Introduced by Dr. Charles Kelman in 1962, phacoemulsification machines have undergone constant improvement, ever increasing both their complexity and safety. There is one principle, however, that remains unchanged. All phaco machines consist of a computer to generate electrical signals and a transducer to turn these electronic signals into mechanical energy. The energy thus produced is passed through a hollow needle and is controlled within the eye to overcome the inertia of the lens and emulsify it. Once turned into emulsate, fluidic systems remove the emulsate, replacing it with balanced salt solution (BSS).

**Power Generation**

Power is created by an interaction between frequency and stroke length.

Frequency is defined as the speed of the needle movement. The manufacturer of the machine determines it. Presently, most machines operate at a frequency between 27,000 cycles per second (Hz) to 50,000 cycles per second. This frequency range is efficient for nuclear emulsification. Lower frequencies become less efficient and higher frequencies create excess heat.

Stroke length is defined as the length of the needle movement. This length is generally 2 to 6 mils (thousandths of an inch). Most machines operate in the 2 to 4 mil range. One mil is 25 microns. Therefore, most phaco needles travel a distance of 50 to 100 microns. The longer the stroke length, the greater the physical impact on the nucleus and the greater the generation of cavitation energy. Longer stroke lengths, like higher frequencies, however, tend to generate extra heat.

Stroke length is determined by foot pedal excursion in position 3 during linear control of phaco. As the foot pedal is depressed, the stroke length and therefore the power increase to the preset maximum. New foot pedals allow the surgeon to control the throw length in each major division, increasing the capability of the surgeon to manage control of both the fluidic and ultrasonic components of phaco.

**Tuning**

The central processing unit (CPU) of modern phaco machines recognizes when the phaco needle passes into different intraocular media. For example, the resistance of the aqueous is less than the resistance of the cortex, which in turn, is less than the resistance of the nucleus. As the resistance to the phaco tip varies to maintain maximum efficiency dependent on the machine, small alterations in frequency or stroke length are created by the tuning circuitry in the CPU.
This is important to minimize the excessive generation of ultrasonic energy, which is harmful to the intraocular contents. The surgeon will subjectively determine good tuning circuitry by a sense of smoothness and power.

**Phaco Energy**

The actual tangible forces that emulsify the nucleus are thought to be a blend of the “jackhammer” effect and cavitation energy.\(^1\) The jackhammer effect is the physical striking of the needle against the nucleus. The cavitation effect is more convoluted. Recent studies indicate that there are two kinds of cavitation energy. One is transient cavitation and the other is sustained cavitation.

**Transient Cavitation**

The phaco needle, moving through a liquid medium at ultrasonic speeds, gives rise to intense zones of high and low pressure. Low pressure, created with backward movement of the tip, pulls dissolved gases out of solution, thus producing micro bubbles. Forward tip movement then creates an equally intense zone of high pressure. This initiates compression of the micro bubbles until they implode. At the moment of implosion, the bubbles create a temperature of 7204°C degrees and a shock wave of 5,171,100 mbar. Of the micro bubbles created, 75% implode, amassing to create a powerful shock wave radiating from the phaco tip in the direction of the bevel with annular spread. However, 25% of the bubbles are too large to implode. These micro bubbles are swept up in the shock wave and radiate with it. Transient cavitation is a violent event. The energy created by transient cavitation exists for no more than 4 milliseconds and is present only in the immediate vicinity of the phaco tip and within its lumen. It is this form of cavitation that is thought to generate the energy responsible for emulsification of cataractous material. Additionally, transient cavitation is instrumental in clearing nuclear fragments within the phaco needle, preventing repetitive needle clogging.

The transient cavitative energy can be directed in any desired direction. The angle of the bevel of the phaco needle governs the direction of the generation of the shock wave and micro bubbles.

I have developed a method of visualization of these forces called "enhanced cavitation." Using this process, it can be seen that with a 45-degree tip, the cavitation wave is generated at 45 degrees from the tip. Similarly, a 30-degree tip generates cavitation at a 30-degree angle from the bevel, and a 15-degree tip 15 degrees from the bevel. A 0-degree tip creates the cavitation wave directly in front of the tip and the focal point is 0.5 mm from the tip. The Kelman tip has a broad band of powerful cavitation that radiates from the area of the angle in the shaft. A weak area of cavitation is developed from the bevel but is inconsequential.

Taking into consideration analysis of enhanced cavitation, it can be concluded that phacoemulsification is most efficient when both the jackhammer effect and cavitation energy are combined. To accomplish this, the bevel of the needle should be turned toward the nucleus or nuclear fragment. This simple maneuver will cause the broad bevel of the needle to strike the nucleus. This will enhance the physical force of the needle striking the nucleus. In addition, the cavitation force is then concentrated into the nucleus rather than away from it. Finally, in this configuration, the vacuum force can be maximally exploited as occlusion is encouraged. This causes energy to emulsify the nucleus and be absorbed by it. A 0-degree tip automatically focuses both the jackhammer and cavitation energy directly in front of it. When the bevel is turned away from the nucleus, the cavitative energy is directed up and away from the nucleus toward the iris and endothelium.

**Sustained Cavitation**

If phaco is energized beyond 4 milliseconds, transient cavitation with generation of micro bubbles and shock waves ends. The bubbles then begin to vibrate without implosion. No shock wave is generated. Therefore, there is no emulsification energy produced. Sustained cavitation is ineffective for emulsification. Water bath, hydrophonic studies indicate that transient cavitation is significantly more powerful than sustained cavitation. With this information in mind, it would appear that continuous phaco is best used to emulsify the intact nucleus, held in place by the capsular bag, during the sculpting phase of divide and conquer or stop and chop. Jackhammer energy is most important for emulsification in this setting.

Transient cavitation is maximized during micropulse phaco. This is best used during phaco of the nuclear fragments in the later phase of the above two procedures or during phaco chop procedures.

**Modification of Phaco Power Intensity**

Application of the minimal amount of phaco power intensity necessary for adequate emulsification of the
nucleus is desirable. Unnecessary power intensity is a cause of heat with subsequent wound damage, endothelial cell damage, and iris damage with alteration of the blood-aqueous barrier. Phaco power intensity can be modified by the following:

- Alteration in stroke length
- Alteration of duration
- Alteration of emission

**Alteration in Stroke Length**

Stroke length is determined by foot pedal adjustment. When set for linear phaco, depression of the foot pedal will increase stroke length and therefore power. New foot pedals, such as those found in the AMO (Santa Ana, CA) Sovereign/Signature and the Alcon (Fort Worth, TX) Infinity, permit surgeon adjustment of the throw length of the pedal in position 3. This can refine power application.

The Bausch & Lomb (Rochester, NY) Millennium/Stellaris dual linear foot pedal permits the separation of the fluidic aspects of the foot pedal from the power elements.

**Alteration of Duration**

The duration of application of phaco power has a dramatic effect on overall power delivered. Usage of pulse or burst mode phaco will considerably decrease overall power delivery. New machines allow for a power pulse of duration alternating with a period of aspiration only. Burst mode (parameter is machine dependent) is characterized by 80- or 120-millisecond periods of power combined with fixed short periods of aspiration only. Pulse mode utilizes fixed pulses of power of 50 or 150 milliseconds with variable short periods of aspiration only.

**Micro-Pulse (Hyper-Pulse)**

Through the development of highly responsive and low mass piezo crystals, combined with software modifications, the manufacturers of phaco machines have shortened the cycle of on and off time. This process, patented by AMO, is called “micro-pulse.” This technology is now available in most phaco machines.

A duty cycle is defined as the length of time of power on combined with power off. The short bursts of phaco energy followed by a short period without phaco energy allows two important events to occur. First, the period without phaco energy permits the nuclear material to be drawn toward the phaco tip to increase efficiency. Second, the absence of power allows inflow of irrigating fluid in the micro cavity between the phaco tip and nuclear fragment. This renewal of fluid is important to provide new fuel for transient cavitation as well as for cooling of the phaco tip.

The cool phaco tip has been termed **cold phaco**. This is a misnomer as the phaco tip is not cold but warm. However, studies indicate that it will not develop a temperature greater than 55°C, the temperature required to create a wound burn. Phaco techniques such as phaco chop utilize minimal periods of power in pulse mode, or micro-pulse mode, to reduce superfluous power delivery to the anterior chamber. In addition, the use of pulse mode, or micro-pulse mode, to remove the epinucleus provides for an added margin of safety. When the epinucleus is emulsified, the posterior capsule is exposed to the phaco tip and may move toward it due to surge. Activation of pulse phaco, or micro-pulse phaco, will create a deeper anterior chamber to work within. This occurs because, as noted previously, each period of phaco energy is followed by an interval of no energy. The epinucleus is drawn toward the phaco tip during the interval of absence of energy, producing partial occlusion and interrupting outflow. This allows inflow to deepen the anterior chamber immediately prior to onset of another pulse of phaco energy. The surgeon will recognize the outcome as operating in a deeper, more stable anterior chamber.

**Pulse Shaping**

This is a modification of varying power duration. By changing the morphology of the power burst in hyper-pulse phaco, the power can be delivered with greater effectiveness. Different manufactures have developed different burst morphology.

AMO (Whitestar/Signature) uses increased control and efficiency (ICE). A 1-millisecond punch of power with an amplitude of 7% of the preset power maximum is delivered at the beginning of each burst. This “kicker” has two consequences. First, it drives the nucleus away from the phaco tip sufficiently to augment partial occlusion phaco. Second, it allows the phaco tip to accelerate to the preset velocity almost instantly. The result is more effective phaco of the fragments.

Bausch & Lomb (Millennium/Stellaris) has taken a different approach. They bring the power up to maximum more slowly. They believe the slow increase in power enhances partial occlusion by not pushing the fragment away from the phaco tip.
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Alteration of Emission

The emission of phaco energy is modified by tip selection. Phaco tips can be modified to accentuate the following:

- Power
- Flow
- A combination of both

Power intensity is modified by altering bevel tip angle. Noted previously, the bevel of the phaco tip will focus power in the direction of the bevel. The Kelman tip will produce broad powerful cavitation directed away from the angle in the shaft. This tip is excellent for the hardest of nuclei. New flare and cobra tips direct cavitation into the opening of the bevel of the tip. Thus random emission of phaco energy is minimized. Designer tips such as the “Flathead” designed by Dr. Barry Seibel and power wedges designed by Mr. Douglas Mastel modify the direction and focus delivery of phaco energy intensity.

Power intensity and flow are modified by utilizing a 0-degree tip. This tip will focus power directly ahead of the tip and enhance occlusion due to the smaller surface area of its orifice. Small diameter tips, such as 21-gauge tips or flair tips, change fluid flow rates. Although they do not actually change power intensity, they appear to have this effect, as the nucleus must be emulsified into smaller pieces for removal through the smaller diameter tip.

The Alcon aspiration bypass system (ABS) tip modification is available with a 0-degree tip, a Kelman tip, or a flare tip. The flare is a modification of power intensity and the ABS a flow modification. In the ABS system, a 0.175-mm hole in the shaft permits a variable flow of fluid into the needle, even during occlusion. Therefore, occlusion is never allowed to occur. This flow adjustment serves to minimize surge.

Finally, flow can be modified by utilizing one of the microseal tips. These tips have a flexible outer sleeve to seal the phaco incision. They also have a rigid inner sleeve or a ribbed shaft configuration to protect cooling irrigant inflow. Thus a tight seal allows low flow phaco without danger of wound burns. Phaco power intensity is the energy that emulsifies the lens nucleus. The phaco tip must operate in a cool environment and with adequate space to isolate its actions from delicate intraocular structures. This portion of the action of the machine is dependent upon its fluidics.

Fluidics

The fluidics of all machines is fundamentally a balance of fluid inflow and fluid outflow. Inflow is determined by bottle height above the eye of the patient and irrigation tubing diameter. It is important to recognize that with recent acceptance of temporal surgical approaches and modifications of the surgical table, the eye of the patient may be physically higher than in the past. This requires that the irrigation bottle be adequately elevated. A shallow, unstable anterior chamber will otherwise result.

Outflow is determined by the sleeve-incision relationship, as well as the paracentesis size, aspiration rate, and vacuum level commanded. The incision length selected should create a snug fit with the phaco tip selected. This will result in minimal uncontrolled wound outflow with resultant increased anterior chamber stability.

Aspiration rate, or flow, is defined as the flow of fluid, measured in cc/min, through the tubing. With a peristaltic pump, it is determined by the speed of the pump. Flow determines how well particulate matter is attracted to the phaco tip. Aspiration level or vacuum is a level measured in mmHg. It is defined as the magnitude of negative pressure created in the tubing. Vacuum is the determinant of how well particulate material will be held to the tip, once occluded on the phaco tip.

Vacuum Sources

There are three categories of vacuum sources or pumps. These are flow pumps, vacuum pumps, and hybrid pumps. The primary example of the flow pump type is the peristaltic pump. These pumps allow for independent control of both aspiration rate (flow) and aspiration level (vacuum). The primary example of the vacuum pump is the Venturi pump. This pump type allows direct control of only vacuum level. Flow is dependent upon vacuum level setting. Additional example types are the rotary vane and diaphragmatic pumps. The primary example of the hybrid pump is the AMO Sovereign/Signature peristaltic pump or the Bausch & Lomb Concentrix pump. These pumps are interesting as they are able to act like either a vacuum or flow pump depending on programming. They are generally controlled by digital inputs creating incredible flexibility and responsiveness.

The challenge to the surgeon is to balance the effect of phaco power intensity, which tends to push nuclear fragments away from the phaco tip, with the effect of flow, which attracts fragments toward the phaco tip, and vacuum, which holds the fragments on the phaco tip. Generally, low flow slows down intraocular events, and high vacuum speeds them up. Low
or zero vacuum is helpful during sculpting of hard or large nucleus where the high power intensity of the tip may be applied near the iris or anterior capsule. Zero vacuum will prevent inadvertent aspiration of the iris or capsule, avoiding significant morbidity.

**Surge**

A fundamental limiting factor in the selection of high levels of vacuum or flow is the development of surge. When the phaco tip is occluded, flow is interrupted and vacuum builds to its preset level. Emulsification of the occluding fragment then clears the occlusion. Flow instantaneously begins at the preset level in the presence of the high vacuum level. In addition, if the aspiration line tubing is not reinforced to prevent collapse (a function of tubing compliance), the tubing will have constricted during the occlusion. It then expands on occlusion break. This expansion is an additional source of vacuum production. These factors trigger a rush of fluid from the anterior segment into the phaco tip. The fluid in the anterior chamber may not be replaced rapidly enough by infusion to prevent shallowing of the anterior chamber. Therefore, with sudden volume reduction in the anterior chamber there is succeeding rapid anterior movement of the posterior capsule. This abrupt forceful stretching of the bag around nuclear fragments (especially if the fragment is hard with jagged edges) may be a cause of capsular tears. In addition, the posterior capsule can be literally sucked into the phaco tip, tearing it. The magnitude of the surge is contingent on the duration of occlusion and the pre-surge settings of flow and vacuum.

Classically selecting lower levels of flow and vacuum control surge. The phaco machine manufacturers help to decrease surge by providing noncompliant aspiration tubing that will not constrict in the presence of high levels of vacuum. More important are the following noteworthy new technologies:

- **CASE: AMO Sovereign/Signature**—Microprocessors sample vacuum and flow parameters 50 times a second, creating a “virtual” anterior chamber model. At the moment of occlusion, the computer senses the decrease in flow and instantaneously slows the pump to stop surge production. The Alcon Infinity works in a similar manner.
- **Dual Linear: Bausch & Lomb Millennium/Stellaris**—The dual linear foot pedal can be programmed to separate both the flow and vacuum from power. In this way, flow or vacuum can be lowered before beginning the emulsification of an occluding fragment. The emulsification therefore occurs in the presence of a lower vacuum or flow so that surge is minimized.
- **ABS: Alcon Infinity/Legacy**—The ABS tips have 0.175-mm holes drilled in the shaft of the needle. During occlusion, the hole provides for a constant alternate fluid flow. This will cause dampening of the surge on occlusion break.

**Nonlongitudinal Phaco: Modification of Fluid Control by Power Modulations**

Three significant, trend-setting technologies have revolutionized the way power is modulated. When employing these power modulations, the duration of power operation and the motion of needle movement are significant on their effect on fluid flow and occlusion. These modulations have an effect on the fluidic balance during phaco, which is as important to chamber maintenance and ease of removal of nuclear fragments as the preset vacuum and flow.

- **Micro-Pulse Phaco**—Discussed previously, the rapid 4-millisecond power on cycle maximizes the development of transient cavitation energy. All cavitation energy in the 4-millisecond burst is capable of emulsifying tissue. The ensuing 4-millisecond period of aspiration replenishes fluid at the phaco tip and cools it. The use of micro-pulse phaco is necessary to create the shift in phaco technique from post-occlusion phaco to partial-occlusion phaco.
- **Torsional Phaco (Alcon Infinity Ozil Handpiece)**—Classic phaco has utilized a phaco tip that moves forward and backward, or longitudinally. Torsional phaco is defined as a 32-kHz oscillatory movement of an angled (Kelman) phaco tip. This can be combined with longitudinal movement of the needle at 44 kHz. The torsional component is linear and the longitudinal component can be micro-pulse. The potential flexibility of this system is enormous.
- **Ellips Phaco (AMO Signature)**—In this system the longitudinal movement of the phaco tip at 38 kHz is combined with a transversal motion at 26 kHz. The resultant movement of the needle can be described as prolate-spheroid (shaped much like an egg cut in half).
**Partial-Occlusion Phacoemulsification**

The way to avoid surge is to prevent total occlusion entirely. By definition, a surge requires total occlusion. In partial-occlusion phaco, micro-pulse phaco is the catalyst. The nuclear fragment is brought close to the phaco tip with a 4-millisecond period of aspiration until the fragment partially occludes it. With the onset of a 4-millisecond burst of phaco energy, the fragment is emulsified before it can totally occlude the phaco tip. Therefore, flow never falls to zero and vacuum never builds to maximum. Surge is avoided. This appears to be an exceptionally proficient process of emulsification. It allows for fragment removal with minimal energy intensity and duration and results in a deep and controlled anterior chamber.

Torsional (Ozil) technology (Alcon) and Ellips (AMO) also generate preocclusion phaco. The oscillatory movements of the phaco tip automatically knock the fragments off the phaco tip. Unlike longitudinal phaco where the removal of tissue is described as coring, the removal with nonlongitudinal phaco is described as shaving. Since the oscillatory movement holds lens material close to the phaco tip without total occlusion, the partial occlusion environment of this system generates remarkable followability and deep, stable anterior chambers.

**Phacoemulsification Technique and Machine Technology**

The patient will have the best visual result when total phaco energy delivered to the anterior segment is minimized. Additionally, phaco energy should be focused into the nucleus. This will prevent damage to iris blood vessels, trabecular meshwork, and endothelium. Finally, proficient emulsification will lead to shorter overall surgical time. Therefore, a lesser amount of irrigation fluid will pass through the anterior segment. The general principles of power management are to focus phaco energy into the nucleus, vary fluid parameters for efficient sculpting and fragment removal, and minimize surge.

Generally, all phaco procedures have two phases. The first is the creation of fragments. This requires sculpting or chopping. The second phase is the removal of the fragments in a controlled approach. Occlusion is mandatory to move fragments to the iris plane. Fragment removal is assisted by partial-occlusion phaco.

All phaco techniques are preceded by capsulorhexis, cortical cleaving hydrodissection, and removal of the superior cortex and epinucleus to expose the endonucleus.

**Divide and Conquer Phaco**

**Sculpting**

To focus cavitation energy into the nucleus, a 0-degree tip or a 15- or 30-degree tip turned bevel down ought to be utilized. Zero or low vacuum (depending on the manufacturer’s recommendation) is mandatory for bevel-down phaco. This will prevent occlusion. Occlusion, at best, will cause excessive movement of the nucleus during sculpting. At worst, occlusion occurring near the equator, or deep within the nucleus, may capture nucleus, adherent cortex, capsule, and vitreous. This is an origin of tears in the equatorial or posterior bag early in the phaco procedure. Once the groove is judged to be adequately deep (about 3 phaco tip diameters deep), the bevel of the tip should be rotated to the bevel-up position and vacuum can be increased. This will improve visibility and prevent the risk of phaco through the posterior nucleus and posterior capsule. Sculpting is assisted by the use of panel control continuous phaco. This is because the nucleus is held in place by the capsular bag. Therefore, pressure against the nucleus will allow the jackhammer effect to take over and emulsify a groove.

If micro-pulse phaco is used for sculpting, duty cycles with longer power on than off should be selected. This will allow phaco to proceed with clean emulsification and avoid pushing the nucleus ahead of the phaco tip, potentially damaging zonules.

Nonlongitudinal phaco is generally not as effective as longitudinal phaco for sculpting.

When the initial groove is judged adequate, the nucleus is rotated 90 degrees and another groove is created. Next a 180-degree rotation allows access for creation of the final groove.

**Quadrant and Fragment Removal**

The grooves are expanded cracking a fragment, which is then mobilized to the level of the iris. The tip selected, as noted previously, is retained. Vacuum and flow are increased to reasonable limits governed by the machine being used. The limiting factor to these levels is the development of surge. Therefore, the use of micro-pulse phaco or nonlongitudinal phaco is best used at this stage. The bevel of the tip is turned toward the quadrant or fragment. Low pulsed or burst power
is applied at a level high enough to emulsify the fragment without driving it away from the phaco tip.

“Chatter” is defined as a fragment bouncing away from the phaco tip due to excessively aggressive application of phaco energy.

**Epinucleus and Cortex Removal**

If cortical cleaving hydrodissection has been performed, the endonucleus is removed first as noted above. The result is a shell of epinucleus and cortex. For removal of epinucleus and cortex, the vacuum is decreased while flow is maintained. This will allow for grasping of the epinucleus just deep to the anterior capsule. The low vacuum will help the tip hold the epinucleus on the phaco tip without breaking off chunks. High vacuum results in breaking off pieces of epinucleus and cortex, making it more difficult to remove. With the fluid parameters balanced, the epinucleus/cortex scrolls around the equator and can be pulled to the level of the iris. There, low power pulsed or hyper pulse phaco is employed for emulsification.

**Stop and Chop Phaco**

Groove creation is performed as noted above under divide and conquer sculpting techniques. Once a single deep groove is adequate vacuum and flow are increased to improve holding capability of the phaco tip. The nucleus is rotated 90 degrees and the phaco tip is driven into the mass of one heminucleus using pulsed linear phaco. The sleeve should be 1 mm from the base of the bevel of the phaco tip to create adequate exposed needle length for sufficient holding power. Excessive phaco energy application is to be avoided, as this will cause nucleus immediately adjacent to the tip to be emulsified. The gap thus created in the vicinity of the tip is responsible for interfering with the seal around the tip and therefore the capability of vacuum to hold the nucleus. The nucleus will then pop off the phaco tip, making chopping more difficult. With a good seal, the heminucleus can be drawn toward the incision and the chopper can be inserted at the endonucleus-epinucleus junction. The chopper is then drawn down and left, while the phaco tip is pushed up and right. This will result in chopping of the heminucleus.

After the first chop, a second similar chop is performed so the heminucleus is divided into three pieces. One pie-shaped piece of nucleus thus created is elevated to the iris plane (occlusion is utilized to move fragments) and removed with low power hyper-pulsed phaco or nonlongitudinal phaco as discussed in the divide and conquer section. Each fragment and the remaining heminucleus are removed in turn. Epinucleus and cortex removal are also performed as noted above.

**Phaco Chop**

Phaco chop requires no sculpting. Therefore, the procedure is initiated with high vacuum and flow and linear pulsed or micro-pulse phaco power. Nonlongitudinal phaco does not work well for the actual chopping as the shaving movement of the phaco tip prevents an adequate vacuum seal to assist chopping and fragment mobilization. For a 0-degree tip, especially when emulsifying a hard nucleus, a small trough may be required to create adequate room for the phaco tip to push deep into the nucleus. For a 15- or a 30-degree tip, the tip should be rotated bevel down to engage the nucleus. The phaco tip should be encased within the endonucleus with the minimal amount of power necessary. All chopping procedures require 1 mm of exposed phaco tip to create adequate holding power for chopping. If the phaco tip is inserted into the nucleus with excess power, the adjacent nucleus will be emulsified, creating a poor seal between nucleus and tip. This will make it impossible to remove fragments, as the tip will just “let go” of the nuclear material. Additionally, the bevel should be turned toward the fragment to create a seal between tip and fragment, allowing vacuum to build and create holding power.

**Horizontal Chop**

A few bursts or pulses of phaco energy will allow the tip to be encased within the nucleus. Then can be drawn toward the incision to allow the chopper access to the epi-endo nuclear junction. The chopping instrument is passed over the nucleus and under the anterior capsule into this junction. It may be helpful to rotate the chopper to horizontal as it passes below the anterior capsule. If the nucleus comes off the phaco tip, excessive power has produced a space around the tip, impeding vacuum holding power as noted above. Pulling the chopper down and left and pushing the phaco tip up and right will generate the first chop. Minimal rotation of the nucleus will allow for creation of the second chop. The first pie-shaped piece of nucleus is mobilized with high vacuum and elevated to the iris plane. There it is emulsified with low linear hyper-pulse or nonlongitudinal power, high vacuum, and moderate flow.
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Vertical Chop

Once the phaco tip is embedded within the nucleus as previously described, a sharp chopper (Nichamin, Katena, Denville, NJ) is pushed down into the mass of the nucleus at the same time the phaco tip is elevated. The chopper is then drawn down and left and the phaco tip up and right. This creates a cleavage plane in the nucleus. With a second chop the fragment created is mobilized to the iris plane and removed as noted above. When the nucleus is noted to be hard, the process of rotation and vertical chopping is repeated until the entire nucleus is chopped. Usually, at this point, the nucleus loses its rigidity, allowing the segments to be mobilized without difficulty.

Microincisional Phaco

The development of micro-pulse and nonlongitudinal phaco (‘cold phaco’) has led to the performance of phaco through increasingly small incisions with tighter irrigation sleeves, no irrigation sleeves, and decreased inflow.

Bimanual Microincisional Phaco

Two incisions are created 90 degrees apart. Their size is dependant on the instrumentation. Twenty-gauge instruments require 1.4-mm incisions while 21-gauge instruments require 1.2-mm incisions. There is no irrigating sleeve on the phaco tip. The instrumentation for this procedure is important and the relationship between the instrument and incision size is essential. If the wound is too tight, it is difficult to manipulate the instruments. If the wound is too large, excessive outflow permits chamber shallowing with an unstable anterior segment. The instruments can be moved forward and backward through the incisions without creating corneal distortion. If the instruments are angled in the incision, sufficient corneal distortion occurs that the procedure is appreciably more difficult. The irrigating chopper should be parallel to the iris and above it. The inflow current thus created tends to wash fragments toward the unsleeved phaco tip. The small incisions cause less disruption of the blood-aqueous barrier and are more stable and secure. Presently a new incision is created for intraocular lens (IOL) implantation. In the future, with insertion of an IOL through the 1.4-mm incision, there should be less disruption of ocular integrity, immediate return to full activities, and less risk of postoperative wound complications.

Microincisional Coaxial Phaco

A thin-walled, flared 21-gauge phaco tip and thinner irrigation sleeve is available for Infinity (Alcon) machines and now permits phaco though a 2.2-mm incision. Despite the smaller incision, inflow is adequate to maintain a deep anterior chamber. The procedure is no more difficult than when performed through a 2.8-mm incision. Alcon also manufactures a one-piece acrylic IOL and injector that is capable of implanting the IOL through the 2.2-mm unenlarged incision.

Irrigation and Aspiration

Similar to phaco, anterior chamber stability during irrigation and aspiration (I/A) is due to an equilibrium of inflow and outflow. Wound outflow can be minimized by employing a soft sleeve around the I/A tip. Combined with a small incision (2.8 to 3 mm), a deep and stable anterior chamber will result. Generally, a 0.3-mm I/A tip is used. With this orifice, a vacuum of 500 mmHg and flow of 20 cc/min is excellent to tease cortex from the capsular fornices. Linear vacuum allows the cortex to be grasped under the anterior capsule with low vacuum and drawn into the center of the pupil at the iris plane. There, in the safety of a deep anterior chamber, vacuum can be increased and the cortex aspirated.

Bimanual I/A is also a viable procedure. A 21-gauge irrigating cannula provides inflow through one paracentesis while an unsleeved 21-gauge aspiration cannula is used through the opposite paracentesis. The instruments can be easily switched, making removal of stubborn cortex considerably easier.

Vitrectomy

Most phaco machines are equipped with a vitreous cutter that is activated by compressed air or by electric motor. As noted previously, preservation of a deep anterior chamber is contingent upon an equilibrium of inflow and outflow. For vitrectomy, a 23-gauge cannula, or chamber maintainer, inserted through a paracentesis, provides inflow. Bottle height should be adequate to prevent chamber collapse. The vitrector should be inserted through another paracentesis. If equipped with a Charles Sleeve, this should be removed and discarded. Utilizing a flow of 20 cc/min, vacuum of 250 mmHg, and a cutting rate of 450 or more cuts/min, the vitrector should be placed through the tear in the posterior capsule, orifice facing upward, pulling vitreous out of the anterior chamber and back to the plane of the posterior capsule.
Alternatively, the vitrector can be inserted through a pars plana incision 3 mm posterior to the limbus. Recently, 25-gauge vitrectomy instruments have been introduced. Their ultimate utility, however, is not yet clear. In an effort to better visualize the vitreous for thorough vitrectomy, unpreserved sterile prednisone acetate (Kenalog), previously purchased from a formulating pharmacy, can be injected into the vitreous. The prednisone particles adhere to the vitreous strands, making the invisible visible.

**SUMMARY**

The phaco process is a balance of technology and technique. Awareness of the principles that influence phaco machine settings is a prerequisite for the performance of a proficient and safe operation. Additionally, often during the procedure, there is a demand for modification of the initial parameters. A thorough understanding of fundamental principles will enhance the capability of the surgeon for appropriate response to this requirement. It is this crucial attitude that through relentless evaluation of the interaction of the machine, and the phaco procedure, the skillful surgeon will find innovative methods to enhance technique.

**BIBLIOGRAPHY**


Fishkind WJ. Pop Goes the Microbubbles. ESCRS Film Festival Grand Prize Winner, 1998.


