, in the ciliary sulcus or capsular bag.

Phacoemulsification techniques such as chip and flip, crack and flip, and choo-choo chop and flip represent the synthesis of a variety of integral steps designed to enhance protection of the posterior capsule and thereby reduce the risk of posterior segment complications of cataract surgery.[11] The use of cortical cleaving hydrodissection[12] permits the elimination of irrigation and aspiration as a separate step in the procedure, thus eliminating its attendant risk of a capsular tear. Hydrodelineation[17] allows the creation of a protective cushion, which provides a space within the epinuclear shell where mechanical forces can be confined, and maintains the capsule in an expanded configuration, which reduces the possibility of a knuckle of capsule prolapsing forward into the phaco tip. The use of power modulation during phacoemulsification enhances control of nuclear material by reducing

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chatter through application of continuous vacuum with intermittent vibration. Maintenance of the bevel down position of the phaco tip allows emulsification of nuclear material at a safe distance from the posterior capsule by permitting the surgeon to draw material up rather than dive deeply within the endolenticular space to mobilize material. Flipping of the epinucleus enables its removal from the neighborhood of the posterior capsule and further increases the margin of safety in phacoemulsification. Special techniques to avoid capsular rupture in the presence of a small pupil or weakened zonule caused by pseudoexfoliation or trauma enable the surgeon to proceed safely in these high-risk eyes.

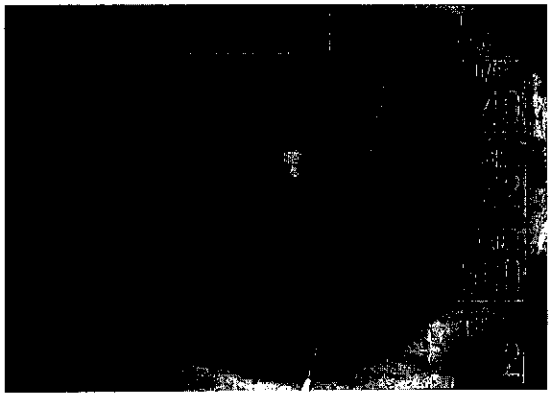

Figure 1. Placement of the cannula under the anterior capsulorhexis in one of the distal quadrants, elevating the capsule. (See Color Plate I, Fig. 1.)

CORTICAL CLEAVING HYDRODISSECTION

Hydrodissection of the nucleus in cataract surgery traditionally has been perceived as the injection of fluid into the cortical layer of the lens under the lens capsule to separate the lens nucleus from the cortex and capsule.[10] With increased use of continuous curvilinear capsulorhexis[21,32] and phacoemulsification in cataract surgery, hydrodissection became an important step to mobilize the nucleus within the capsule for disassembly and removal.[8,14,20,38] Following nuclear removal, cortical cleanup proceeded as a separate step, using irrigation and aspiration handpieces.

Fine[12] has previously described cortical cleaving hydrodissection, which is a hydrodissection technique designed to cleave the cortex from the lens capsule and thus leave the cortex attached to the epinucleus. Cortical cleaving hydrodissection usually eliminates the need for cortical cleanup as a separate step in cataract surgery by phacoemulsification, thereby eliminating the risk of capsular rupture during cortical cleanup.

A small capsulorrhexis, 5 mm to 5.5 mm, optimizes the procedure. The large anterior capsular flap makes this type of hydrodissection easier to perform. The anterior capsular flap is elevated away from the cortical material with a 26-gauge blunt cannula (Katena Instruments No. K7-5150, Denville, New Jersey) before hydrodissection (Fig. 1). The cannula maintains the anterior capsule in a tented-up position at the injection site near the lens equator. Irrigation before elevation of the anterior capsule should be avoided because it will result in transmission of a fluid wave circumferentially within the cortical layer, hydrating the cortex and creating a path of least resistance that will disallow later cortical cleaving hydrodissection. Once the cannula is properly placed and the anterior capsule is elevated, gentle, continuous irrigation results in a fluid wave that passes circumferentially in the zone just under the capsule, cleaving the cortex from the posterior capsule in most locations. When the fluid wave has passed around the posterior aspect of the lens, the entire lens bulges forward because the fluid is trapped by the firm equatorial cortical-capsular connections (Fig. 2). The procedure creates, in effect, a temporary intraoperative version of capsular block syndrome as seen by enlargement of the diameter of the capsulorrhexis. At this point, if fluid injection is continued, a portion of the lens prolapses through the capsulorrhexis. However, if before prolapse the capsule is

Figure 2. Enlargement of capsulorhexis as seen following second cortical cleaving hydrodissection fluid wave placed in the opposite distal quadrant just before decompression of the capsular bag. (See Color Plate I, Fig. 2.)

decompressed by depressing the central portion of the lens with the side of the cannula in a way that forces fluid to come around the lens equator from behind, the cortical-capsular connections in the capsular fornix and under the anterior capsular flap are cleaved. The cleavage of cortex from the capsule equatorially and anteriorly allows fluid to exit from the capsular bag via the capsulorrhexis, which constricts to its original size, and mobilizes the lens so that it can spin freely within the capsular bag (Fig. 3). Repeating the hydrodissection and capsular decompression starting in the opposite distal quadrant may be helpful. Adequate hydrodissection now can be demonstrated by the ease with which the nuclear-cortical complex can be rotated by the cannula.

HYDRODELINEATION

Hydrodelineation is a term first used by Anis[3] to describe the act of separating an outer epinuclear shell or multiple shells from the central compact mass of inner nuclear material, the endonucleus, by the forceful irrigation of fluids (balanced salt solution) into the mass of the nucleus.

The technique described here uses the same hydrodissection cannula as previously discussed. The cannula is placed in the nucleus, off center to either side, and directed at an angle downward and forward towards the central plane of the nucleus. When the nucleus starts to move, the endonucleus has been reached; it is not penetrated by the cannula. Next, the cannula is directed tangentially to the endonucleus, and a to-and-fro movement of the cannula is used to create a tract within the nucleus. The cannula is backed out of the tract approximately halfway, and a gentle but steady pressure on the syringe allows fluid to enter the *empty* distal tract without resistance. Driven by the hydraulic force of the syringe, the fluid will find the path of least resistance, which is the junction between the endonucleus and the epinucleus, and flow circumferentially in this contour. Frequently, a circumferential golden ring will be seen outlining the cleavage between the epinucleus and the endonucleus. Sometimes the ring will appear as a dark circle rather than a golden ring.

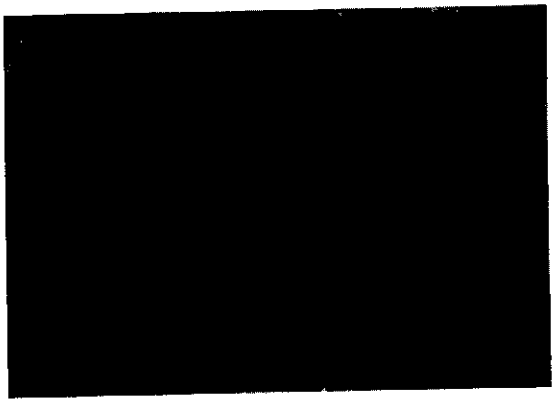

Figure 3. Return of capsulorhexis to its original size following decompression of the bag. (See Color Plate I, Fig. 3.)

Occasionally, an arc will result and surround approximately one quadrant of the endonucleus. In this instance, creating another tract the same depth as the first but ending at one end of the arc, and injecting into the middle of the second tract, will extend that arc (usually another full quadrant). This can be repeated until a golden or dark ring verifies circumferential division of the nucleus.

For soft nuclei, the placement of the cannula allows creation of an epinuclear shell of any thickness. The cannula may pass through the entire nucleus if it is soft enough, so the placement of the tract and the location of the injection allow an epinuclear shell to be fashioned as desired. In firm nuclei, the surgeon appears to be injecting into the cortex on the anterior surface of the nucleus, and the golden ring will not be seen. A thin, hard epinuclear shell, however, is achieved even in the most brunescent nuclei. That shell will offer the same protection as a thicker epinucleus in a softer cataract.

Hydrodelineation circumferentially divides the nucleus and has many advantages. Circumferential division reduces the volume of the central portion of nucleus removed by phacoemulsification by up to 50%. This allows less deep and less peripheral grooving and smaller, more easily mobilized quadrants after cracking or chopping. The epinucleus acts as a protective cushion within which all of the chopping, cracking, and phacoemulsification forces can be confined. In addition, the epinucleus keeps the bag on stretch throughout the procedure, making it unlikely that a knuckle of capsule will come forward, occlude the phaco tip, and rupture.

COMPLETION OF THE PROCEDURE

After evacuation of all endonuclear material, the epinuclear rim is trimmed in each of

the three quadrants, mobilizing the 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 (Figs. 4, 5). Then, the floor is pushed back to keep the bag on stretch until three of the four quadrants of the epinuclear rim and forniceal cortex have been evacuated (Fig. 6). It is important not to allow the epinucleus to flip too early, thus avoiding a large amount of residual cortex remaining after evacuation of the epinucleus.

The epinuclear rim of the fourth quadrant is then used as a handle to flip the epinucleus (Fig. 7). As the remaining portion of the epinuclear floor and rim is evacuated from the eye, 70% of the time the entire cortex is evacuated with it (Fig. 8).[15] Downsized phaco tips, with their increased resistance to flow, are less capable of mobilizing the cortex because of the decreased minisurge accompanying the clearance of the tip when going from foot position two to foot position three in trimming of the epinucleus.

After the intraocular lens is inserted, these strands and any residual viscoelastic material are removed using the irrigation-aspiration tip, leaving a clean capsular bag.

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

Alternatively, if the surgeon wishes to complete cortical cleanup with the irrigation-

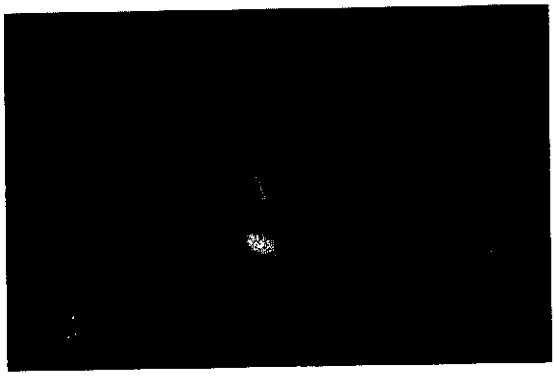

Figure 4. Purchase of the epinuclear rim and roof in foot position 2, being pulled central to the capsulorhexis. The cortical layer is seen superior to the rim and roof of the epinuclear shell. (See Color Plate I, Fig. 4.)

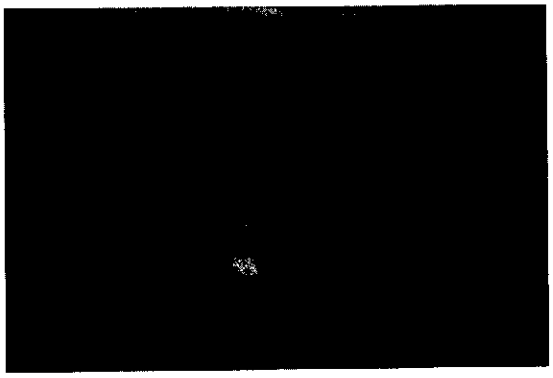

Figure 5. Following trimming of the initial purchase of the rim and roof in foot position 3, one can see the cortex flow over the floor and into the tip, removing it from that same quadrant. (See Color Plate I, Fig. 5.)

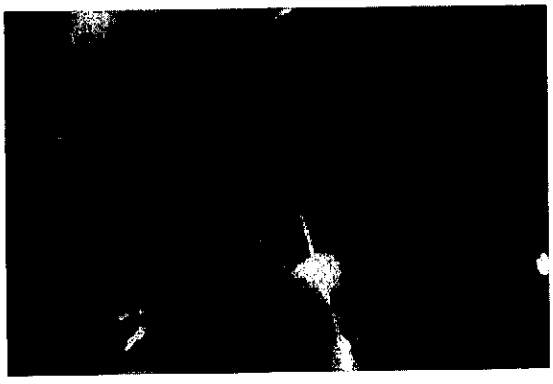

Figure 6. Repositioning of the floor of the epinucleus after rim and roof of the epinuclear shell have been trimmed and the cortex has been evacuated from the third epinuclear quadrant. (See Color Plate I, Fig. 6.)

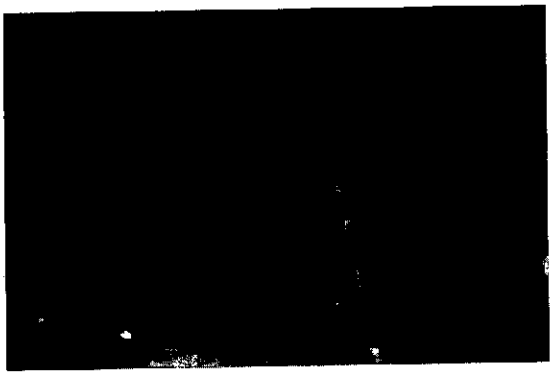

Figure 7. Initiating the flipping maneuver of the residual epinucleus utilizing the fourth quadrant of epinuclear rim and shell. (See Color Plate I, Fig. 7.)

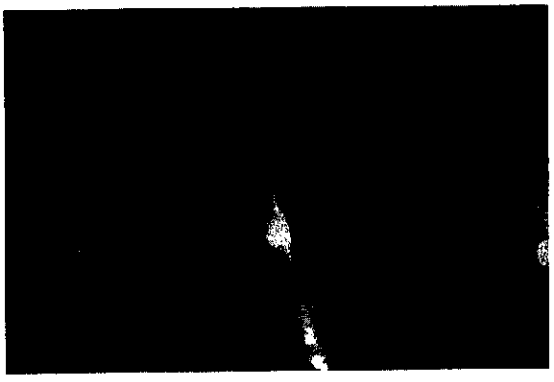

Figure 8. The capsular bag is clear of cortex, except for a single strand to the right following flipping and evacuation of the residual epinucleus. (See Color Plate I, Fig. 8.)

aspiration handpiece before lens implantation, the residual cortex almost always can be mobilized as a separate and discrete shell (reminiscent of the epinucleus) and removed without ever turning the aspiration port down to face the posterior capsule.

The third option is to viscodissect the residual cortex by injecting the viscoelastic through the posterior cortex onto the posterior capsule. The preferred method is to use the dispersive viscoelastic device chondroitin sulfate-hyaluronate (Viscoat). 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 device (e.g., Provisc) and the intraocular lens is implanted through the capsulorrhexis, leaving the anterior extension of the residual cortex anterior to the intraocular lens.

Removal of residual viscoelastic material accompanies mobilization and aspiration of residual cortex anterior to the intraocular lens, which protects the posterior capsule, leaving a clean capsular bag.

In summary, the lens can be divided into an epinuclear zone with most of the cortex attached and a more compact central nuclear mass. The central portion of the cataract can be removed by any endolenticular technique, after which the protective epinucleus is removed with all or most of the cortex attached. In most cases, irrigation and aspiration of the cortex as a separate step are not required, thereby eliminating that portion of the surgical procedure and its attendant risk of capsular disruption. Residual cortical cleanup may be accomplished in the presence of a posterior chamber intraocular lens, which protects the posterior capsule by holding it remote from the aspiration port.

CHIP AND FLIP TECHNIQUE

Phacoemulsification of soft nuclei is made easier with a chip and flip technique.[14] Following cortical cleaving hydrodissection and hydrodelineation, (Fig. 9) the central nucleus is converted first to a bowl with gentle sculpting at a 0 mm Hg to 6 mm Hg vacuum and a flow rate of 16 mm/min. Rotating and removing the rim of the bowl up to the golden ring converts the bowl into a plate or chip (Fig. 10). The chip is elevated into the center of the capsular bag with the second handpiece (Fig. 11) and, using pulsed phacoemulsification at 8 pulses/sec and the second handpiece to hold the chip down (Fig. 12), the chip is emulsified

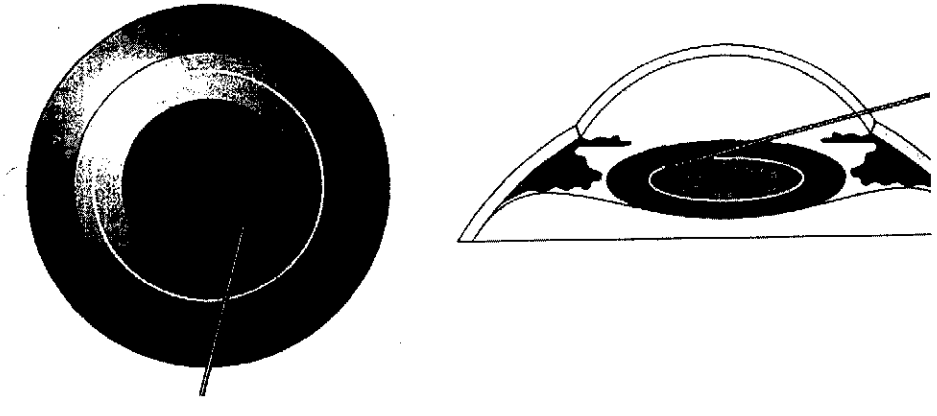

Figure 9. Hydrodelineation of the nucleus.

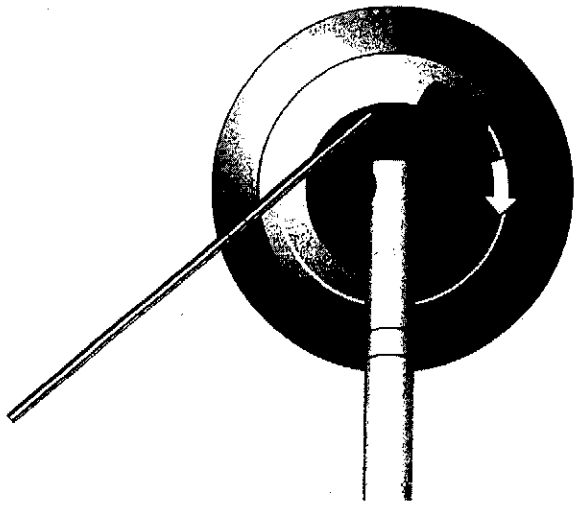

Figure 10. The nucleus is rotated and another clock hour of the endonuclear rim is removed at 5 to 6 o'clock.

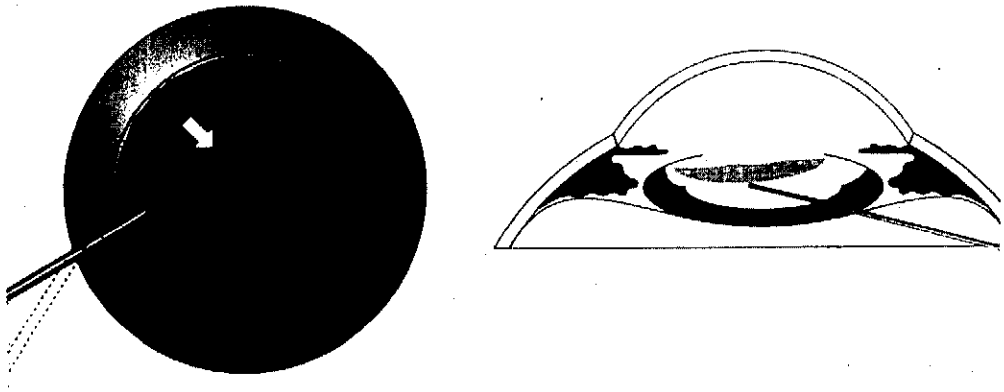

Figure 11. Elevation of the nuclear tip.

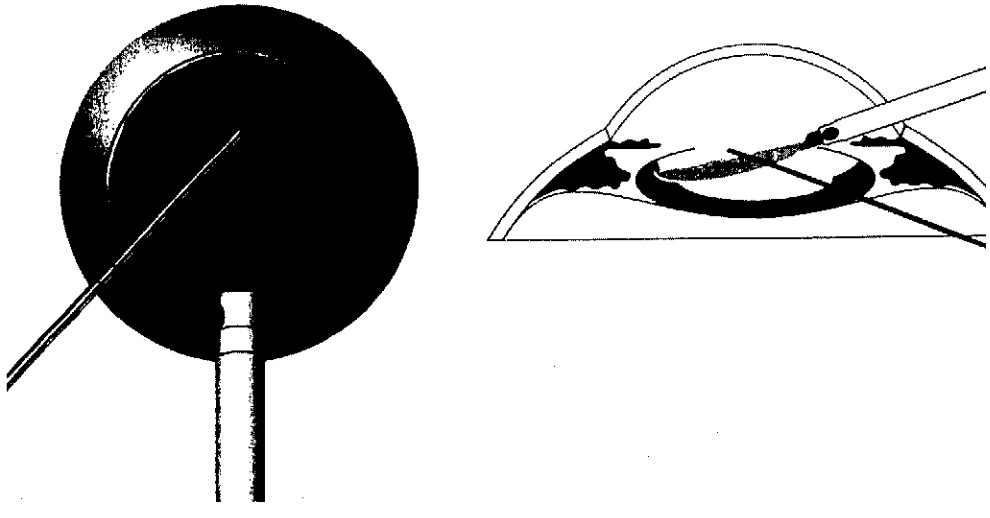

Figure 12. During its removal, the chip is controlled by the second handpiece.

and removed from within the capsular bag and the epinucleus, if possible. The epinucleus is then trimmed and removed as described previously (Figs. 13 and 14).

CRACK AND FLIP PHACOEMULSIFICATION

Crack and flip phacoemulsification is a modification of the techniques of Howard Gimbel[20] and John Shepherd[38] using quadratic grooving of the nucleus central to the hydrodelineation golden ring (Fig. 15). Once the grooving, done in a 0 mm Hg to 6 mm Hg vacuum, is completed, the nucleus is cracked in each location without rotation by combining cross-action and parallel forces (Figs. 16, 17, 18). Once the cracking has taken place, every effort is extended to remove the quadrants within the epinuclear shell. They are tilted so that the apex is elevated (Fig. 19); the tip is occluded with the bevel down and a relatively high vacuum, and the second handpiece holds the quadrant down in the epinucleus while it is consumed in pulsed phacoemulsification (Fig. 20). This procedure creates the most protective environment for removal of each quadrant without disturbance of the posterior capsule (Fig. 21).

CHOO-CHOO CHOP AND FLIP PHACOEMULSIFICATION

This surgical technique is designed to take maximum advantage of new technologies, including high vacuum cassettes and tubing, multiple programmable features, and phaco tip design. After the hydrodissection and hydrodelineation, the nucleus should rotate easily within the capsular bag. The phaco tip is introduced bevel down to aspirate the epinucleus uncovered by the capsulorrhexis. The Fine/Nagahara chopper (Rhein Medical, Tampa, Florida) is placed in the golden ring and is used to stabilize the nucleus by lifting and pulling toward the incision slightly (Fig. 22), after which the phaco tip lollipops the nucleus in pulse mode at 2 pulses/sec or 80 msec burst mode. With this power modulation, ultrasound energy is minimized into the eye and control of the nucleus as the vacuum builds between pulses or bursts is maximized. Because of the decrease in cavitational energy around the tip at this low-pulse rate or in burst mode, the tunnel in the nucleus in which the tip is embedded fits the needle tightly and gives an excellent hold on the nucleus as the surgeon scores and chops it in foot position two (Fig. 23).

Bringing the chop instrument to the side of the phaco needle scores the nucleus. Pulling the chopper to the left and slightly down while moving the phaco needle, still in foot position two, to the right and slightly up chops the nucleus in half. Then the nuclear complex is rotated. The chop instrument is again brought into the golden ring (Fig. 24), and the nucleus is again lollipopped, scored, and chopped, with the resulting pie-shaped segment now lollipopped on the phaco tip (Fig. 25). The segment is then evacuated using high vacuum and short bursts or pulse mode at 2 pulses/sec

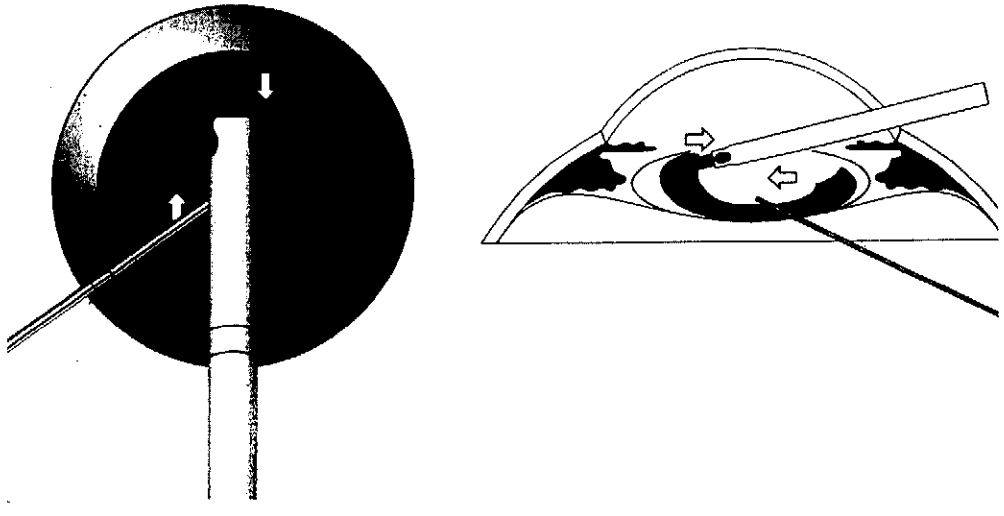

Figure 13. Initial maneuver for flipping the epinucleus.

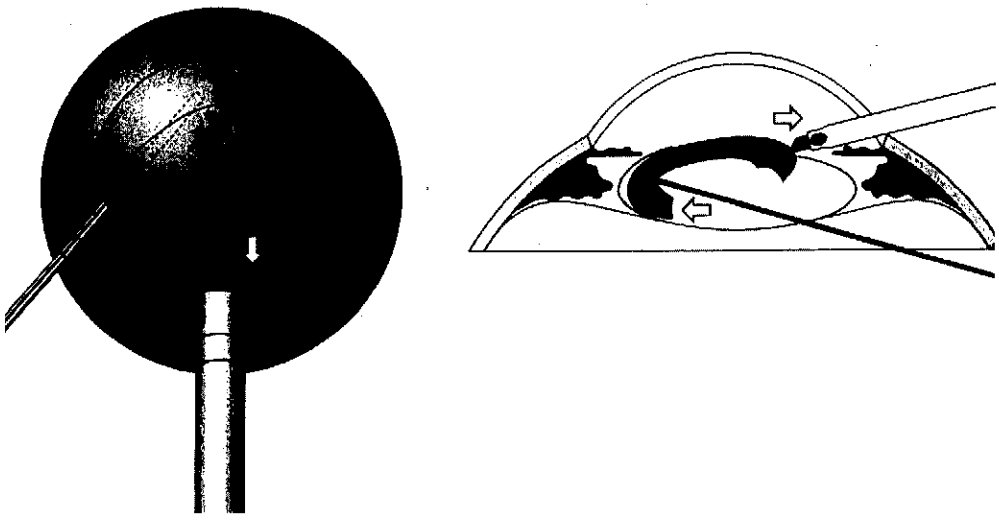

Figure 14. Epinucleus completely tumbled.

(Fig. 26). The nucleus is continually rotated so that pie-shaped segments can be scored, chopped, and removed by the high vacuum which is assisted by short bursts or pulses of ultrasound energy. With burst mode or the low-pulse rate, the nuclear material tends to stay at the tip rather than chatter as the vacuum holds between pulses. The chop instrument is used to stuff the segment into the tip or keep it down in the nuclear shell.

After evacuation of the first hemi-nucleus, the second hemi-nucleus is rotated to the distal portion of the bag, and the chop instrument stabilizes it while it is lollipopped. It is then scored (Fig. 27) and chopped. The pie-shaped segments can be chopped a second time to reduce their size (Fig. 28) if they appear too large to evacuate easily. After evacuation of all endonuclear material, the tip is turned bevel up, and the epinucleus is trimmed and removed as described previously.

Using cortical cleaving hydrodissection and hydrodelineation, mechanical disassembly of the nucleus in the form of chopping, rather than grooving and cracking, and vacuum extraction of nuclear material, rather than converting it into an emulsate and aspirating it from the eye, along with power modulations

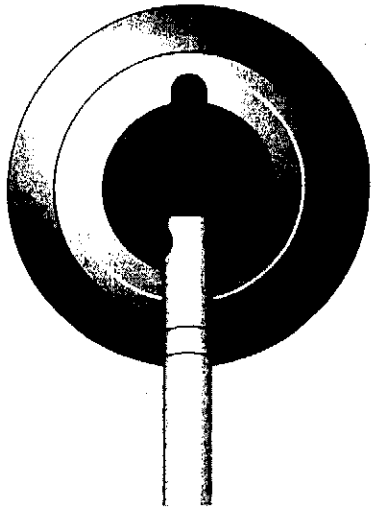

Figure 15. Nucleus being grooved central to the hydrodelineation demarcation circle or golden ring.

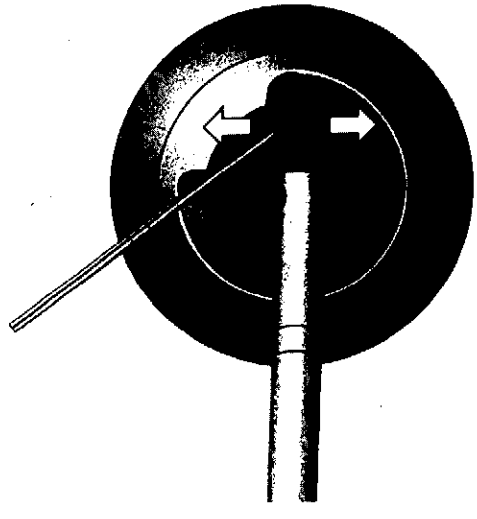

Figure 16. Cracking the distal groove.

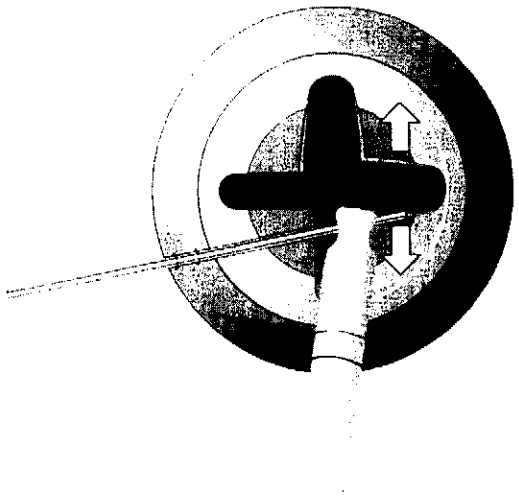

Figure 17. Cracking the right groove.

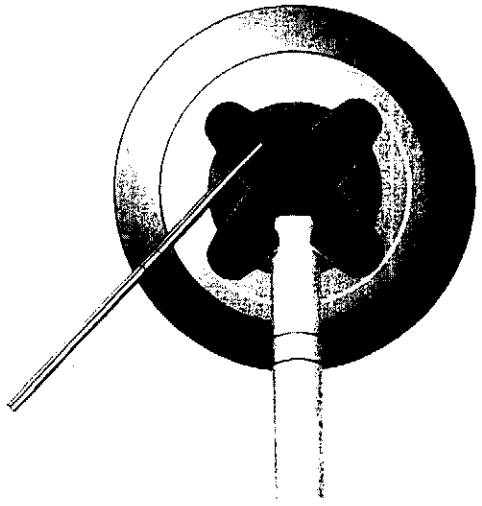

Figure 19. Elevating the apex of the quadrant by rotating its blunt periphery down.

and low levels of average phaco power, the surgeon may not only enhance protection of the posterior capsule but also achieve minimal disturbance of intraocular structures and maximize both the rapidity and the level of visual rehabilitation.[18]

SMALL PUPILS

The small pupil creates increased risk of capsular rupture and vitreous loss and, therefore, must be managed effectively to prevent posterior segment complications of phacoemulsification. A variety of techniques exist for the management of the small pupil, including sector iridectomy, iris hooks, iris rings, and pupillary stretching with or without the use of multiple half-width sphincterotomies.[13] The Beehler pupil dilator (Moria #19009, Doylestown, Pennsylvania), uniformly applicable in the presence of small pupils, usually stretches the pupil to 6.0 mm to 7.0 mm while creating tiny microsphincterotomies circumferentially around the pupil. The pupil can then be mechanically reduced at the end of the procedure with a Lester hook supplemented with an intraocular miotic agent. Pupils en-

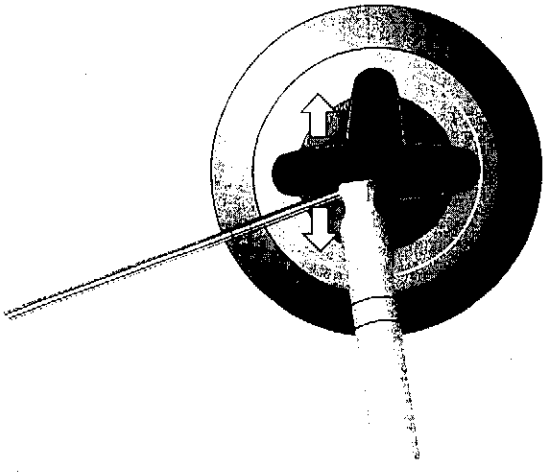

Figure 18. Cracking the left groove.

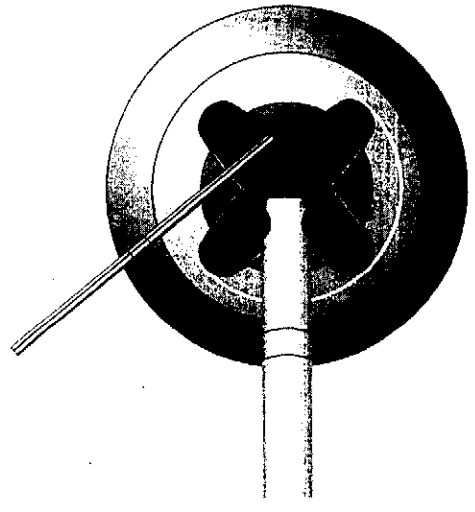

Figure 20. Using a second handpiece to keep the quadrant within the epinucleus.

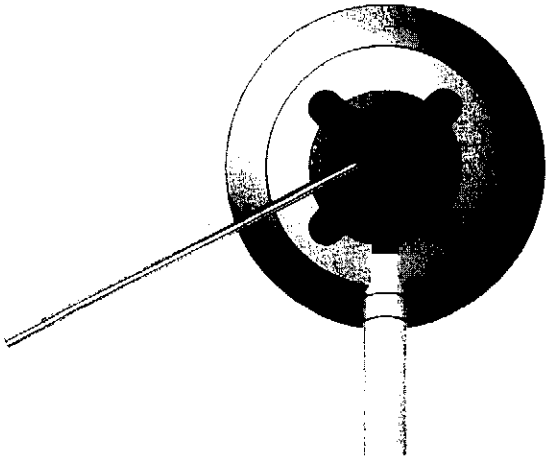

Figure 21. The epinuclear shell after removal of the quadrants.

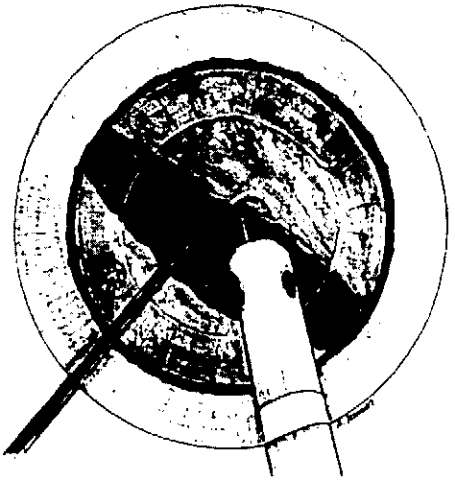

Figure 23. Completion of the initial chop.

larged in this manner maintain a good cosmetic appearance and an ability to react to light but may require miotic drops after cataract surgery to avoid synechia to the capsulorrhexis margin.

ZONULAR COMPROMISE

Weak zonules lead to challenging situations during phacoemulsification. It is important not to challenge the integrity of the zonule by overpressurizing the eye. This can occur after peribulbar or retrobulbar injection with digital pressure or Honan balloon, when the anterior chamber is overexpanded with viscoelastic before capsulotomy, or as a result of an excessively high-bottle height during phacoemulsification.

Because of the lack of zonular integrity, it frequently is difficult to perforate the capsule to begin a capsulorrhexis. A pinch-type forceps such as the Kershner capsulorrhexis cystotome forceps (Rhein Medical 05-2320, Tampa, FL) allows the surgeon to grasp the capsule and initiate the tear without exerting downward pressure on the lens. During capsulotomy, special care and attention are required because traction on the capsule can unzip weakened zonular fibers. If there are areas of missing zonular fibers, centripetal traction on the capsular flap may result in further damage. Techniques of two-handed capsulotomy using tangential forces as described by Neuhann[31] are excellent adjunctive

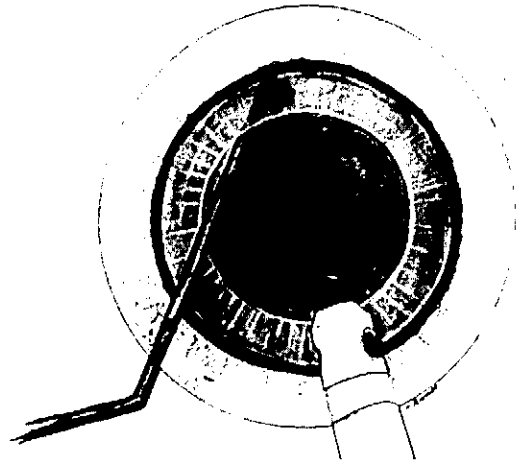

Figure 22. Stabilization of the nucleus during lollipopping for the initial chop.

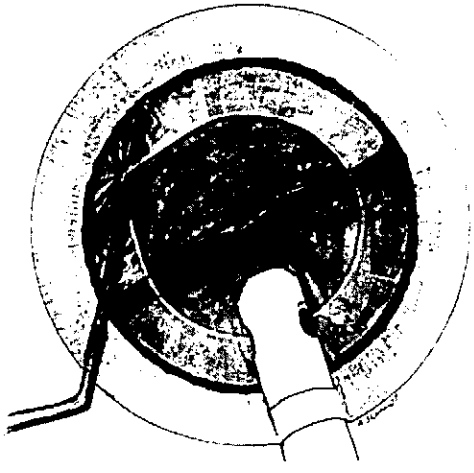

Figure 24. Stabilization of the nucleus before commencing the second chop.

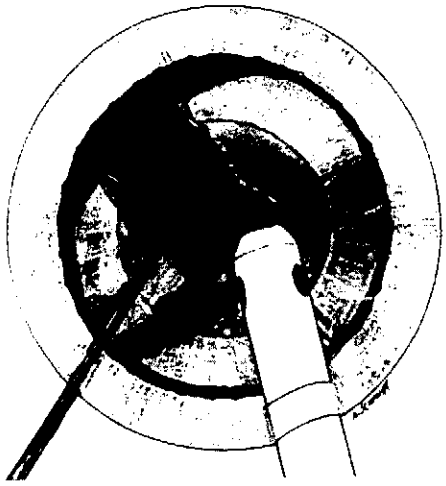

Figure 25. Pie shaped segment adherent to the phaco tip following completion of the second chop.

techniques in eyes with zonular compromise. After initiating the capsulotomy, the capsular flap is stabilized with the forceps through the main incision, and a second instrument, such as a bifurcated spatula, is introduced through the side-port incision. Slight backward traction is placed on the flap with the forceps while the second instrument directly advances the torn edge in a tangential manner.

Another useful modality in the management of the compromised zonule is the capsular tension ring (Morcher, Stuttgart, Germany, not currently approved by the US Food and Drug Administration).[7] This polymethylmethacrylate (PMMA) ring comes in two sizes, 10.0 mm and 14.0 mm, for high myopia. When placed in the capsular bag, the ring keeps the bag stretched and provides several

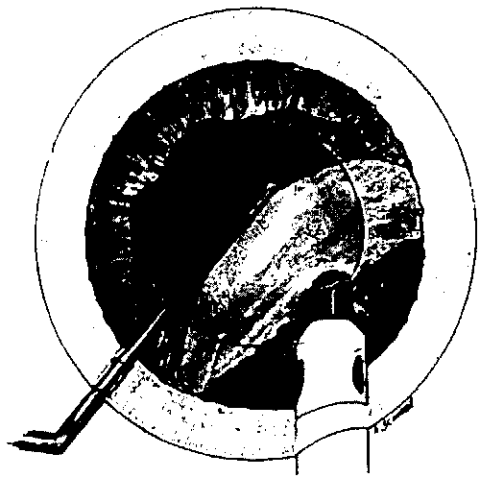

Figure 27. Scoring of the second heminucleus.

advantages. It prevents concentration of forces on individual zonular fibers by distributing all forces to the entire zonular apparatus. It also keeps the bag stretched throughout the procedure, allowing for greater safety during all intraocular manipulations. Finally, the continuous pressure of the ring against the capsular fornices bolsters the zonular traction on the capsule and counters the force of constriction after metaplasia and fibrosis of the capsulorrhexis.

The ring is slipped into the incision and fed under the capsulorrhexis with a forceps while the second hand guides it with a Lester hook. Once the ring is in place, cortical cleaving hydrodissection is performed followed by hydrodelineation. The remainder of the procedure can be done using many of the guidelines described previously. Although cortical cleav-

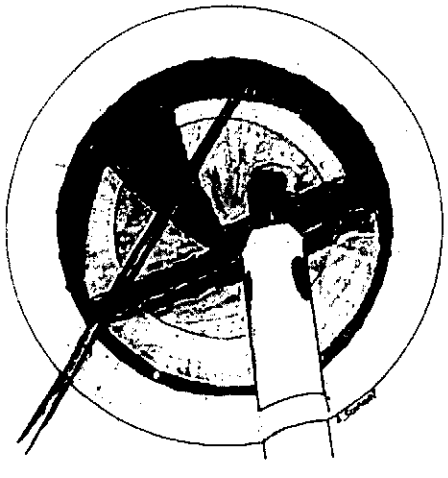

Figure 26. Mobilization of the first pie shaped segment.

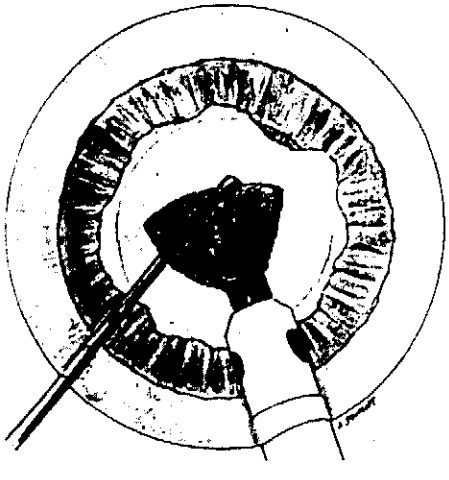

Figure 28. Mobilizing the final quadrant.

ing hydrodissection may have been performed, the endocapsular ring holds much of the cortex pressed up against the capsular fornices, requiring additional force to remove the cortex with irrigation/aspiration. Despite this requirement, there is more safety during the procedure because of the equal distribution of forces by the ring and the stabilization of the capsular bag.[16]

SUMMARY

The prevention of posterior segment complications of cataract surgery depends on the maintenance of an intact lens capsule and zonular apparatus. The phacoemulsification techniques presented here, including cortical cleaving hydrodissection, hydrodelineation, ultrasound power modulation, and management of the epinucleus and cortex, together with the special techniques presented for management of small pupils and compromised zonule, minimize the risk of damage to the posterior capsule by maximizing control of nuclear disassembly and evacuation. Choo-choo chop and flip phacoemulsification, in particular, provides a management strategy for cataracts of all grades of nuclear hardness whether in the presence of a small pupil or compromised zonule.

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