

PHACOEMULSIFICATION

ARTICLE BY PENELOPE L. KUHN, CST

In 1967, an extraordinary innovation in cataract surgery was introduced by Dr Charles D. Kelman.¹ Distressed by cataract extraction procedures resulting in wound-related complications and long recuperative periods, Dr Kelman developed a technique enabling surgeons to remove a cataract from a small, 3.0-mm incision utilizing a sophisticated form of machine-assisted extracapsular cataract extraction (ECCE). Kelman's development revolutionized cataract surgery, which until then had been plagued by large incisions and traumatic techniques. To describe his new procedure, Kelman coined the term *phacoemulsification*.

This paper provides the surgical technologist with an overview of phacoemulsification mechanics, instrumentation, and operative procedure.

Kelman Phacoemulsification

The term phacoemulsification implies emulsification of the crystalline lens. In actuality, the lens is not liquified but fragmented into pieces small enough to be aspirated. To safely and effectively accomplish this, Kelman successfully perfected three major innovations: (1) an ultrasonic vibrator tip that fragmented lens material within the anterior chamber without causing excessive mechanical trauma to associated structures, (2) a system for inflow and outflow of irrigating fluids to maintain the desired depth of the anterior chamber, and (3) surgical techniques to remove the anterior portion of the lens capsule in order to bring the lens nucleus forward into the anterior chamber where effective fragmentation and aspiration of lens material could be performed with decreased risk of rupturing the posterior capsule.

The advantages of Kelman phacoemulsification (KPE) over other cataract extraction techniques used to revolve around incision size. A smaller incision results in decreased postoperative recovery period and less chance of significant wound-induced astigmatism.² However, current use of the surgical microscope and finer, nonabsorbable sutures have also greatly reduced wound-related complications, even with large incisions. Therefore, whereas the small incision allows a more uneventful and quicker recovery — allowing the patient to resume activities almost immediately — a greater contribution of KPE has been recognized in the efficacy of leaving associated structures intact, including the posterior capsule, thereby preventing vitreous loss, retinal detachment, and macular edema and providing structural support for intraocular lens (IOL) implantation (Table 1).³

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Instrumentation

The Machine

Several generations of phacoemulsification units have been introduced since Kelman's early prototype in 1967. While these models differ with respect to various features, instrumentation and mechanics are comparable between units. The following information is based upon the Phaco-Emulsifier Aspirator (PEA) by Alcon Laboratories.

The PEA is an extremely complex piece of equipment, yet its operation is relatively simple. It has three basic functions: irrigation, aspiration, and ultrasonic vibration. Later PEA models include vitrectomy capabilities. These functions are selected by compression of a footswitch. In addition, manual control switches are placed on the PEA unit's front console and consist of varying combinations of the following: a main power switch, a footswitch position

Table 1. Kelman Phacoemulsification

Advantages

- Less surgical trauma to associated structures
- Leaves posterior portion of capsule intact, providing protection for internal eye structures and support for placement of an IOL
- Decreased incidence of retinal breaks and detachment
- Decreased incidence of cystoid macular edema
- Small incision provides shorter recuperation time, faster return to normal activities, less chance of significant wound-induced astigmatism
- In special cases, KPE is procedure of choice: patient on anticoagulants, highly myopic, soft sclera, extremely soft lens nucleus

Disadvantages

- Prolapsing the nucleus into the anterior chamber risks damage to corneal endothelium
 - Performing emulsification in the posterior chamber risks rupture of the posterior capsule and mixture of lens with vitreous or possible retinal tears
 - 50% of all intact posterior capsules opacify and require discission within 2 years after primary surgery
 - Complexity and expense of instrument; specialized training required
-

indicator, a vacuum-select switch, an ultrasonic power control switch, a tuning control/meter, a cooling-fault indicator, and an elapsed-time indicator.

For each KPE procedure, a sterile PEA kit provides necessary items such as irrigation and aspiration tubing sets, and components for assembly of instrument hand-pieces. In addition, detailed instructions for every phase of

PEA setup and use are included in an operator's manual.

Irrigation

While working within the eye, irrigation fluids maintain the optimal depth of the anterior chamber. This decreases risk of injury to delicate corneal tissues.

The irrigation system design is simple and based on gravity flow. A nonvented bottle of irrigating solution is suspended from an intravenous fluid hanger attached to the rear of the unit. The bottle hanger is calibrated and adjustable so that the hanger and bottle may be moved up or down, depending on the patient's position, to achieve the desired depth of the anterior chamber. During setup, the 0 point of the IV pole should be lined up with the patient's eye level. The water level in the irrigation tubing drip chamber is set at 65 cm above the 0 point. Balanced salt solution (BSS, Alcon) is the most frequently used solution, and many surgeons prefer to add the Plus (Alcon) component, which contains bicarbonate, dextrose, and glutathione (a tripeptide important in cellular respiration). These additives have been reported to facilitate sustenance of corneal endothelium.⁴ Epinephrine 1:1000 (0.3 to 0.5 ml) is often added to the 500 ml of irrigating solution to maintain necessary mydriasis during the procedure. Maximum dilation of the pupil is required for visual exposure of eye structures throughout the procedure and to avoid inadvertent fragmentation or aspiration of the iris.

The irrigation handpiece is a hollow-handled instrument that connects to the irrigation tubing. Various devices such as bent-tipped needles for anterior and posterior capsulotomy, cystitome, and capsule polishers can be attached to the handpiece.

To convey fluids to the handpiece, the drip chamber on tubing supplied in the sterile kit is passed off the field and inserted into the fluid supply bottle on the IV pole hanger. The circulator carefully secures a section of tubing into a pinch valve (irrigation solenoid) on the front console, while at the sterile field the luer fitting is attached to the handpiece. The irrigation solenoid valve pinches the irrigation tubing closed in footswitch position 0 (zero) and stops the flow of fluid. On the console, the pinch valve is opened in footswitch positions 1, 2, and 3, and fluid is allowed to flow through the tubing into the handpiece and out the surgical tip being used.

Aspiration

The aspiration function of KPE serves two purposes: it removes material from the eye and holds lens particles against the ultrasonic tip to allow efficient fragmentation of the cataract.

The irrigation/aspiration (I/A) handpiece provides irrigation in footswitch position 1 or permits simultaneous irrigation and aspiration in footswitch position 2. The I/A handpiece is used to remove residual cortical material *after* ultrasonic fragmentation of the lens nucleus. A variety of I/A tips are available with lumen diameters as follows: 0.2, 0.3, 0.5, and 0.7 mm. Identification bands on each tip indicate the size of the lumen (Figure 1).

During setup, the luer fitting of the aspiration tubing is connected to the I/A handpiece and the tubing is passed off the sterile field. A Cam Lock T-fitting is inserted into the aspiration vacuum port on the console, tubing is threaded around a peristaltic pump also on the console, and the tubing end inserted into a drainage bag. After setup, the irrigation and aspiration manifolds should be primed and

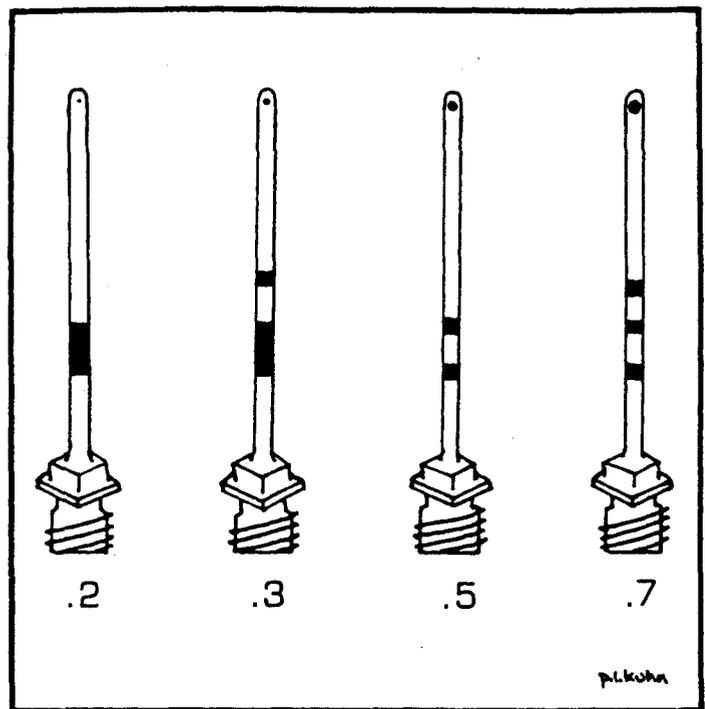


Figure 1. Lumen diameters in millimeters of irrigation/aspiration tips with corresponding identification bands.

vacuum levels tested on both the I/A and ultrasound (U/S) handpieces (see section on procedure setup).

Aspiration of lens material is accomplished by the peristaltic pump. This pump creates a vacuum within the tubing by the actions of an internal roller that simply "milks" the aspiration tubing. To aspirate material, the operating tip of the handpiece engages lens fragments and a vacuum build-up begins due to occlusion of the tip lumen. The peristaltic pump continues to run, creating the vacuum strength necessary to aspirate the material into the tip and convey it through the tubing and into the drainage bag located at the rear of the unit. A safety mechanism is built into the PEA that limits the vacuum potential to the preselected level so that vacuum strength cannot collapse the anterior chamber of the eye by rising to excessive levels when the occlusion breaks and material starts moving through the tip.

The manual vacuum-select switch on the front console controls vacuum levels during the surgical procedure. In the U/S position, vacuum levels are equivalent to 41 mm Hg, the I/A MIN mode provides a level of 65 mm Hg, and I/A MAX mode 370 mm Hg. In the I/A MAX mode, it is recommended that only I/A tips of 0.3 mm or 0.2 mm be used, as vacuum strength in a larger lumen may cause collapse of the anterior chamber.

The aspiration function includes a vent system. Lens material is held by the tip until it is either aspirated or released by a break in the vacuum. To break the vacuum, the aspiration line can be momentarily opened (vented) to the outside air by shifting the footswitch from position 2 to 1. This allows air to enter the tubing at the Cam Lock T-fitting, which rapidly reduces the vacuum in the system. The vent system allows control of vacuum strength potential, as well as manipulation of lens material.

Occasionally, lens material completely occludes the aspiration line. A bulb on the aspiration manifold proximal to the handpiece may be manually compressed, which will

flush the particle through and restore normal aspiration function.

Ultrasound

The ultrasonic handpiece provides three functions that occur separately or simultaneously: irrigation (footswitch position 1), irrigation and aspiration (footswitch position 2), and irrigation, aspiration, and fragmentation (footswitch position 3). Two significantly different handpieces are available with the PEA system.

One type of U/S handpiece turns electrical impulses into ultrasonic vibrations by way of *magnetostrictive* mechanisms. The internal component of the handpiece is called the Acoustic Vibrator and is composed of numerous, flat, metal bands joined at both ends. These bands elongate and contract rapidly due to changes in the magnetic field created by electrical impulses coming from the U/S generator — after receiving signals from the footswitch — within the PEA unit. The rapid vibrations of the metal bands convey linear motion to the instrument tip, allowing effective fragmentation of the lens nucleus. The magnetostrictive handpiece is assembled at the field after sterilization and disassembled for cleaning after each use. It is used with a power cord that must be ETO gassed or soaked for sterilization.

A newer handpiece utilizes *piezoelectric* (piezo is Greek for pressure) mechanisms to stimulate the instrument tip. This handpiece has a one-piece design, is not assembled/disassembled for cleaning, and is autoclavable with the corresponding power cord. To produce ultrasonic vibrations, electrical impulses from the PEA unit stimulate crystals that rapidly expand and contract. This mechanical energy is then conveyed to the instrument tip imparting the same linear motion as the magnetostrictive model.

The conversion of electrical energy into mechanical energy creates heat that can damage eye tissues. Therefore, a cooling system is provided to ensure that the handpiece and tip remain cool throughout the procedure. In older models, a reservoir for distilled water is located in the bottom of the PEA unit. During ultrasonic activation, the cooling pump circulates this nonsterile fluid through the U/S power cord to the magnetostrictive handpiece and back. Due to the mechanics of the cooling system, several factors are crucial to the proper and safe operation of the U/S handpiece. Care must be taken to assemble the handpiece correctly; nonsterile fluids might otherwise leak onto the sterile field. In addition, the appropriate level of coolant must be maintained, and bacterial growth in the cooling system must be controlled. Refer to the operator's manual for the specific procedures. In contrast, the newer piezoelectric handpieces are air cooled, avoiding the hazard of nonsterile fluids.

The U/S instrument tip is a removable, single-use, hollow, titanium needle. To protect adjacent eye tissues, the needle is covered before use with a soft silicone sleeve to expose only the last millimeter of the sharp tip. Linear motion produces vibrations longitudinally along the axis of the needle, forward and back, at a frequency of 40 kHz (40,000 times/second). The U/S needle is available in varying bevels: 15, 30, 45, and 60 degrees, with either a round or oval lumen. In general, bevels with a greater degree of angulation allow the surgeon to view the entire cutting edge of the tip for safer manipulation, yet proper occlusion of the lumen is more difficult. However, the oval-shaped lumen restores occlusion mechanics to the tip providing effective

fragmentation and aspiration. For these reasons, a tip with a large bevel and oval lumen may be preferred.

The KPE instrumentation must be tuned before use to ensure that the electronic characteristics of the machine are balanced with the handpiece. Once tuned, the U/S power control switch setting can be changed without altering the electronic tuning. When the setting is increased, the power output of the ultrasonic generator is increased and the back and forth excursion rate of the ultrasonic tip is increased. If the stroke is too forceful, lens fragments will be thrown away from the tip, scattering within the eye and causing possible damage. Decreasing the setting prevents this "chattering" of small nuclear particles against the corneal endothelium.

Operative Procedure

Phacoemulsification is an increasingly preferred form of cataract extraction. A study presented at the 1989 annual meeting of the American Society of Cataract and Refractive Surgery showed that among surgeons performing over 51 cataract extractions per month, 65% prefer phacoemulsification.⁵ This figure continues to increase each year. In addition, 86% of ophthalmologists surveyed have taken a phaco course, and 63% plan on using phaco more often in the future.

The following discussion assumes knowledge of ophthalmic anatomy, physiology, and previous experience with cataract extractions; emphasis is placed on KPE technique, without reference to insertion of an IOL.

Patient Selection

Considerations included in patient selection for KPE are (1) extent of pupillary dilation (minimum of 6.0 mm), (2) hardness of the lens nucleus (hard nuclei are more difficult and require more time to emulsify), (3) condition of the cornea (clear, with no evidence of endothelial disease), and (4) depth of the anterior chamber, particularly if the anterior chamber technique is employed.

Procedure Setup

Preparation for KPE is similar to planned ECCE with respect to general ophthalmic instrumentation. However, setup procedures vary according to the PEA model being used, and instructions included in the operator's manual should be followed carefully. The following are general setup procedures.

1. Drape the tray holder and form the tray pouch.
2. Place the sterilized phaco instrument tray on tray holder.
3. Assemble the ultrasonic handpiece.

On the magnetostrictive model, make sure the O-rings are properly and securely placed (Figure 2, see p 10), insert the Acoustic Vibrator into the ultrasonic handpiece, attach the ultrasonic nose cone, attach the ultrasonic tip to the acoustic vibrator using the tip wrench, attach the tip cap/sleeve, and place the tip protector on assembled handpiece. Hand off the ultrasonic handpiece power cord connector to the circulator.

On the piezoelectric model, connect the ultrasonic tip to the handpiece, attach the tip cap/sleeve, place the tip protector on assembled handpiece, and pass off the power cord connector to the circulator.

On both models, the silicone cap/sleeve is placed over the titanium tip so that the two irrigation ports on the sleeve are facing laterally and medially to the flat bevel surface of the



Figure 2. Application of rubber O-ring on Acoustic Vibrator of magnetostrictive ultrasound handpiece.

tip. Irrigating fluids pass between the tip and sleeve, exiting through these two ports. As the surgical tip is used in a bevel-up position, this allows irrigating fluids to be directed laterally and medially, not toward the cornea and posterior capsule.

4. Assemble the I/A handpiece.

Insert the interbody in handpiece housing, tighten securely, attach the I/A tip using the tip wrench, and attach the tip cap/sleeve. The irrigation ports of the sleeve should be oriented 90 degrees away from the aspiration port to avoid conflict in fluid dynamics.

5. Attach the irrigation and aspiration manifolds to the I/A handpiece and pass off drip chamber and drainage tubing ends to the circulator.

6. Manifolds are properly secured into appropriate fittings on the PEA console and into fluid receptacles by the circulator (Figure 3). This can be accomplished on recent PEA models by insertion of a disposable cassette that houses all manifold connections.

7. Prime the manifolds on the I/A handpiece using the test chamber. Check vacuum levels. For all operational checks, hold the handpiece horizontally at the PEA tray level.

Priming Manifolds/Vacuum Check. For all operational checks, hold the handpiece horizontally at the PEA tray level. To prime the manifolds, the circulator sets the vacuum to I/A MAX; depress the footswitch to position 2 to allow irrigating fluids to fill tubing and test chamber, removing all air. To check vacuum levels, activate the I/A function by depressing the footswitch to position 2 and manually occlude both manifolds simultaneously for five seconds; release. The test chamber, representing the anterior chamber of the eye, should remain inflated to indicate that vacuum levels and fluid mechanics are operating normally and anterior chamber collapse will be avoided. Refer to the troubleshooting section of the operator's manual if the test chamber collapses.

8. Repeat the aforementioned operational check with the manifolds on U/S handpiece. In addition, check ultrasonics using the test chamber.

Ultrasonics Check. If automatic tuning is not available, a U/S power setting of 8 is selected, the footswitch depressed to position 3, and the tuning control switch is rotated until

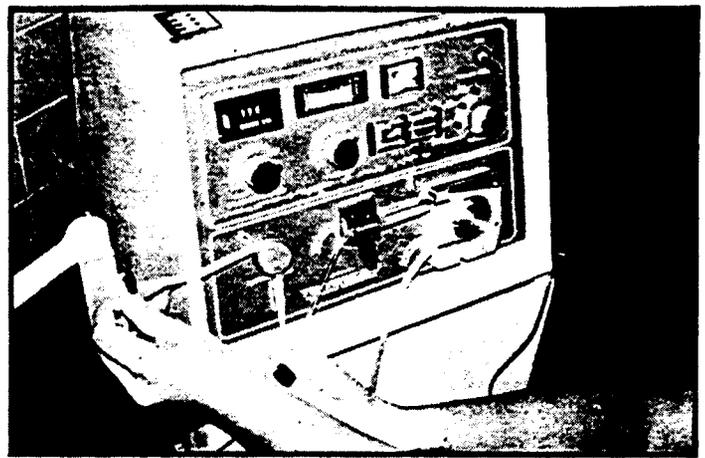


Figure 3. Irrigation tubing is stretched before insertion in pinch valve (solenoid) with footswitch depressed. Note aspiration manifold Cam Lock T-fitting and peristaltic pump. PEA Model 8000V.

the tuning meter is deflected to the right as far as possible. At this point, a characteristic sound is heard that the well-trained ear will immediately recognize.

9. After operational checks are completed, place irrigation manifold on irrigation handpiece and attach irrigating cystitome tip.

Surgical Technique

Incision. After anesthesia, a conjunctival flap is created. Scissors expose a 4.0 mm zone of sclera that is then cleaned and vessels cauterized. An incision along the limbus allows entry into the anterior chamber. The incision is measured with callipers to equal a chord length of 3.0 mm, parallel with the iris plane.

Anterior Capsulotomy. The irrigating cystitome is designed to supply irrigating solution to the anterior chamber; this maintains the distance between the cornea and lens while the anterior lens capsule is being opened. Some surgeons also use sodium hyaluronate (Healon). In footswitch position 1, the cystitome tip is inserted into the anterior chamber and used to incise the capsule using an O- or H-shaped "can-opener" incision. Numerous small cuts are made in the anterior capsule, close together, radial to the optic axis (Figure 4,A). Alternatively, some surgeons prefer a "single tear" method with the cystitome, while others use the Nd:YAG laser for anterior capsulotomy. After opening the capsule, the tip of the cystitome is used to snag a free edge of the anterior capsule to determine if it is fully separated. The anterior capsule is either coaxed through the incision and cut, or later aspirated.

Posterior Chamber Phacoemulsification. The lens can be effectively fragmented with ultrasound in the posterior chamber. This is preferred if the anterior chamber is shallow as it causes less corneal endothelial cell loss; however, it involves risk of rupturing the posterior capsule.

Anterior Chamber Phacoemulsification. Kelman's technique originally involved an anterior chamber method. After capsulotomy, the lens is prolapsed into the anterior chamber using the tip or flat edge of the cystitome. Once the irrigation and aspiration manifolds are secured on the ultrasonic handpiece, the titanium tip is inserted bevel down, rotated upward, and used to fragment and aspirate the lens nucleus in footswitch position 3. As a safety mea-

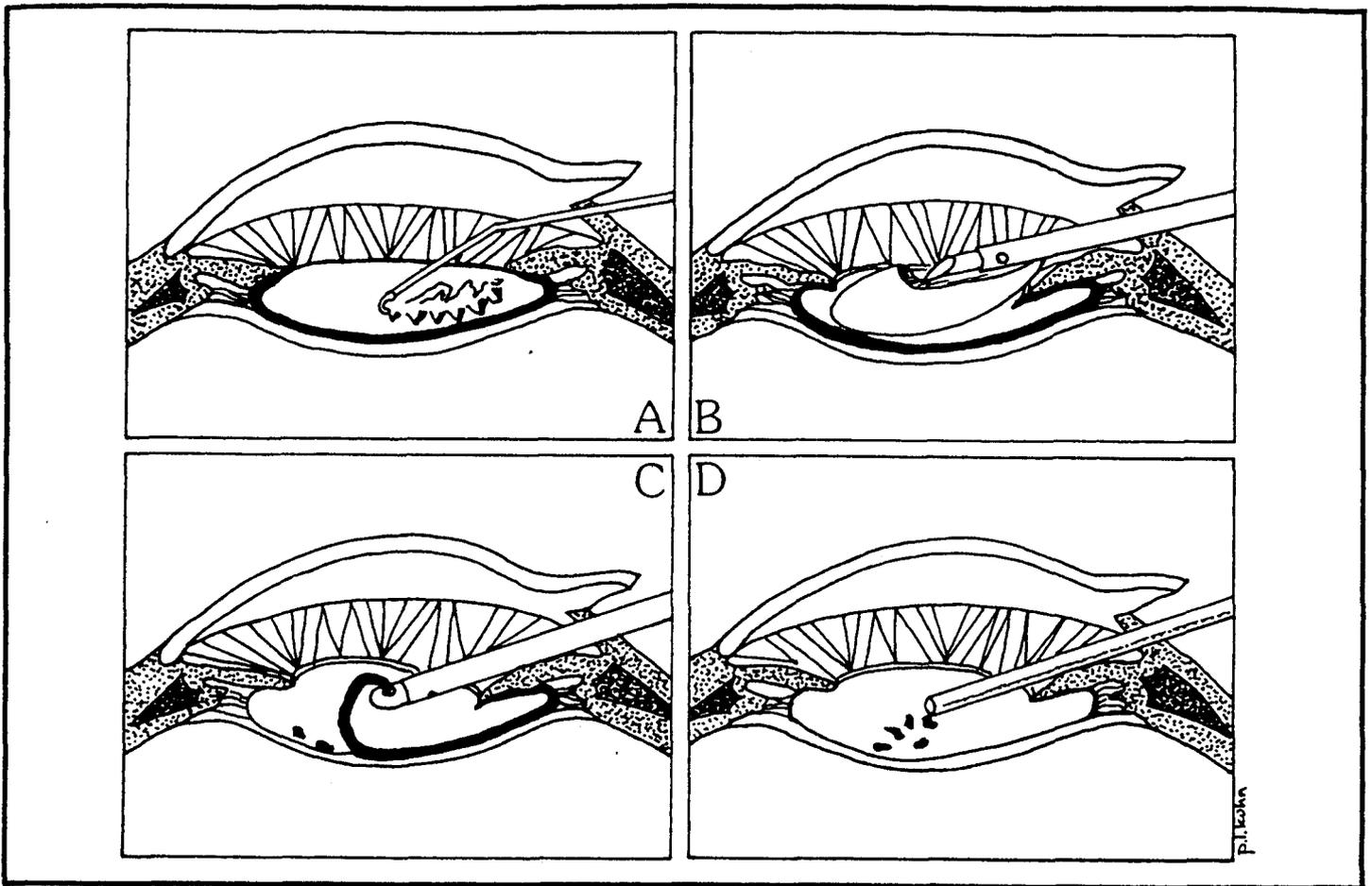


Figure 4. A, anterior capsulotomy; B, anterior chamber phacoemulsification; C, aspiration of cortical material off posterior capsule; and D, aspiration of cellular debris; posterior capsule polishing.

sure, the U/S power setting on the console is not selected until successful entry into the anterior chamber is complete.

Three different methods of fragmenting the lens nucleus can be used. One method involves fragmenting a pie-shaped sector of nucleus, rotating the lens to another sector, and repeating this process until fragmentation is complete. The "carousel" or "cartwheel" technique is effective with a soft nucleus and involves rotating the lens around the tip of the stationary titanium needle using a spatula or nucleus rotating instrument that has been inserted through a side port. The "croissant" technique involves boring through the center of the nucleus in a sagittal direction using short energy bursts (Figure 4,B).

KPE is the procedure of choice for soft nuclei. However, a pretreatment procedure allows surgeons to utilize KPE on even the hardest, most sclerotic lenses in grades III and IV. Nd:YAG laser photodisruption of the lens nucleus before KPE has been reported to decrease the phaco time for lenses in all grades.^{6,7} Laser pulses create shock and pressure waves that mechanically disrupt tissues adjacent to areas disintegrated by the focused laser beam. This dispersion property effectively softens any hard nucleus which might otherwise be considered too dense for effective KPE.

Irrigation/Aspiration. After the nuclear fragments have been aspirated, the manifolds are transferred to the I/A handpiece, and the power setting placed on I/A MAX to allow high vacuum power to aspirate residual cortical material from beneath the iris. The vacuum setting is then changed to I/A MIN and the remaining edge of cortex is

engaged, peeled off the posterior capsule, and aspirated (Figure 4,C).

At this point, the posterior capsule is cleaned using the I/A tip, or the irrigating manifold can be transferred to the irrigation handpiece and a capsule polishing/scraping tip used to remove particle debris on the posterior capsule (Figure 4,D).

In some cases, a posterior capsulotomy is performed on opaque capsules, and a peripheral iridectomy or iridotomy is performed to decrease the risk of pupillary block. Finally, to complete the KPE, one or two closing sutures are placed.

Complications

Studies show that KPE compares favorably with other methods.^{4,8} However, as with any surgical procedure, complications may result. Several factors contribute to the complexity of KPE.

Machine

Proper depth of the anterior chamber is vital to the success of KPE. The anterior chamber may become too shallow or even collapse if the height of the irrigation bottle is too low or if the vacuum level is set too high for the I/A tip lumen size being used. Conversely, the anterior chamber may become too deep and cause iris prolapse if the irrigation bottle is too high. Faulty power settings can also disrupt KPE. All of these factors are easily eliminated by proper maintenance, testing, and troubleshooting of the PEA unit's functions and associated instrumentation prior to the operative procedure.

Operative

Some operative complications require that the KPE strategy be converted to an alternate plan using a different technique and larger incision. These complications include posterior dislocation of the nucleus, capsular rupture, vitreous loss, zonular dialysis, shallowing of the anterior chamber, endothelial damage, or accidental fragmentation of the iris. During KPE, small tears in Descemet's membrane may also occur during insertion of either the I/A or U/S tips.

Postoperative complications are similar to those after intracapsular cataract extraction (ICCE) but differ in rate of occurrence.⁹ These include corneal edema from irrigation or mechanical trauma, hemorrhage, opacification of the posterior capsule, glaucoma, endophthalmitis, cystoid macular edema, retinal detachment, and phacoantigenic uveitis — an autoimmune disease where retained lens material is the antigen.

Discussion

Phacoemulsification offers surgeons exquisite control over the entire cataract extraction procedure. It is a closed-chamber technique allowing manipulation of anterior chamber depth thereby increasing maneuverability of the lens nucleus. In addition, KPE avoids blind passes of instruments within the eye and does not result in expulsion hemorrhages as in ICCE or ECCE with lens expulsion. Without IOL implantation, KPE utilizes the smallest incision of any other technique. Yet, as IOL design and implantation methods improve in taking advantage of such a small incision, an increasing number of surgeons will rely on KPE to prepare for IOL insertion.

President's Message — continued

We need to constantly reexamine and retool ourselves as we go through life — be recreators of ourselves. That's not always easy and it requires *stark* honesty with ourselves, which is not always comfortable. A couple of months ago I was walking through the Physical Education building on my campus when I saw a guy coming out of the weight training room wearing a t-shirt that read, "Pain is temporary, Pride is forever."

If we can not only *adapt* to changes occurring in the health care system, but help to find new *solutions* by participating more actively in the larger world of health care delivery, we, individually and as an organization, will not just survive — we will thrive!

There is a passage in *Alice's Adventures in Wonderland* where Alice is standing at a crossroad and she looks up and sees the Cheshire Cat.

Alice says, "Would you tell me, please, which way I ought to go from here?"

"That depends a good deal on where you want to get to," said the Cat.

"I don't much care where —," said Alice.

"Then it doesn't matter which way you go," said the Cat.

Do you, individually and collectively, know where you want surgical technology and AST to go? If you will communicate that to me, to your elected Board, to your regional committee representatives, or to your headquarters staff, I promise you that AST will do its *utmost* to help us get there! □

These advantages account for the continued increase in number of KPE procedures being performed annually. In light of the surgical technologist's role, often functioning as first assistant in ophthalmic procedures, a thorough understanding of KPE and appreciation of its use are indicated. □

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