Cataract Surgery: An Update on Basics and Surgical Tips

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Abstract
In this chapter, the basics of fluidics and ultrasound action are rehearsed, which are fundamental to better understand the challenges and solutions of all kinds of non-routine phacoemulsification cases. Specific properties of torsional ultrasound are explained, which give a better insight of the advantages of this ultrasound modality. Practical tips and tricks are provided to improve one's hydrodissection skills, soft lens removal and the pitfalls of posterior polar cataract. Hard cataracts and chop techniques are thoroughly discussed as well as small pupil management. Challenging situations such as mature and hypermature cataracts, floppy iris syndrome, weak zonules and last but not least posterior capsule rupture management are explained.

There are many textbooks on cataract surgery, which can help the reader understand cataract surgery technology and techniques in depth.

Basics Fluidics and Ultrasound

The key point in fluid dynamics during phacoemulsification surgery is that the fluid going into the eye should always exceed the amount of fluid going out of the eye at all times. If not, the anterior chamber shallows and the posterior capsule will move upward and potentially come into contact with the phacotip, which can result in a posterior capsule rupture.

The inflow is determined by the irrigation flow only; the hydrostatic pressure of the water column in the irrigation line until the level of the drip chamber underneath the infusion bottle is expressed in centimeters (bottle height). The resistance in the entire irrigation line including the narrow space between the sleeve and the phacotip determines the final irrigation flow: irrigation pressure/irrigation resistance.

When the phacotip is completely occluded, and no leak flow occurs through any of the incisions, one must be aware of the actual intraocular pressure. The entire fluid (water) column of the irrigation line presses in the eye. For instance, a
bottle height of 75 cm H₂O translates into 750 mm H₂O, and divided by the relative weight of mercury of 13.6 results in an intraocular pressure of approximately 55 mm Hg. Extreme bottle heights of 150 cm are used by some surgeons, which results in 110 mm Hg pressure when the tip is occluded (fig. 1)! One should be extremely cautious about utilizing bottle heights exceeding 100 cm which causes pressure spikes of more than 73 mm Hg.

Irrigation pressure is either passive with a bottle hanging above the level of the eye as described above, or is active by a pressurized system, which is not discussed in this chapter. With an active pressure system, the required pressure can be set on the machine in mm Hg.

Before discussing outflow, we have to understand the different pump systems of existing phacomachines: peristaltic pump systems and Venturi pump systems.

Peristaltic pumps consist of rollers which push fluid through a flexible aspiration tubing. The aspiration flow increases with the increasing speed of the rollers (fig. 2).

Venturi pumps create a vacuum in a rigid cassette by forcing gas through a pipe connected to the cassette. With more gas force blown through the pipe, higher vacuum is created in the cassette, which in turn attracts more fluid from the aspiration line (fig. 3).

The main difference between the two systems is that in Venturi pump systems, the vacuum and aspiration flow are directly linked to each other. One cannot set a high vacuum and a low flow. With a peristaltic pump, vacuum and aspiration flow can be controlled independently (fig. 4).

Outflow of the eye during phacoscary is more complex and consists of the following: aspiration flow, leak flow and surge flow.
As a cataract surgery specialist, I have a very specific preference for peristaltic pump systems. The ability to control vacuum and flow separately is essential for managing challenging cases for me. I am discussing fluidic dynamics in the peristaltic machine in the next paragraph.

**Aspiration Flow**
The speed of rollers in the cassette determines the aspiration flow and can be set on the machine in ml/min. Aspiration flow can only occur when the tip is not fully obstructed. When the phacotip is fully occluded, there is no flow. The actual flow passing through the aspiration line is dependent on the force of the phacopump pulling the fluid, and the total resistance in the aspiration line. Pump capacities and aspiration line lumen sizes vary among the available phacomachines. The preset values displayed on the machines do not necessarily occur in real time. A good example is that the aspiration flow at the same machine setting of e.g. 50 ml/min can be close to that value with a large bore phacotip of 0.7 mm and a normally large lumen aspiration tubing. In contrast, the preset value of 50 ml/min will not be reached through the very small 0.3-mm port of the I/A aspiration port opening. This can be easily less than half of that value, depending on the system specifications.

**Vacuum**
The vacuum which is displayed on the machine is the preset maximum level. When the tip is occluded, the pump rollers will continue to spin until the preset maximum vacuum level is reached. The time necessary to reach this maximum vacuum level (vacuum rise time) is dependent on the speed of the rollers (aspiration flow setting). The same high vacuum level can be reached either at a high speed/high flow setting or at a slower pace/low flow setting. The maximum vacuum level is lost when the tip occlusion breaks. This normally happens anytime when ultrasound is activated in footswitch position 3. Vacuum is only built up in footswitch position 2 when both irrigation and aspiration occur. (fig. 5).

Vacuum is the holding force of the machine, which keeps lens material at the tip to be emulsified and to pull the lens material through the aspiration line. There is always a debate about the required level of vacuum in phacosurgery. In essence, it can simplified by the following: high enough to do the job, but not too high because of one potential drawback. This ‘drawback’ phenomenon is ‘surge flow’.

**Surge**
The mechanism of surge flow only occurs at the moment of occlusion break and vacuum loss. It is a very brief moment in a fraction of a second, when the contracted aspiration line under vacuum suddenly springs back to its original shape and volume when vacuum is lost (fig. 6–9).
The severity of the surge flow is determined by the following factors:

- Vacuum; surge increases with higher vacuum
- Phacotip lumen; a smaller lumen will restrict the amount of fluid during the surge
- Sleeve size; a larger sleeve will allow more fluid into the eye during surge
- Infusion pressure; a higher bottle will push more fluid in the eye during surge
- Compliance of tubing; softer tubing material will contract more resulting in higher surge

Beware of Air!

When a significant amount of air is inadvertently aspirated, the post-occlusion surge response can be dramatically higher because air is much more compliant than fluid. The air in the aspiration line will enlarge significantly under vacuum. On occlusion break, the air will return to its original volume, markedly adding to the force of the surge. Air is easily aspirated when the phacotip is retracted from the eye while in footswitch position 2. This happens often, and many surgeons are unaware of the danger.

If air is aspirated inadvertently, one must place the phacotip in a fluid container and aspirate fluid until the air has emptied completely from the aspiration line.

Ultrasound

In phacoemulsification surgery, ultrasound designates the longitudinal or sideways displacement of a hollow metal phacotip at a frequency of approximately 28,000–40,000 Hz and an amplitude of approximately 0–140 μm. The direct impact of the metal tip has an emulsification effect on the lens. There is a debate whether cavitation plays an important role in phacosurgery. This is not discussed in this chapter.

Ultrasound energy dissipated in the eye can be derived from the phacotip stroke × frequency. On the various machines, ultrasound stroke is displayed in percentages with a maximum of 100%. One should know that ultrasound power settings cannot be compared between different manufacturers. In the table below, the tip stroke of earlier generation machines is shown. 20% power in one machine results in a twice or three times longer stroke than in another machine (fig. 10).
Ultrasound and Heat Production
The friction between a moving phacotip and the silicon phacosleeve induces a temperature increase, similar to rubbing hands when they are cold. The heat production is dependent on the following factors:
- Higher ultrasound power induces more heat
- Higher frequency induces more heat
- Higher duty cycle induces more heat (duty cycle is percentage ‘on time’/total time)
- Higher friction between tip and sleeve induces more heat (more pressure of tip against sleeve)

Ultrasound Modulation
Ultrasound modulation has been introduced for 2 reasons: reduction of heat and reduction of repulsion.

Repulsion is the unwanted effect caused by the forward stroke of longitudinal ultrasound, which not only emulsifies the crystalline lens, but also pushes the lens away from the tip.

A simple measure to limit the repulsive effect is to set a maximum power level during the quadrant removal step. This maximum power should be set at a level where the desired emulsification is taking place without significant repulsion (fig. 11, 12).

Ultrasound modulation can be managed in two different ways, both sharing pauses between pulses of ultrasound activation, during which the nuclear fragment can come back to the tip: pulse mode and burst mode.

In the pulse mode, the duty cycle (fig. 15) is preset on the machine, and the surgeon controls phacopower with the footswitch (fig. 13). In the burst mode, the ultrasound power is preset on the machine, and the surgeon controls the pause time between ultrasound bursts with the footswitch (fig. 14).

It is a matter of preference of the surgeon whether to use either mode. There are more sophisticated hybrid modes of ultrasound modulation available on modern phacomachines, which are beyond the scope of this chapter.

Torsional Ultrasound
Torsional ultrasound technology was introduced in 2006. The mode of action is very different from traditional longitudinal ultrasound. The slight oscillatory movement of the phacotip of a Kelman style bent tip induces a sideways movement of the tip end (fig. 16). The phacotip now acts as an ultra-
sonic chafing machine instead of the ultrasonic jackhammer of longitudinal ultrasound. The main difference is that the side to side movement of the tip does not have any repulsive effect, and therefore it is more effective than traditional ultrasound. Torsional ultrasound does not require ultrasound modulation because of the lack of repulsion.

Transversal Ultrasound
Transversal ultrasound is combined and simultaneous action of the phacotip. The movement is elliptical, partly sideways and longitudinal. This technology can work with straight design phaco-tips, but tends to be also more efficient with bent tips.

OZil Tips and Tricks
Torsional ultrasound has a completely different mode of action than longitudinal ultrasound, and one should understand a few tips and tricks to experience the advantages of this technology.

In contrast to longitudinal ultrasound, which continuously repels and repositions nuclear fragments, torsional ultrasound keeps the nuclear piece right at the tip and chafes of the surface of the fragment. New lens surface has to be presented to the tip end surface for continued emulsification. For this reason, the nuclear piece has to be free to turn and tumble to emulsify efficiently. If a piece of nucleus is somehow blocked in its movement by a capsulorhexis edge, neighboring quadrant, pupil edge or sticky viscoelastic, no new lens surface can get close to the tip and emulsification stops.

Another characteristic of torsional ultrasound is that it does not give the tactile feedback of vibration as longitudinal ultrasound. And below 50% amplitude, it is hardly audible (fig. 17). Sur-
geons can inadvertently step into foot position 3 without hearing or feeling the activated ultrasonic action, which immediately breaks occlusion (fig. 18). To overcome this problem, one can set a louder artificial ‘OZil’ sound on the Infiniti machine to become aware of the foot position 3 entry.

**Chop Setting**

For achieving a good grip of a nuclear piece for chopping or to get a firm hold of the first quadrant after cracking the nucleus, a special ‘chop’ setting can be helpful. This is an extra procedure step between ‘sculpt’ and ‘quadrant removal’. I personally recommend using longitudinal ultrasound in the pulse mode, which gives an instant tactile feedback when reaching foot position 3. I also recommend setting a high fixed vacuum, which allows the surgeon to keep a firm grip of the quadrant in the entire range of foot position 2 (fig. 19). My personal ‘chop’ setting (for the Infiniti machine only; fig. 20) is: pulse mode – longitudinal US only 40% fixed, 10% duty cycle, 3 pulses/s; vacuum 450 mm Hg fixed – aspiration flow 20 ml/min.

This procedure step is only to acquire a firm grip for chopping and/or pulling a quadrant to the middle of the eye. It is not suitable for emulsification of the quadrant! This should be performed with the next procedure step ‘quadrant removal’.

**Torsional Ultrasound and Viscoelastic Clearing**

Viscoelastic should be aspirated first to clear the space on top of the lens, prior to sculpting. Any viscoelastic can obstruct the phacotip when it drills in the lens, but dispersive viscoelastics are more sticky and should be cleared from the tip before starting to sculpt the lens. Most machines

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**Fig. 17. Sound volume.**

**Fig. 18. Footswitch action.**

**Fig. 19. Position 2.**

**Fig. 20. Chop setting.**
have a default pre-phacoprocedure step with a low ultrasound setting and moderate fluidics setting only to clear the viscoelastic. If the tip is not cleared, the tip can heat too much and unwanted wound damage can occur.

**Hydrodissection**

There is a consensus among ophthalmologists regarding the necessity of adequate hydrodissection prior to nucleus disassembly and emulsification. For phacochop and divide-and-conquer techniques, the lens must be completely mobilized to allow easy nucleus rotation. Hydrodissection should result in a fluid wave travelling completely across the posterior surface of the lens. This ensures that complete dissection of the lens from the posterior capsule has occurred. Hydrodissection cannulas of various designs are used to accomplish the dissection.

I have noticed that many colleagues do not intentionally separate the lens from the anterior capsule. If these connections are not adequately separated, the lens will be unable to rotate. In this chapter, I describe my method for dissecting anterior capsular connections. Residents in our clinic learn this method without significant difficulty. This is a simple and logical technique that many surgeons may already practice.

**Technique**

After a complete posterior fluid wave crosses the entire posterior surface of the lens (fig. 21), depress the nucleus, which will subsequently separate itself from the anterior capsule at approximately the 4- or 5-o’clock position (fig. 22, 24). As you press on the nucleus, fluid underneath the nucleus will shift to the opposite side. Next, depress the nucleus on the opposite side (fig. 23, 25). The nucleus can move a little posteriorly into the accumulated fluid pool, separating itself further from the anterior capsule. If the anterior capsule remains in position when the nucleus is pressed downward close to the anterior capsulorhexis edge (fig. 4), this means that the anterior capsule and lens have separated. If one observes this separation at opposite sides of the lens, the anterior connections should be sufficiently dissected to allow easy rotation.