Power modulations in new phacoemulsification technology: Improved outcomes

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Purpose: To evaluate the clinical outcomes of new phacoemulsification technology.

Setting: Oregon Eye Institute, Eugene, Oregon, USA.

Methods: After optimization of surgical parameters, patients were randomly assigned to cataract extraction with 1 of 4 phacoemulsification machines using new technology available within the past 1 to 2 years. Outcomes were compared with previously published results for these same machines obtained before the advent of the new technology.

Results: Improvements in effective phaco time, average phaco power, percentage of clear corneas, and 20/40 or better uncorrected visual acuity at the first postoperative visit were noted for most systems using new technology.

Conclusion: New phacoemulsification technology offers surgical advantages that translate into improved clinical outcomes.

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Phacoemulsification represents a complex interplay of various forms of energy with lens material (W.J. Fishkind, MD, et al. "The Physics of Phaco: The Physical Principles for Successful Surgical Outcomes," course presented at the American Academy of Ophthalmology joint meeting, Orlando, Florida, USA, October 2002). The forms of energy used to break up the cataract include (1) a jackhammer effect created as the needle physically impacts the nucleus, (2) an acoustic wave traveling in front of the advancing needle, and (3) cavitational energy, in which microbubbles are stripped out of solution.[1] The fluid wave and microbubbles move away from the phaco tip in conical fashion with annular spread from the direction of the bevel of the needle.

The mechanics of phacoemulsification depend on the relationships among ultrasonic energy, anterior chamber irrigation, flow rate, and vacuum extraction of lens material. The phacoemulsification handpiece includes 1 or more piezoelectric crystals that convert electric energy into mechanical energy.

Phaco power represents a combination of frequency and stroke length. The frequency is the speed of needle movement measured in cycles per second, or Hertz. The frequency is preset by the machine manufacturer and is usually not under surgeon control. In general, the preset frequency is between 27 kHz and 54 kHz (thousand cycles per second). The most efficient frequency for ultrasonic phacoemulsification is between 38 kHz and 48 kHz.

The stroke length represents the actual distance the phaco needle travels as it moves back and forth. The surgeon can control this value by selecting "surgeon control" on the panel and footpedal excursion.

Linear control of phaco power generally occurs in footpedal position 3. The power gradually increases

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until the full excursion is reached and the power setting on the machine represents the maximum power available.

Panel control of phaco power means that the setting on the machine panel is achieved instantaneously on entering foot position 3.

There is a direct relationship between increasing frequency, increasing stroke length, and the production of heat from friction. Because of the production of heat and the need to protect ocular tissues from heat damage, the phaco needle is covered with an irrigation sleeve. Balanced salt solution flowing in the irrigation sleeve carries away most of the heat produced around the needle. However, a small, tight incision increases the risk for incision burn. The risk for burn also increases when flow is interrupted during an occlusion. Various tips and irrigation sleeves have been designed to minimize wound burn.

Modulations of phaco power have been developed to reduce the risk for thermal injury and to increase efficiency. In pulse mode, the power is modulated to turn on and off a certain number of times per second (described as pulses per second, or pps). In pulse mode, there is linear power (%) but a fixed interval between pulses, resulting in 2 pulses/s in a 250 millisecond pulse (linear power) followed by a 250 millisecond pause in power followed by a 250 millisecond pulse, etc. The use of pulse mode reduces phaco power delivery by 50% and maintains a more stable anterior chamber. It also allows a firmer grasp on lens material and reduces chatter at the tip because vacuum builds between each pulse.

Burst mode is a power modulation that uses a fixed percentage of power (panel control), a programmable burst width (duration of power), and a linear interval between bursts. As the surgeon enters foot position 3, the interval between bursts is 2 seconds; with increasing depressions of the footpedal in foot position 3, the interval shortens until there is continuous phacoemulsification at the bottom of foot position 3.

To improve the safety and efficacy of phacoemulsification, manufacturers have introduced new technologies over the past 2 to 3 years. Before the introduction of these newer systems, we published a summary of our technique and outcomes using power modulations.[2] At the time, we believed we would not see improvement in these outcomes for quite a while. Nevertheless, we now report improved outcomes with 4 new phacoemulsification technologies.[3]

Patients and Methods

Four phacoemulsification systems were evaluated. For each system, a series of cases was performed to optimize operational parameters using newly available technology before data were collected. All surgery was performed by 1 surgeon (I.H.F.) using the same standardized technique previously reported[4] and briefly described below. In all cases, the same biometry techniques, intraocular lens (IOL) power calculation formulas, and surgical correction of preexisting astigmatism were used.

Keratometry was performed, and axial length, anterior chamber depth, and corneal white-to-white measurements were done with the IOLMaster (Carl Zeiss Meditec). Axial length measurements were evaluated for accuracy by judging the shape of the peak ("Chrysler Building" configuration) and the signal-to-noise ratio. Immersion ultrasound (Axis II, Quantel Medical) was used as a second check if there was greater than a 0.15 mm variation in axial length with 10 measurements per eye or a greater than 0.20 mm variation between the eyes. The comparison of measurements by these different techniques is helpful in determining the best measurement for use in IOL calculation.[5] Computerized corneal topography (EyeSys, Tracey Technologies) was used as a second check if the keratometry readings were more than 1.0 diopter (D) different from the refractive cylinder. In these cases, the simulated keratometry values from the topographer were used in the IOL calculation formula.

Astigmatism correction was done in all eyes with more than 1.0 D of with-the-rule or 1.5 D of against-the-rule astigmatism. Limbal relaxing incisions were used as described by Nichamin.[6] The Holladay IOL Consultant software package was used for IOL calculation and outcomes analysis. The Holladay 2 IOL calculation formula was used to select the power of the IOL for implantation.

The phacoemulsification technique used has been described.[2] Briefly, after a paracentesis was constructed and the aqueous was exchanged for a viscoelastic material comprising sodium hyaluronate 3%–chondroitin sulfate 4% with sodium hyaluronate 1% (DuoVisc®) by the soft-shell technique,[7] a 2.5 mm single-plane temporal clear corneal incision was made with a trapezoidal, differentially beveled diamond blade (3D Blade, Rhein Medical). After a continuous curvilinear capsulorhexis was created and cortical-cleaving hydrodissection and hydrodelineation were performed, phacoemulsification proceeded in the capsular bag with a horizontal or vertical chop technique. In the tables showing the parameters for each machine (Tables 1 to 4), the initial setting used for nuclear disassembly and extraction is described in the column labeled "Chop." Management of the epinucleus and cortex, facilitated by cortical-cleaving hydrodissection, usually allowed elimina-

Table 1. Parameters for NeosoniX. The tube top is first removed from the phaco sleeve.

Memory	Chop Advantec Pulse Mem 1	Trim Advantec Burst Mem 2	I/A Mem 2 Cortical Cleanup	I/A Mem 1 Viselastic Removal	Bimanual I/A
Power (%)	40	15	—	—	—
Flow (cc/min)	45	42 linear	25	40	18
Vacuum (mm Hg)	500 (linear)	350	500 (surge)	500 (surge)	300–325
Amplitude (%)	80	40	—	—	—
Threshold (%)	15	NA	—	—	—
Other	2 pps	Burst 50 m/s	—	—	—
Bottle height (inches)	110	110	110	110	Up to top

I/A = irrigation/aspiration; Mem = memory; pps = pulses per second
Tips: Use a 0.9 mm microflare straight ABS tip (rose) with purple sleeve with tube top out. Incision size is 2.5 mm. Use silicone I/A with blue sleeve with tube top out. Wet inside of sleeve before putting it on. Put sleeve hole just under aspiration port.

Table 2. Parameters for phaco burst.

Phaco Mode	Choo-Choo Chop (Flow)	US Epinucleus (Flow)	I/A	
			Vacuum	Viscoelastic Removed (Flow)
Power (%)	15 (fixed)	3 (linear)	—	—
Vacuum (mm Hg)	325–400 (linear yaw)	200–300 (linear yaw)	0–450 (linear)	500
Flow (cc/min)	46 (fixed)	42 (fixed)	—	25–40 (linear)
Mode	Burst 200 m/s	Pulses 3/sec	—	—
Bottle height (inches)	130	115	85	85

I/A = irrigation/aspiration; US = ultrasound; yaw = vacuum
Tips: Use blue handpiece and straight 30-degree thin tip (#8430, silver). Vacuum linear only on yaw. The ultrasound rise is 1. Absolute phaco time is the same as effective phaco time.

Table 3. Parameters for Sonic Wave.

Memory	Chop Sonic Random Pulse Mem 1	Trim Sonic Random Pulse Mem 2	Flip Sonic Random Pulse Mem 3	Cortical I/A Mem 3 (Bimanual)	Viscoelastic Removal Mem 4
Power (%)	55	55	55	—	—
Aspiration (flow rate, cc/min)	43	35	33	38 (18)	50
Vacuum (mm Hg)	500	300	200	550 (linear)	550 (linear)
Pulse mode	2	2	2	—	—
Bottle height (inches)	39	39	39	Way up	—

I/A = irrigation/aspiration; Mem = memory
Tips: Use silver 20-gauge 30-degree tip with blue sleeve. Can toggle between sonic and ultrasonic using the footswitch. (Do not try to store ultrasonic settings into memory 1, 2, or 3.)

tion of the irrigation/aspiration step and included trimming the rim of 3 quadrants of the epinucleus before the final quadrant was flipped. Tables 1 to 4 show the settings for these steps in the columns labeled "Trim," "Flip," and "Epinucleus". Several types of IOLs were used according to the characteristics of each case. All IOLs were placed in the capsular bag with the appropriate injection system.

Once the surgeon felt that the best possible performance of each system had been achieved, a series of consecutive cases was randomly assigned to surgery with 1 of the 4 systems and the data were recorded. Eyes with ocular pathology other than cataract, including previous keratorefractive surgery, were excluded from the evaluation. Primary outcome measures included effective phaco time (EPT), average phaco power, slitlamp examination of the cornea, and uncorrected visual acuity (UCVA) 2 to 24 hours after surgery. The reported finding of edema or striae specifically indicated the type of folds in Descemet's membrane characteristic of endo-

Table 4. Parameters for WhiteStar.

Memory	Sculpt Phaco 1	Chop Phaco 2	Trim Phaco 3	Flip Phaco 4	I/A Control: Cortical Cleanup I/A 1	I/A Control: Viscoelastic Removal I/A 2
Power (%)	60 (linear)	40/40 (linear)	20/20 (linear)	20/20 (linear)	—	—
Flow (cc/min) (unoccluded/occluded)	18 (panel)	36/36 (panel)	32/28 (panel)	28/22 (panel)	30 (panel)	40 (linear)
Vacuum limit/threshold (mm Hg)	30 (linear)	350/175 (panel)	200/50 (linear)	200/80 (linear)	500 (linear)	500 (panel)
Ramp	50	50	50	50	80	80
Mode (unoccluded/occluded)	WhiteStar CB	WhiteStar CL	WhiteStar CL	WhiteStar CL		
Other	Cont irrig	Cont irrig	Cont irrig	Cont irrig	Cont irrig	Cont irrig
Bottle height (inches)	30	30	30	30	30	30

Cont irrig = continuous irrigation; I/A = irrigation/aspiration

Program: Use Fine WhiteStar. Bottle height actually 6 inches higher with bottle extender in place. Bottle 21 inches from top of machine to drip chamber.

Tips: Start phaco at Chop Phaco 2 stage. Use straight 30-degree silver yellow sleeve (laminar flow) for phaco and I/A regular tip (not silicone). Foot pedal; right toggle, continuous on and off. Vacuum sound in all modes; foot pedal 5-25-65; reflux on left. Use Legacy or Staar vit.

thelial trauma from phacoemulsification and the resulting overlying epithelial microcystic edema.

Effective phaco time allows a comparison of outcomes using a particular phaco system. It is calculated by multiplying the total phaco time by the average percentage power used and represents how long the phaco time would have been if 100% power in continuous mode had been used.

The 4 new technologies evaluated are described below.

NeoSoniX Phacoemulsification

NeoSoniX technology (NeoSoniX with AdvanTec, Legacy, Alcon Surgical) represents a hybrid modality involving low-frequency oscillatory movement that can be used alone or in combination with standard high-frequency ultrasonic phacoemulsification. Softer grades of nuclear sclerosis can be completely addressed with the low-frequency modality, while denser grades require the addition of ultrasound.

In the NeoSoniX mode, the phaco tip has a variable rotational oscillation up to 2 degrees at 120 Hz. As with sonic phacoemulsification, this lower frequency does not produce significant thermal energy and thus minimizes the risk for thermal injury.

The Legacy can be programmed to initiate NeoSoniX at any desired level of ultrasound energy. Thus, the surgeon can use the low-frequency mode to burrow into the nucleus for stabilization before chopping by setting the lower limit of NeoSoniX to 0% phaco power. This approach works best with a straight tip, which acts like an apple corer to impale the nucleus. Alternatively, NeoSoniX can be initiated as an adjunct to ultrasound at the 10% or 20% power level. NeoSoniX is most efficacious as an adjunct to ultrasound, helping to reposition lens material at the tip and improving followability (Table 1).

Phaco Burst

Phaco burst mode (Millennium, Bausch & Lomb) uses enhanced software to provide fixed ultrasound power with the lowest frequency available (28.5 kHz). The burst range can be programmed from 80 to 600 milliseconds with an initial 1.2 second burst interval in footpedal position 3. The Millennium scroll pump allows increased versatility by emulating flow-based peristaltic systems or vacuum-based venturi systems. The Millennium dual linear footpedal allows simultaneous, independent control of aspiration and ultrasound. By increasing aspiration, the surgeon can draw material toward the phaco tip. Once occlusion is achieved, with or without the use of ultrasound to embed the tip, the surgeon can increase the vacuum to evacuate material, again with or without ultrasound assistance. Simultaneous linear management allows meticulous control with low power and low fluid consumption (Table 2).

Sonic Phacoemulsification

Sonic technology (Staar Wave, Staar Surgical) removes cataractous material without generating heat or cavitational energy by using sonic rather than ultrasonic technology. Its operating frequency, between 40 Hz and 400 Hz, is in the sonic rather than the ultrasonic range. In contrast to ultrasonic tip motion, the sonic tip moves back and forth without changing its dimensional length. The tip of an ultrasonic handpiece can exceed 500°C, while the tip of the Staar Wave handpiece in sonic mode barely generates any frictional heat. In addition, the sonic tip does not generate cavitational effects; thus, fragmentation takes place rather than emulsification or vaporization of material.

The same handpiece and tip can be used for both sonic and ultrasonic modes. The surgeon can alternate between the 2 modes using a toggle switch on the footpedal when more or less energy is required. The modes can also be used simultaneously with varying percentages of both sonic and ultrasonic energy. The same chopping cataract extraction technique can be used in both sonic and ultrasound modes with no discernible difference in efficiency.

The Staar Wave also improves anterior chamber stability with coiled SuperVac tubing, which increases vacuum capability to up to 650 mm Hg. The key to chamber maintenance is a positive fluid balance between infusion flow and aspiration flow. When occlusion is broken, vacuum previously built in the aspiration line generates a high aspiration flow that can be higher than the infusion flow. This results in anterior chamber instability. The coiled SuperVac tubing limits surge flow resulting from occlusion breakage in a dynamic way. The continuous change in the direction of flow through the coiled tubing increases resistance through the tubing at high flow rates such as upon clearance of occlusion of the tip. This effect only takes place at high flow rates (greater than 50 cc/min). The fluid resistance of the SuperVac tubing increases as a function of flow, and unoccluded flow is not restricted (personal communication, Alex Urich, Staar Surgical, March 2002)[8] (Table 3).

WhiteStar

WhiteStar (Sovereign, American Medical Optics) is a new power modulation within ultrasonic phacoemulsification that eliminates the production of thermal energy. Analogous to the ultrapulse mode familiar to users of carbon dioxide lasers, WhiteStar extrapolates pulse mode phacoemulsification to its logical limit. As the duration of the energy pulse is reduced, it eventually becomes less than the thermal relaxation time of ocular tissue. Thus, it is theoretically impossible to produce a corneal wound burn.

WhiteStar technology sets the stage for bimanual cataract extraction with the Sovereign phaco machine. The absence of thermal energy obviates the need for an irrigation sleeve on the phaco tip, permitting a smaller incision and allowing irrigation through a second instrument, such as an irrigating chopper, placed through the side port. With an incision for cataract extraction smaller than 1.5 mm, the challenge becomes the production of IOLs capable of insertion through ultrasmall incisions.

Olson and Packard report excellent results using a 21-gauge irrigating chopper and a 21-gauge bare phaco needle with the bimanual technique. Olson's study of cadaver eyes demonstrated that thermal injury does not occur even in the absence of aspiration with 100% for 3 minutes. Packard reports an absence of wound burns with excellent surgical ease and efficiency via incisions smaller than 2.0 mm (R.J. Olson, MD, "Safety and Efficacy of Bimanual Phaco Chop Through Two Stab Incisions with the Sovereign," R. Packard, MD, "Evaluation of a New Approach to Phacoemulsification: Bimanual Phaco with the Sovereign System Rapid Pulse Software," presented at the XIIIth Congress of the European Society of Ophthalmology, Istanbul, Turkey, June 2001).

Table 5. Effective phaco time and average phaco power compared with previously reported data.[2]

Technology*	EPT (s)	Average Phaco Power (%)
Legacy	11.51	15.0
NeoSoniX	1.50	6.5
Millennium	5.44	13.0
Phaco burst	3.10	8.8
Wave	2.85	7.2
Sonic Wave	3.95	7.6
Sovereign	2.65	2.0
WhiteStar	1.55	1.8

EPT = effective phaco time
*New technology appears under old technology in column 1.

WhiteStar technology has important advantages including improved safety and efficiency of cataract extraction, whether used in standard fashion or with the microphaco technique (Table 4).

Results

The Millennium phaco burst group included 18 eyes of patients with a mean age of 70.4 years. The mean grade of nucleus was 1.4.

The Staar Wave sonic group included 43 eyes of patients with a mean age of 76.0 years. The mean grade of nucleus was 1.9.

The Legacy NeoSoniX group included 46 eyes of patients with a mean age of 71.9 years. The mean grade of nucleus was 1.9.

The WhiteStar group included 18 eyes of patients with a mean age of 69.2 years. The mean grade of nucleus was 1.9.

There were no statistically significant differences between groups in the age of the patients or the grade of nucleus ($P = .08$ and $P = .10$, respectively; single-factor analysis of variance).

There were no intraoperative or postoperative complications.

Table 5 shows the EPT and average phaco power for each system compared with our previously reported data. Table 6 shows the percentage of clear corneas at the first postoperative visit. Table 7 shows the percentage of eyes with 20/40 or better UCVA at the first postoperative visit.

Table 6. Percentage of clear corneas at the first postoperative visit (at 2 to 24 hours).

Technology*	%
Legacy	90
NeoSoniX	98
Storz Millennium	91
Phaco burst	100
Staar Wave	95
Sonic Wave	95
Sovereign	88
WhiteStar	100

*New technology appears under old technology in column 1.

Table 7. Percentage of eyes with 20/40 or better UCVA at first postoperative visit (at 2 to 24 hours).

Technology*	%
Legacy	70
NeoSoniX	96
Storz Millennium	91
Phaco burst	100
Staar Wave	79
Sonic Wave	74
Sovereign	81
WhiteStar	94

*New technology appears under old technology in column 1.

Discussion

Any discussion of the relative merits of new phacoemulsification technology should be based on clinical outcomes. Engineers may argue the finer points of the relative contributions of cavitational and jackhammer effects; surgeons are more interested in getting the best results for their patients today. Therefore, our analysis of new technology is based on simple measures and clinically relevant outcomes. Limitations of this study include the lack of preoperative and postoperative endothelial cell counts, the absence of data on the efficacy of limbal relaxing incisions, and the long range of sampling times for the postoperative visit.

For NeoSoniX, phaco burst, and WhiteStar, new technology led to a reduction in EPT and improvement in the percentage of clear corneas and patients having a UCVA of 20/40 or better at the first postoperative visit. However, the percentages did not change from the Wave to the Sonic Wave. (The percentage of corneas without edema or striae was already quite high for this machine in its older ultrasonic mode.) This outcome is in agreement with our earlier published results of this technology.[9] Here, we echo our previous conclusion that the reduction in energy with sonic technology does not improve outcomes in healthy eyes with moderate-grade nuclear cataract, although it may reduce the potential for thermal injury or enhance outcomes in compromised eyes. These are areas for future research.

Although outcomes such as slitlamp examination and visual acuity may be fairly represented as comparative, we caution against using EPT and average power for drawing conclusions about the relative efficiency of different phaco machines. Here, we use these measures to evaluate newer technology as applied to 4 individual units. Because manufacturers may use different algorithms to calculate these quantities, comparison among different machines remains fraught with difficulty.

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