Defining Parameters

Phaco parameters represent a group of numbers that control the various functions of a phaco machine. Although all phaco machines obey the same general principles, each model of machine is unique; therefore, the parameters do not transfer identically from machine to machine. Each surgeon should adjust to best effect, or optimize, his or her parameters for each machine he or she uses. While surgical facility or ease of use and absence of complications represent intraoperative criteria for optimization, early postoperative outcomes best reflect the impact of phaco on the eye.

Programming phaco parameters varies with surgical technique. An understanding of the actions of aspiration, vacuum, and power allows the surgeon to begin with a rational selection and make changes on the fly to improve qualities such as sculpting, followability, holding power, chamber stability, and evacuation of material. A sample of parameters for a variety of machines is given at the end of this section as a starting point for each surgeon’s customization process.

Irrigation: Gravity and Pressure

The anterior segment of the eye exhibits elasticity, which means that the cornea, limbus, and zonulocapsular complex respond to pressure by allowing an increase in volume. The response of the cornea measured on an artificial anterior chamber is in the range of 0.34 to 1.6 mmHg/microliter, while the response of the anterior chamber measured during cataract surgery is 0.0126 mmHg/microliter. Because the amount of ocular elasticity is low, the intraocular pressure (IOP) during phaco is essentially determined by the height of the irrigation fluid above the eye and the rate of leakage of fluid out of the eye. The fluid pressure at the base of a column of water can be calculated (in mmHg,
at standard atmospheric pressure) using the following equation:

\[
\text{Pressure (mmHg)} = \text{Column height (cm)} \times \left( \frac{10}{13.6} \right)
\]

where the density of mercury is 13.6 g/cm\(^3\) and the density of water is 1 g/cm\(^3\).

The measured IOP closely agrees with the calculated IOP unless there is significant incisional leakage.\(^5\)

Chamber stability means the maintenance of volume in the working space of the aqueous environment, from the apex of the corneal endothelium to the central posterior capsule. The balance between irrigation on the one hand and aspiration plus leakage on the other hand determines this volume. Leakage can be minimized by proper incision construction.

However, the aspiration flow rate of fluid exiting the eye can increase suddenly but predictably during surgery due to the phenomenon known as surge flow. Surge flow means the loss of aqueous volume in the working space of the anterior segment that can occur when material that has occluded the phaco tip is suddenly evacuated from the chamber. The surge occurs because the high vacuum reached during occlusion actually exerts its force throughout the aspiration tubing and creates a pinching or narrowing of the tubing. When the vacuum is released, the pinched tubing expands and fluid rushes in to fill the void.

Phaco machine innovations such as low compliance tubing and rigid cassettes minimize the elasticity in the system and reduce surge flow. Other designs intended to reduce surge include the aspiration bypass system (a small aperture on the side of the phaco tip that allows fluid flow into the handpiece despite an occlusion on the front of the tip) and in-line filters (mesh to trap material upstream from a small aperture, which poses a size restriction to flow).\(^6\)

Regardless of specific phaco machine technology, irrigation must be adequate to at least balance aspiration plus leakage. We depend on gravity and atmospheric pressure to provide irrigation; however, pressurization of the irrigation bottle with forced gas may also be employed. In general, the intraoperative response of the surgeon to an unstable chamber should first be to raise the irrigation bottle. If the instability is occurring due to surge, then reducing the vacuum level makes sense. If the instability is unrelated to occlusion or surge, then it is time to reduce the aspiration flow rate. In the postoperative analysis of an unstable chamber, the surgeon should also examine the incision construction and watch for leakage.

**Aspiration and Peristaltic Pumps**

In a peristaltic pump system, depression of the foot pedal in position 2 directly controls the rate at which the pinch roller rotates. Machines offer fixed rates of flow or linear control of flow, as well as alterations in the flow rate when the machine senses an occlusion (ie, in the face of rising vacuum). No vacuum is present in peristaltic systems until the tip begins to become occluded and resistance to flow is sensed. Vacuum pressure rises as flow is reduced by material on the tip. Aspiration flow ceases at occlusion and the maximum vacuum is reached. The maximum vacuum level is set by the surgeon as one of the parameters of a peristaltic system, but in fact this setting specifies the vacuum level at which the pump stops. One mechanism for reducing surge involves an occlusion mode setting with reduction of maximum vacuum, so that when the occlusion breaks (as the material is emulsified and evacuated), the fall in vacuum is reduced (the fall is reduced because the vacuum level falls from a lesser height). Ultrasound power is usually necessary at the point of occlusion to emulsify material and allow evacuation.

In general, the higher the flow rate, the faster fluid and material will move toward the phaco tip and the faster vacuum will rise when material occludes the tip. Machines offer independent control of vacuum rise time or ramp, essentially changing the pump speed as the machine first senses resistance to flow, in order to either speed up or slow down the process of reaching full occlusion (get a firm hold on material more quickly or less quickly).

The concept of followability means the facility with which nuclear material flows toward, is held by, and evacuated through the phaco tip. One antonym of followability is chatter, which means that material repeatedly bounces off the phaco tip without following the aspiration flow up the tube. The metaphor of magnetism is sometimes used to describe the attraction of material to the tip; in fact, it is the aspiration flow that brings the material toward the tip. In coaxial phaco (with the irrigation sleeve on the phaco tip), the irrigation stream tends to push material away so that aspiration must overcome irrigation for magnetic attraction to occur. In both coaxial and biaxial phaco, longitudinal ultrasonic vibration of the phaco tip also acts as a repulsive force that must be overcome by aspiration flow and, during occlusion, by vacuum pressure, to bring material and hold it on the tip as it
is mobilized and emulsified. Alleviating the repulsive force of longitudinal tip motion has been the impetus behind the development of nonlongitudinal sonic and ultrasonic energy delivery systems, such as oscillatory, torsional, or transverse tip motions. The balancing of these competing forces at the phaco tip underlies much of the logic of setting parameters for efficient surgery.

**Vacuum and Venturi Pumps**

In a Venturi pump (named for the Italian physicist Giovanni Battista Venturi), the foot pedal directly controls the application of vacuum; aspiration flow occurs in response to vacuum pressure. According to the classic Venturi principle, it is the flow of pressurized gas through a narrowed tube that creates the vacuum. Unlike a peristaltic pump, with which vacuum does not exist until there is resistance to flow, with a Venturi pump vacuum is always present. The surgeon sets the maximum vacuum level as one of the parameters. There is no setting for aspiration flow. The vacuum increases in a linear fashion as the foot pedal is depressed in foot position 2. Machines that feature a bidirectional foot pedal also allow control of vacuum with yaw (ie, movement of the foot pedal in a direction parallel [rather than perpendicular] to the floor). This feature permits greater flexibility in separately controlling the application of vacuum and ultrasound power.

Conventional wisdom regards Venturi pumps as more aggressive than peristaltic pumps. This perception comes about primarily because of surge. Vacuum increases as the surgeon depresses (or yaws) the foot pedal in order to evacuate material, and the vacuum remains high even after the material is evacuated unless the surgeon actively reduces the vacuum by moving the foot pedal. This process is in contradistinction to a peristaltic pump in which the vacuum will drop to zero once the occlusion has passed regardless of foot pedal action. Of course, surge can still occur with a peristaltic pump because of stored energy in the tubing and cassette (low compliance systems are designed to reduce this problem). Nevertheless, with an appropriate initial Venturi vacuum setting and a good foot pedal control, one can maintain a stable chamber. Therefore, not only do Venturi pumps have a reputation for being more aggressive, they also have a reputation for allowing exceptionally rapid clearing of material, excellent followability, and fast surgery.

One of the technological advances that has made Venturi pumps safer involves the insertion of a filter and flow restriction device in the aspiration line. The capacious filter element traps emulsate so that it will not clog the small diameter flow restrictor, which is placed just up the aspiration line. The inner diameter of the flow restrictor is about the same as the aperture on an aspiration tip used for removing cortex and viscoelastic (0.2 mm). This device has the effect of greatly reducing or eliminating surge because it limits the rate at which fluid can move up the line. Fortunately, the flow restriction does not impact flow at the usual rates applied during phaco. In this light, it is interesting to note that one of the situations where Venturi is most safe and efficient is during irrigation/aspiration.

**Power and Power Modulations**

The ability to variably control the application of ultrasound power to within a period of several milliseconds has revolutionized phaco technology. The first generation of phaco machines only allowed application of continuous power at a fixed level. Following the development of linear power control, the first power modulations were developed, pulse and burst modes. In 2001, we showed how application of these modulations reduces the use of ultrasound energy and permits rapid visual rehabilitation after surgery. We also showed that reduction of effective phaco time correlates with improved uncorrected visual acuity at the first visit after surgery. Subsequently, the introduction of millisecond level control and variable duty cycle applications has permitted further reduction of ultrasound energy and eliminated the risk of thermal injury to the cornea, paving the way for the adoption of biaxial microincision cataract surgery. Surgeons should try a variety of power settings, including pulse and burst modes, variable duty cycles, and percentage power ceilings, in order to develop parameters best suited to their individual techniques. Machines also feature standard longitudinal, torsional, and transverse tip motions that can be customized in amplitude to suit a variety of techniques.

Intraoperative awareness and moment-to-moment assessment of surgical success offer the best opportunity to alter settings and improve results. The surgeon should recognize that insufficient holding implies a need for greater vacuum, whereas an uncomfortable amount of surge calls for a reduction in vacuum. Poor followability may require increased aspiration flow or vacuum if the problem is bringing material to the tip, or higher power if material comes to the tip but then
bounces off when ultrasound is applied. A shallow chamber indicates a need to check the irrigation bottle height and the continuity and patency of the irrigation tubing from the bottle to the eye. Understanding the roles of flow, vacuum, and power will allow the surgeon to make machine adjustments that vastly improve the surgical experience.

REFERENCES