Increasing Surgical Safety With Modern Phaco Technology

Despite recent advances in fluidics and ultrasound, surgeons should always employ phacodynamic reasoning.

BY BARRY S. SEIBEL, MD

Phaco technology had humble beginnings: limited handheld instrumentation coupled with the original phaco machine behemoth that was the brainchild of Charles Kelman, MD, and Anton Banko. Although a revolution in its time, the system pales in comparison with today's machines; the former had few settings, limited fluidic performance, and awkward ergonomics. Dr. Kelman understood better than anyone the importance of surgeons' understanding the technology so that they could provide the greatest benefit to the patients.

Advances in phaco technology have paralleled those in surgical technique through the years, particularly with regard to safety. The original phaco method was ultrasound intensive and essentially involved shaving away the nucleus. Control of the ultrasound was limited to "on" or "off" via the foot pedal, and the amount of power was set on the machine's panel. Fluidics were similarly limited, reflecting the low demand on vacuum levels related to the early sculpting-intensive methods, coupled with the limited anterior chamber stability even with those low vacuum levels. Current phaco techniques use more vacuum and occlusion along with lower, more modulated ultrasound that minimizes damage to the adjacent anterior segment anatomy. Therefore, advances can be roughly divided into the areas of fluidics and ultrasound.

FLUID DYNAMICS

Fluid dynamics govern phaco surgery's safety and efficacy. Along with ultrasound, they determine the followability of the procedure, both distally with regard to attracting lenticular fragments to the phaco tip and proximally with regard to how well fragments are fed into the tip and aspirated. Followability is directly proportional to the aspiration outflow rate, with faster rates producing faster anterior chamber currents that more strongly attract lenticular fragments to and through the phaco needle. Linear pedal control of the flow rate was a significant advance, as were lower-compliance systems that increase the phaco unit's responsiveness.

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COMPLIANCE

Compliance is the change in volume per change in pressure. Older machines with higher system compliance had a "sponginess" in that pedal input to change the pump pressure/pull on the fluid in the aspiration line would not only change the flow rate but would also significantly change the volume of the aspiration line tubing by causing it to partially collapse or narrow. Modern machines with less compliance allow more direct responsiveness but can also permit some "sponginess" in response if desired via software modulation. A key to safety in this area, as in all settings, is the surgeon's awareness of adjustability so that he or she can make intelligent choices.

CHAMBER STABILITY

Although a concern with the low-vacuum sculpting methods of phacoemulsification's early years, chamber stability is much more of an issue with today's occlusion-intensive, high-vacuum techniques such as chopping. As with followability, the chamber's stability is largely a function of the phaco machine's compliance. Higher vacuum levels increase the potential change in volume (collapse/narrowing) of the aspiration line's tubing, resulting in the possible buildup of potential excess vacuum. This buildup adds to steady-state outflow upon an occlusion break, causing a momentarily higher rate of outflow that can shallow or collapse the anterior chamber, with attendant comorbidity to the corneal endothelium, lens capsule, and iris. Modern phaco machines' less-compliant tubing and fluidic circuits tend to collapse less under a high-vacuum load and therefore contribute less potential excess vacuum. There is a limit and tradeoff to decreasing system and tubing compliance. Related to ergonomics; less compliant tubing is stiffer and can reduce mobility of the phaco and I/A handpieces. A non-compliant solid metal tube set would be an extreme example.

SURGE CONTROL

Newer phaco machines obtund surge by increasing fluidic resistance to outflow. One of the earlier methods was simply to reduce the diameter of the aspiration tubing, with Poiseuille's law dictating an inverse relationship between resistance and the fourth power of the tubing radius. However, a functional limit to this approach was the potential clogging of the aspiration line due to accumulated lens emulsate. Surgeons must be vigilant for signs of compromised aspiration outflow, which not only impedes followability but is a significant risk factor for incisional burns.

Another approach to surge control is to use a fluidic resistor in the circuit, a point of decreased radius. Smaller-diameter phaco tips (eg, Flare Tip [Alcon Laboratories, Inc., Fort Worth, TX] or Microflow [Bausch + Lomb, Rochester, NY]) increase resistance to outflow while limiting clogging of the tip due to ultrasound action. Alex Uriche designed the Vacuum Surge Suppressor (STAAR Surgical Company, Monrovia, CA) that places a filter mesh in front of a portion of narrow tubing to reduce the likelihood of its clogging; this design is incorporated into the current Stellaris Stable Chamber tubeset (Bausch + Lomb). Although the electromechanical feedback loops for chamber monitoring and stability are very sophisticated in today's machines, they cannot quite match the instantaneous responsiveness of reduced overall system compliance and increased fluidic-resistance mechanisms as described earlier. Surgeons encountering unacceptably unstable chambers should avail themselves of the most effective options on a given machine (eg, resistive phaco needle or resistive and/or low-compliant tubeset) or they should adjust the phacodynamic settings to compensate (including increasing bottle height and lowering commanded vacuum).

ULTRASOUND TECHNOLOGY

The first major advance in ultrasound technology occurred more than 2 decades ago in the form of linear pedal control of ultrasound power. Next came ultrasound power modulations, which disrupted continuous ultrasound with intermittent pauses. Modulations of ultrasound power were needed to address the shortcomings of traditional continuous ulstrasound with its limited followability due to the repulsion of lenticular fragments, as well as its potential for a dangerous buildup of heat due to incisional friction from the vibrating phaco needle. Pulsed phacoemulsification was introduced with a nominal 50% duty cycle. As the surgeon depressed the foot pedal into position 3, ultrasound was produced half of the time, such that two pulses per second would produce 250 ms of ultrasound followed by 250 ms of a "rest" interval, followed by another 250 ms of ultrasound, etc. The pulse rate was set at the machine's control panel, and pedal control still modulated overall phaco power. Burst-mode phacoemulsification was an alternative whereby more depression of the pedal resulted in more frequent "bursts" of ultrasound per unit of optional time while maintaining the same power set on the machine's panel (ie, no linear pedal control of power).

More recent ultrasound power modulations include variations of hyperpulse, a term coined by David Chang, MD, that permits duty cycles shorter than the 50% of traditional pulse (like burst mode) along with linear control of phaco power (like traditional pulse). The longer intervals of rest allow more time for thermal dissipation and therefore reduce the risk of wound burn. They also interrupt ultrasonic repulsion to allow re-engagement of a lenticular fragment for more efficient application of the subsequent phaco duty pulse. This phenomenon was elegantly portrayed by Teruyuki Miyoshi, MD, in his award-winning 2007 ASCRS Film Festival video. Abbott Medical Optics Inc. (Santa Ana, CA) was the first company to introduce hyperpulse power modulation in the form of Whitestar, followed by Alcon Laboratories, Inc., and Bausch + Lomb.

NEW DIRECTIONS OF ULSTRASOUND

New designs involve nonlongitudinal excursions of the phaco tip. A longitudinally vibrating ultrasonic needle will jackhammer into a stationery nucleus, but it will push away a mobile lenticular fragment not held sufficiently by the fluidic forces of vacuum and flow. Repulsion can be reduced by proportionate replacement of longitudinal motion with nonaxial displacement of the tip, as introduced initially by Alcon Laboratories, Inc., with its torsional Ozil platform. Using a Kelman-style bent tip, Ozil replicates a similar stroke excursion at the tip of the needle compared with a traditional ultrasound mode, but it occurs in a perpendicular direction to the long shaft of the needle rather than coaxially with it. This design does not interfere with the coaxial attractive fluidic parameters of flow and vacuum. Abbott Medical Optics Inc. introduced its own nonlongitudinal modality, Ellips Transversal Ultrasound, which can be performed with a straight or bent tip.

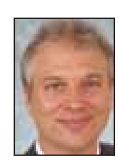
The concept of Ozil amplifies the stroke: the surface of the needle's rotating shaft only moves a fraction of the amount of the tip, due to the bent tip's greater radius from the center of rotation. Therefore, less power is imparted to the incision by the shaft of the needle for a given distal tip stroke length compared with standard longitudinal ultrasound. The lower power should produce less friction and therefore lessen the chance of inadvertent incisional burns. Various studies evaluating the thermal performance of these various ultrasound modalities have produced conflicting results, possibly related to different study designs.[1,2]

SUMMARY

Although the technology of fluidics and ultrasound have certainly evolved to enhance the safety and efficacy of phaco surgery, surgeons must still use phacodynamic reasoning at each step of the phaco procedure is still pertinent to optimize their technique without relying completely on technology. For example, the likelihood of postocclusion surge is dramatically decreased by restricting the application of high vacuum to only those stages of surgery requiring it, such as chopping. More moderate vacuum levels should be used for "carouseling" phacoaspiration of fragments when surgeons anticipate intermittent breaks in occlusion and higher vacuum levels are typically not needed. Dual linear pedal control can help to facilitate this variable application of vacuum (initially introduced by Bausch + Lomb, more recently by Abbott Medical Optics Inc). Similarly, the likelihood of incisional burns can be significantly reduced by avoiding the sustained application of higher ultrasound energy with complete occlusion, a clinically nonproductive combination. Surgeons typically bury the tip for gripping, as in chopping, and it therefore requires only a brief application of ultrasound followed by clinically appropriate application of vacuum only. They should also be cognizant of highly retentive viscoelastics that can reduce flow at what appears to be an unobstructed tip, or they risk a dangerous buildup of heat with sustained ultrasound.

The combination of new technology and surgeons' knowledge is providing patients with the best potential surgery to date. ■

This article was adapted from Dr. Seibel's book, Phacodynamics Mastering the Tools and Techniques of Phacoemulsification Surgery *4th ed.Thorofare,NJ: Slack Inc.; 2005.*



Barry S. Seibel, MD, is in private practice in Los Angeles, California, and is a clinical assistant professor of ophthalmology at the UCLA David Geffen School of Medicine. He receives royalties from Slack Incorporated, and he is a member of the medical advisory board for and holds stock options in Optimedica Corporation. Dr. Seibel may be reached at (310) 444-1134; eyedoc2020@earthlink.net.

1. Han YH, Miller KM. Heat production: longitudinal versus torsional phacoemulsification. *J Cataract Ref Surg.* 2009;35(10):1799-1805.
2. Jun B, Berdahl JP, Kim T. Thermal study of longitudinal and torsional ultrasound phacoemulsification: tracking the temperature of the corneal surface, incision, and handpiece. *J Cataract Refract Surg.* 2010;36(5):832-837.