Use of power modulations in phacoemulsification

Choo-choo chop and flip phacoemulsification

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ABSTRACT

We used power modulations in addition to new technology available from 6 phacoemulsification manufacturers and altered our phacoemulsification techniques to take advantage of these technologies to significantly reduce the amount of ultrasound energy placed into the eye and enhance the rapidity and level of visual rehabilitation in patients. *J Cataract Refract Surg 2001; 27:188–197 © 2001 ASCRS and ESCRS*

In the late 1980s, as phacoemulsification was increasing in popularity, most phacoemulsification surgeons desired systems with increased power to address increasingly hard cataracts. In the 1990s, this became available, as did other important technical innovations such as high-vacuum tubing and cassettes, microprocessor controls integrated with central onboard computers, and downsized tips with better holding power and increased followability. In the late 1980s and early 1990s, Fine described 2 endolenticular phacoemulsification techniques: chip and flip[1] and chop and flip.[2] The techniques used the pulse mode to remove nuclear material, which decreased chattering and increased holding power of the nuclear material.

Many modulations in the delivery of power are now available. With these modulations, significantly less total ultrasound energy is delivered into the eye. In addition, the Allergan systems provide occlusion mode phacoemulsification, allowing for different parameters of percentage power, vacuum levels, and aspiration flow rate on tip occlusion compared to an unoccluded tip. The Alcon Legacy has a bimodal option that allows the surgeon to use linear aspiration flow rate or vacuum in foot position 2.

More recently, Fine described the use of the burst mode[3] and bevel down chop[4] techniques. Here, we describe the choo-choo chop and clip phacoemulsification technique.[5] This technique is designed to take maximum advantage of new technologies available with the following phacoemulsification systems: 20,000 Legacy (Alcon Surgical Inc.) (I.H. Fine, MD, "Choo-Choo Chop and Flip with the Soft-Shell Technique Is Safer and More Efficient," Ocular Surgery News, April 15, 1998), Diplomax (Allergan Medical Optics),[6] Sovereign (Allergan Medical Optics), Mentor, Storz Millennium (Bausch & Lomb Surgical), and Wave (Staar Surgical). These technologies include high-vacuum cassettes and tubing, multiple programmable features, and new tip designs. The result is enhanced efficiency, control, and safety. Parameters for each system are shown in Tables 1 to 6.

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Table 1. Parameters for the Alcon Legacy 20,000 system with performance option package (20 gauge tip).

	Mackool System Hi-Vac Memory Mode				Microtip Flared Tip ABS—Max Vac Memory Mode			
Parameter	**Chop Mem 1 Pulse**	**Trim & Flip Bimodal Mem 2 Pulse**	**Cortical I/A Mem 1**	**Viscoat I/A Mem 2**	**Chop Pulse Mem 1**	**Trim & Flip Bimodal Mem 2**	**I/A**	**Viscoat Removal**
Power (%)	50	35	—	—	40	30	—	—
Aspiration (flow rate, cc/min)	28/33	28/25	38	60	32/35	42/33	38	60
Vacuum (mm Hg)	350	200	500+	500+	500	300	500	500
Other	Pulse 2/sec Cont irrig	Surg asp Cont irrig	Cont irrig Surg vac	Cont irrig Surg asp	Pulse 2/sec Cont irrig	Surg asp Cont irrig	Cont irrig Surg vac	Cont irrig Surg asp
Bottle height (inches)	100	100	70	70	100	100	70	70

I/A = irrigation/aspiration; sec = seconds; Surg vac = (surgeon control of) linear vacuum; Surg asp = (surgeon control of) linear aspiration flow rate; Cont irrig = continuous irrigation

Table 2. Parameters for the Allergan Diplomax system (20 gauge tip).

	Hi-Vac/Chop and Flip			I/A Control Surg Vac Control	
Parameter	**Chop Phaco 1**	**Trim Phaco 2**	**Flip Phaco 3**	**Cortical Cleanup**	**Viscoat Removal**
Power (%)	60	60	60	—	—
Aspiration, continuous flow (cc/min)	26/30	32/26	32/16	10	30
Vacuum (mm Hg)	50/250	40/90	70/150	500	500
Mode	Cont burst Cont irrig	Cont burst Cont irrig	Cont burst Cont irrig	Cont irrig	Cont irrig
Bottle height (inches)	32	32	32	28	28

I/A = irrigation/aspiration; Surg vac = linear vacuum; Cont burst = continuous burst; Cont irrig = continuous irrigation

Surgical Technique

A side-port incision is made to the left with a 1.0 mm trifaceted diamond knife. The anterior chamber is then irrigated with 1/2 cc of preservative-free lidocaine hydrochloride (Xylocaine®). Using the soft-shell technique,[7] sodium hyaluronate 3.0%–chondroitin sulfate 4.0% (Viscoat®) is placed in the anterior chamber angle distal to the side port through the side-port incision. It fills the anterior chamber, but the eye remains relatively soft. Sodium hyaluronate 1.0% (Provisc®) is instilled on top of the center of the lens capsule under the Viscoat. The Provisc forces the Viscoat up against the cornea, creating a soft shell that helps stabilize the anterior chamber and protect the endothelium. The cohesive property of Provisc decreases the tendency for iris prolapse during hydrodissection and hydrodelineation.

After a temporal 2.5 × 2.0 mm clear corneal incision is made, cortical cleaving hydrodissection[8] is performed in the 2 distal quadrants. This is followed by hydrodelineation. The nucleus should now rotate easily in the capsular bag. The Mackool/Kelman aspiration bypass micro flare tip on the Legacy is introduced bevel down to aspirate the epinucleus uncovered by the capsulorhexis and is then turned bevel up. With other systems, an MST chop series SP tip (Microsurgical Technologies) or a 30 degree standard bevel-down tip is used throughout endonuclear removal.

A Fine/Nagahara chopper (Rhein Medical) is placed in the golden ring by touching the center of the endo-

Table 3. Parameters for the Allergan Sovereign system (20 gauge tip).

Parameter	Phacoemulsification			I/A Control	
	Chop Phaco 1	Trim Phaco 2	Flip Phaco 3	Cortical Cleanup I/A 1	Viscoat Removal I/A 2
Power (%)	40/40	20/20	20/20	—	—
Aspiration, unocc/occlus	30/34	30/26	28/22	30	40 (linear)
Vacuum limit/ threshold	375/190	150/20	150/80	500 (linear)	500
Other	Cont irrig Linear vac	Cont irrig Linear vac	Cont irrig Linear vac	Cont irrig Linear vac	Cont irrig Linear asp
Mode	Long pulse 2 pps	Long pulse 2 pps	Long pulse 2 pps	—	—
Bottle height (inches)	30	30	30	30	30

I/A = irrigation/aspiration; unocc = unoccluded; occlus = occlusion; Cont irrig = continuous irrigation; vac = vacuum; pps = pulses per second

Table 4. Parameters for the Storz/Bausch & Lomb Millennium Microflow system (20 gauge tip).

Parameter	Phaco Mode				I/A Viscoat
	Chop (Choo-Choo Chop Flow)	Chop (Soft Nucleus/ Small Pupil) (Choo-Choo Chop Vac)	Trim (Linear Vac)	Flip (Linear Flow)	
Power (%)	20	20	10	10	—
Vacuum (mm Hg)	275–375	115–200	140–225	225	550
Flow (cc/min)	34	—	28	25–32	—
Pulses (pulses/s)	2	2	2	2	—
Bottle height (inches)	95	90	90	90	80

Vac = vacuum; I/A = irrigation

nucleus with the tip and pushing it peripherally so that it reflects the capsulorhexis. The chopper is used to stabilize the nucleus by lifting and pulling toward the incision slightly (Figure 1), after which the phaco tip lollipops the nucleus in pulse mode at 2 pulses/second or at 80 milliseconds burst mode (Diplomax). The burst mode power modulation uses a fixed percentage power (panel control), a programmable burst width (duration of power), and a linear interval between bursts. As one enters foot position 3, the interval between bursts is 2 seconds; with increasing depressions of the foot pedal in foot position 3, the interval shortens until at the bottom of foot position 3, there is continuous phacoemulsification. In pulse mode, there is linear power (%) but a fixed interval between pulses, resulting at 2 pulses/second in a 250 millisecond pulse (linear power) followed by a 250 milliseconds pause in power followed by a 250 millisecond pulse, et cetera. However, in both modulations with tip occlusion, vacuum is continuous throughout the pulse and pause intervals. There is a decrease in cavitational energy around the tip at this low pulse rate or in burst mode. Thus, the tunnel in the nucleus in which the tip is embedded fits the needle tightly, allowing the surgeon to firmly grasp and control the nucleus as it is scored and chopped (Figure 2) in foot position 2.

The Fine/Nagahara chop instrument is grooved on the horizontal arm close to the vertical "chop" element; the groove is parallel to the direction of the sharp edge of the vertical element. When the nucleus is scored, the instrument is always moved in the direction the sharp edge of the wedge-shaped vertical element is facing (as indicated by the groove on the instrument). The nucleus

Table 5. Parameters for the Mentor system (20 gauge tip).

Parameter	Mode				
	Phaco 1 Chop Pulsed Mem 1	**Phaco 2 Trim Pulsed Mem 2**	**Phaco 3 Flip Fixed Phaco 2**	**I/A Cortex Linear Vac**	**I/A Viscoat Linear Asp**
Power (%)	50	28	10	—	—
Aspiration (cc/min)	22/28	20/18	26/20	26	40
Vacuum (mm Hg)	250	185	235	500	500
Other	2 pulse/sec Cont irrig	2 pulse/sec Cont irrig	Cont irrig	Cont irrig	Cont irrig
Bottle height (inches)	94	94	94	89	89

I/A = irrigation/aspiration; Vac = vacuum; Asp = aspiration; sec = seconds; Cont = continuous irrigation

Table 6. Parameters for the Staar Wave system (20 gauge tip).

Parameter	Memory				
	Chop Mem 1	**Trim Mem 2**	**Flip Mem 3**	**Cortical I/A**	**Viscoat Removal**
Power (%)	30	20	20	—	—
Aspiration (cc/min)	30	30	30	38	50
Vacuum (mm Hg)	350	250	180	Linear 550	Linear 550
Other	Cont irrig	Cont irrig	Cont irrig	Cont irrig	Cont irrig
Mode	Pulse 2/sec	Pulse 2/sec	Pulse 2/sec	—	—
Bottle height (inches)	46	46	46	—	—

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

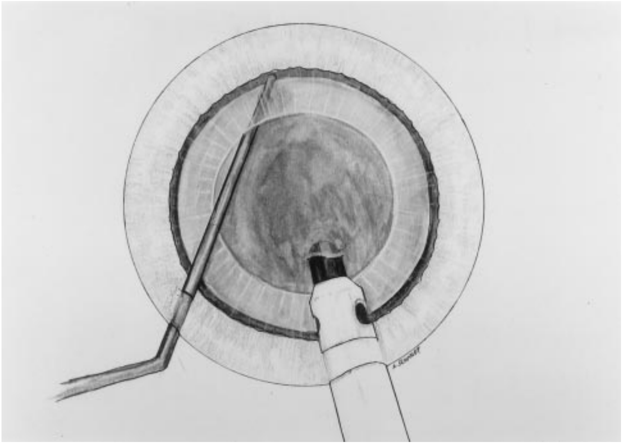

Figure 1. (Fine) The nucleus is stabilized during lollipopping for the initial chop.

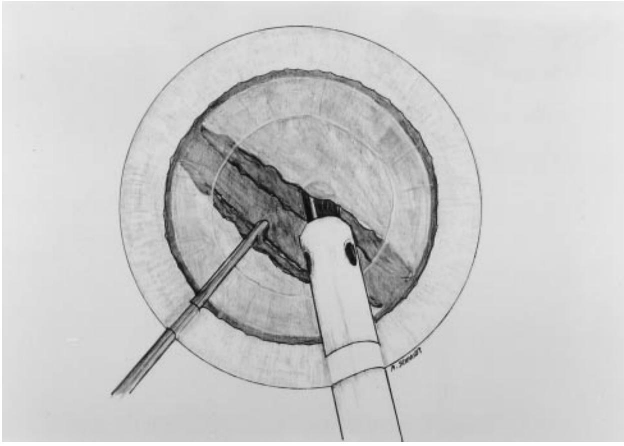

Figure 2. (Fine) The initial chop is completed.

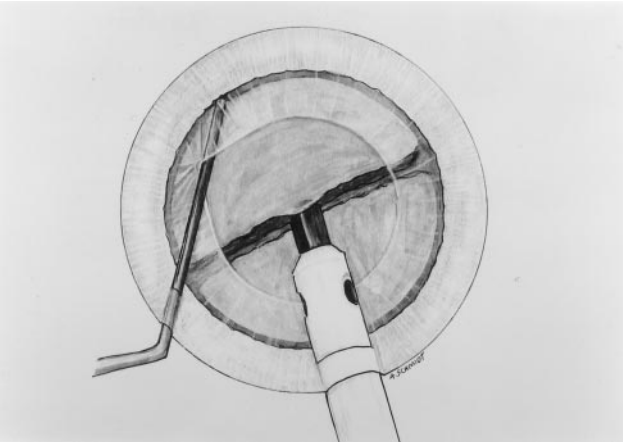

Figure 3. (Fine) The nucleus is stabilized before the second chop is commenced.

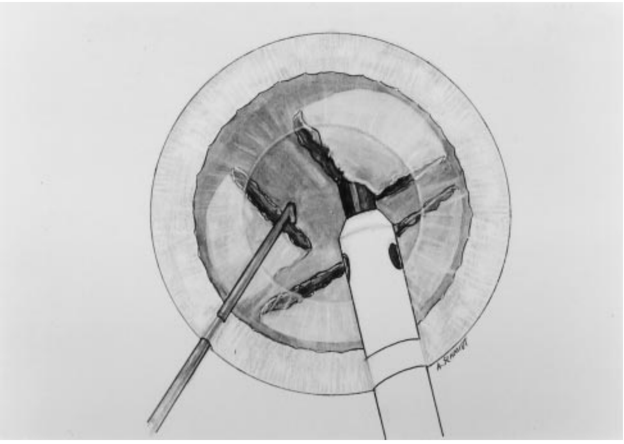

Figure 4. (Fine) A pie-shaped segment adheres to the phaco tip after the second chop is completed.

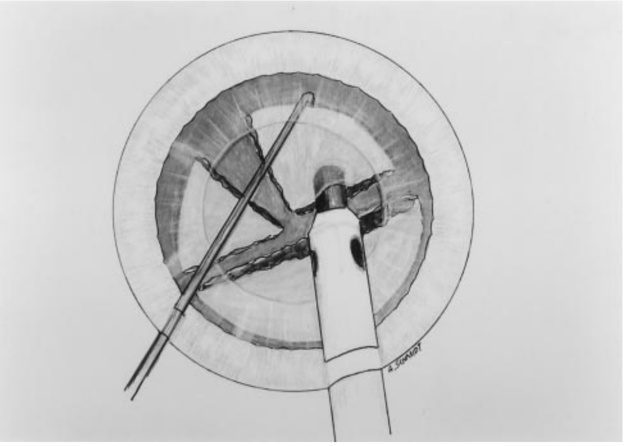

Figure 5. (Fine) The first pie-shaped segment is mobilized.

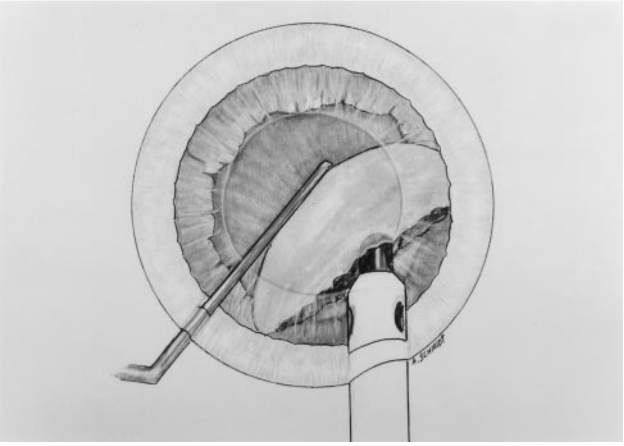

Figure 6. (Fine) The second heminucleus is scored.

is scored by bringing the chop instrument to the side of the phaco needle. It is chopped in half by pulling the chopper to the left and slightly down while moving the phaco needle, still in foot position 2, to the right and slightly up. Then the nuclear complex is rotated. The chop instrument is again brought into the golden ring (Figure 3), and the nucleus is again lollipopped, scored, and chopped. The resulting pie-shaped segment is then lollipopped on the phaco tip (Figure 4). The segment is evacuated using high vacuum and short bursts or pulse mode phaco at 2 pulses/second (Figure 5).

The nucleus is continually rotated so that pie-shaped segments can be scored, chopped, and removed essentially by the high vacuum assisted by short bursts or pulses of phaco. The short bursts or pulses of ultrasound energy continuously reshape the pie-shaped segments, which are kept at the tip, allowing for occlusion and extraction by the vacuum. The size of the pie-shaped segments is customized to the density of the nucleus, with smaller segments for denser nuclei. Phaco in burst mode or at this low pulse rate sounds like "choo-choo-choo-choo"; ergo the name of this technique. With burst mode or the low pulse rate, the nuclear material tends to stay at the tip rather than chatter as vacuum holds between pulses. The chop instrument is used to stuff the segment into the tip or keep it down in the epinuclear shell.

After evacuation of the first heminucleus, the second heminucleus is rotated to the distal portion of the bag and the chop instrument stabilizes it while it is lollipopped. It is then scored (Figure 6) and chopped. If they appear too large to easily evacuate, the

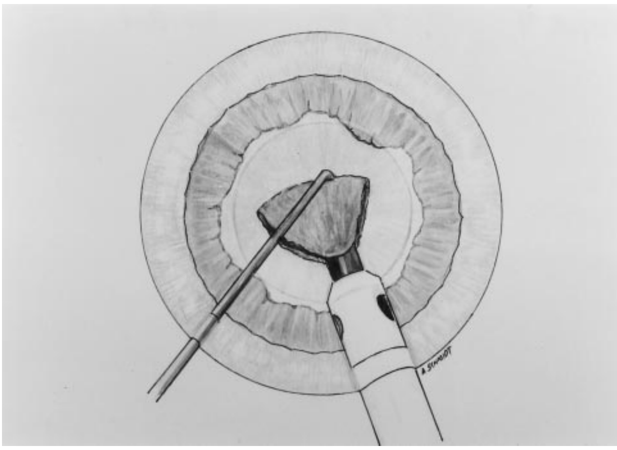

Figure 7. (Fine) The final quadrant is mobilized.

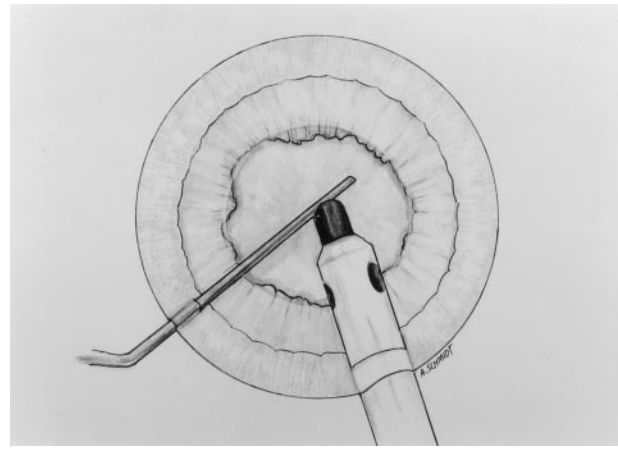

Figure 8. (Fine) The epinuclear shell is rotated for trimming.

pie-shaped segments can be chopped a second time (Figure 7).

Rather than coming up into the anterior chamber, the nuclear material usually stays within the epinuclear shell. However, the position of the endonuclear material can be controlled by the chop instrument. The 30 degree bevel-down tip facilitates occlusion as the angle of approach of the phaco tip to the endonucleus through a clear corneal incision is approximately 30 degrees. Full vacuum is quickly reached, which facilitates embedding the tip into the nucleus for chopping and mobilizes the pie-shaped segments from above. This prevents the need to go deeper into the endolenticular space, as when using a bevel-up tip. In addition, the cavitational energy is directed down toward the nucleus rather than up toward the endothelium.

After evacuation of all endonuclear material (the 30 degree tip is turned bevel up) (Figure 8), the epinuclear rim is trimmed in each of the 3 quadrants, also mobilizing cortex as follows: The distal rim and roof are purchased in foot position 2. Upon occlusion, the roof and rim are drawn central to the capsulorhexis and foot position 3 is entered. This mobilizes the roof and rim and clears the occlusion. As each quadrant of the epinuclear rim is trimmed, the cortex in the adjacent capsular fornix flows over the floor of the epinucleus and into the phaco tip. Then, the floor of the epinucleus is pushed back to keep the capsular bag on stretch and is rotated to bring a new quadrant of roof and rim to the distal position. This is repeated until 3 of the 4 quadrants of epinuclear rim and forniceal cortex have been evacuated. To prevent a large amount of residual cortex after evacuation of the epinucleus, the epinucleus must not be flipped too early.

The epinuclear rim of the fourth quadrant is rotated to the distal position (ie, nasally) and used as a handle to flip the epinucleus (Figure 9). As the remaining portion of the epinuclear floor and rim is evacuated from the eye, all cortex is evacuated with it in 70% of cases (Figure 10). Continuing with the soft-shell technique, the capsular bag is filled with Provisc. Viscoat is injected into the center of the capsulorhexis to help stabilize the anterior chamber and to blunt the movement of the foldable intraocular lens (IOL) as it is implanted. If the cortex is incompletely mobilized during epinuclear removal, Viscoat (rather than Provisc) is instilled to viscodissect the cortex into the capsular fornix and drape some of it on top of the capsulorhexis (Figures 11 and 12). Provisc is then injected into the bottom of the bag, forcing the Viscoat anteriorly. The foldable IOL is implanted. Residual cortex is evacuated with residual viscoelastic material, with the posterior capsule protected by the IOL optic. Mobilization of Viscoat is facilitated as it is encased within the more highly cohesive Provisc, and less time is necessary to evacuate residual viscoelastic material.

The choo-choo chop and flip technique uses the same hydro forces to disassemble the nucleus but substitutes mechanical forces (chopping) for ultrasound energy (grooving) to further disassemble the nucleus. High vacuum is used to remove nuclear material rather than using ultrasound energy to convert the nucleus to an emulsate that is evacuated by aspiration. This maximizes safety, control, and efficiency and allows for phacoemul-

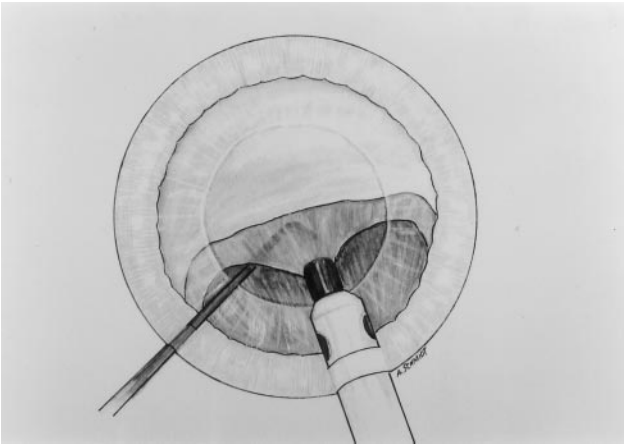

Figure 9. (Fine) The epinucleus is flipped.

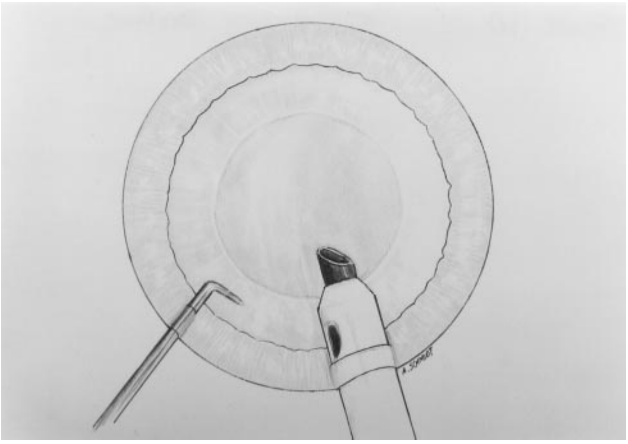

Figure 10. (Fine) After the epinucleus is flipped, the capsular bag is empty.

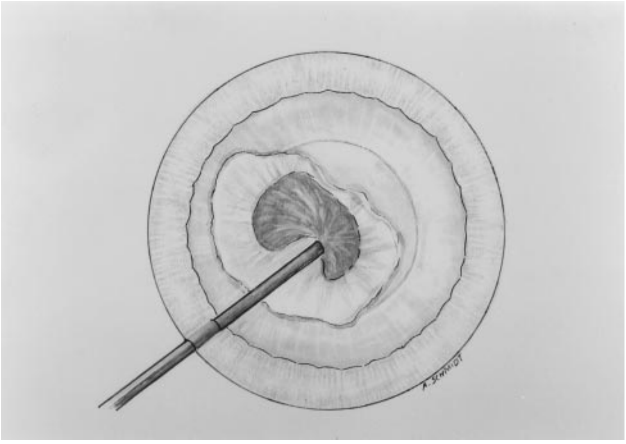

Figure 11. (Fine) Beginning viscodissection of residual cortex.

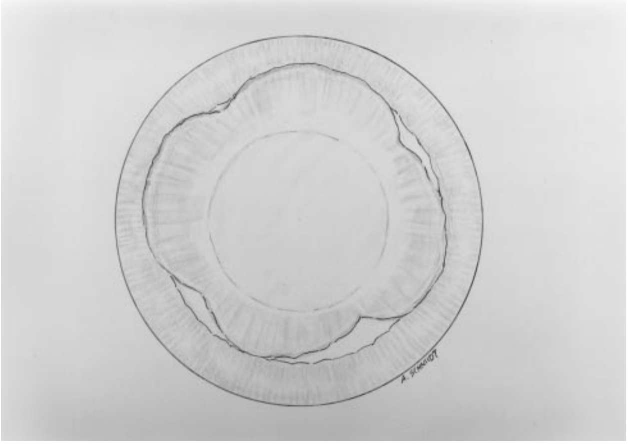

Figure 12. (Fine) Residual cortex is completely viscodissected before the IOL is implanted.

sification of harder nuclei in the presence of a compromised endothelium.

Patients and Methods

After the parameters for each phaco system were standardized, consecutive cases were evaluated for data collection. Cataracts with nuclei of all grades were emulsified. Most of the 4+ nuclei were assigned to the Legacy unit because the surgeon had the most experience with that system.

Figure 13 shows the age distribution of patients. Data were collected for 244 eyes. Figure 14 shows the grade of nuclear hardness for each eye on a scale from 0 to 4 (none = 0.0; trace = 0.5; 1+ = 1.0; 1 to 2+ = 1.5; 2+ = 2.0; 2 to 3+ = 2.5; 3+ = 3.0; 3 to 4+ = 3.5; 4+ = 4.0). Most nuclei were graded as 2+.

All surgery was performed by a single surgeon (I.H.F.). The effective phaco time was calculated, allowing comparison of phaco systems. Calculated by multiplying the total phaco time by the average percentage power used, the effective phaco time represents how long the phaco time would have lasted had 100% power continuous mode been used.

Results

Table 7 shows the systems used and the effective phaco times and average phaco powers. Table 8 shows the visual results. Twenty-six of the 244 eyes showed

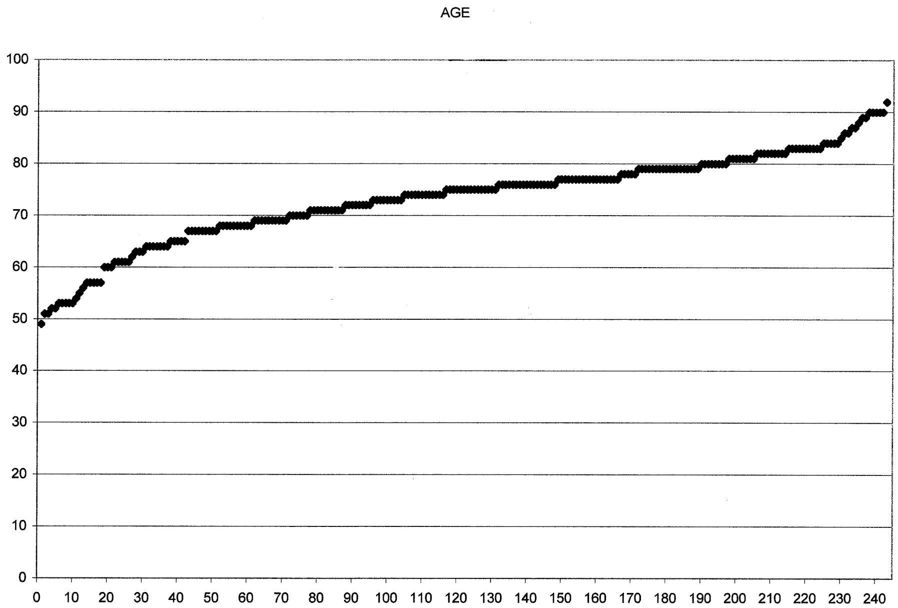

Figure 13. (Fine) Age distribution of patients.

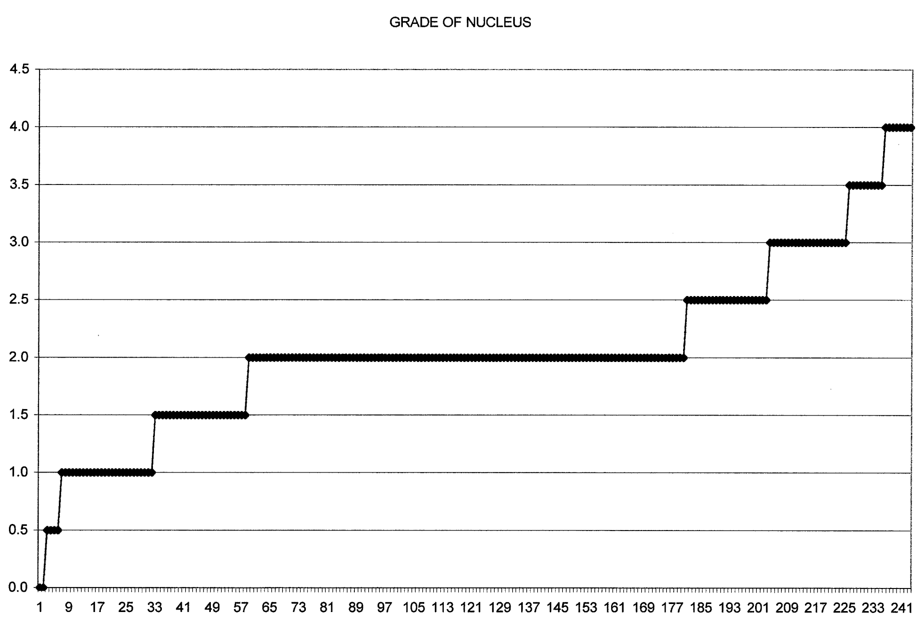

Figure 14. (Fine) Grade of nuclear hardness (244 eyes).

traces of corneal edema or striae. The average effective phaco time in this subgroup of eyes was 8.53 seconds compared with an overall average effective phaco time of 5.89 seconds.

Figure 15 shows the effective phaco time in seconds versus the grade of nucleus. Eight eyes with effective phaco times longer than 15 seconds were excluded from analysis. There was a slight increase in effective phaco time with grade of nucleus. Figure 16 shows the relationship between effective phaco time and postoperative uncorrected visual acuity (UCVA) between 2 and 24 hours after the completion of surgery. Twenty-one eyes were excluded from this analysis because of a postoperative UCVA of 20/100 or worse (13 eyes) or an effective phaco time longer than 15 seconds (8 eyes). There was a correlation between increased effective phaco time and decreased UCVA 1 day postoperatively.

Discussion

DeBray and coauthors[9] compared energy delivered to the eye with 2 phacoemulsification techniques using continuous mode phaco power with the Prestige system (Allergan). In eyes in which divide-and-conquer techniques with grooving and cracking were used, mean total ultrasound energy was 3264 J ± 1218 (SD). Using the same phaco system for chop techniques, the mean energy level decreased to 782 ± 44 J.

Table 7. Power modulation outcomes.

System	EPT (sec)	Avg % Power
AMO Diplomax*	16.36	60.0†
Legacy	11.51	15.0
Mentor*	7.50	8.4
Storz/B & L Millennium*	5.44	13.0
Staar Wave	2.85	7.0
Sovereign	2.65	2.0

EPT = effective phaco time; Avg = average
*Machines display effective phaco time
†Panel

Table 8. Power modulation outcomes 2 to 24 hours postoperatively.

System	No Edema or Striae (%)	UCVA 20/40 or Better (%)
AMO Diplomax	86	81
Legacy	90	70
Mentor	77	54
Storz/B & L Millennium	91	91
Staar Wave	96	79
Sovereign	88	81

UCVA = uncorrected visual acuity

Because frequency (megahertz) is arbitrarily set by the systems' manufacturers and energy levels differ among systems, we asked engineers at some companies to estimate the number of joules into the eye based on our average effective phaco time and average percentage phaco power measurements. These calculations indicated that the energy was in the range of single-digit joules (personal communications, D.D. Lobdell, PhD, Alcon Surgical, June 23, 2000; D. Casey, Storz/Bausch & Lomb, April 25, 2000; K.E. Kadziaukis, Allergan Surgical Products, April 17, 2000). Based on this information, we believe the use of power modulations reduces the total ultrasound energy into the eye to a small percentage of that used by DeBray and coauthors with chop techniques. We believe that this reduced energy has significant benefits including diminished injury and inflammation to surrounding ocular structures, more rapid visual rehabilitation, and better visual outcomes.

Conclusions

Using cortical cleaving hydrodissection and hydrodelineation, mechanical disassembly of the nucleus

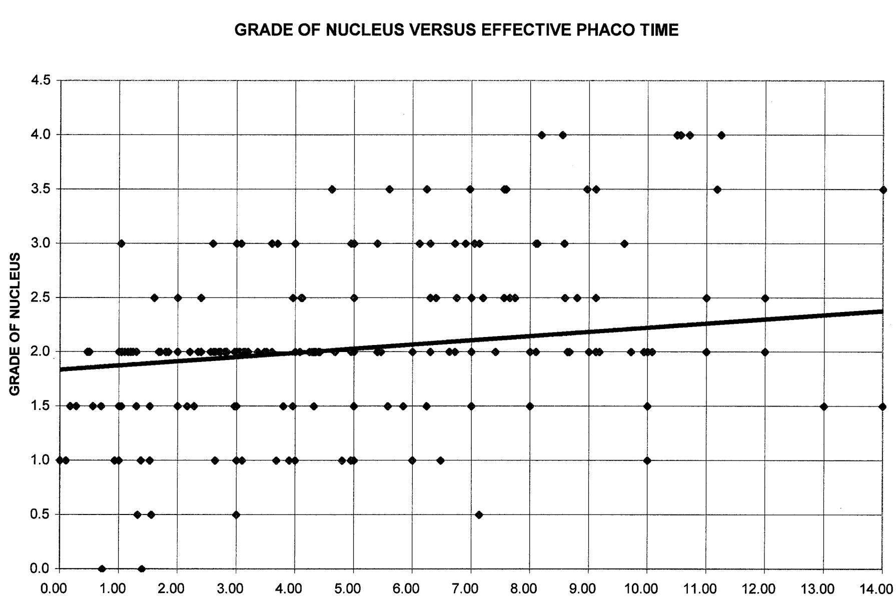

Figure 15. (Fine) Relationship of grade of nucleus to effective phaco time demonstrated by polynomial trendline.

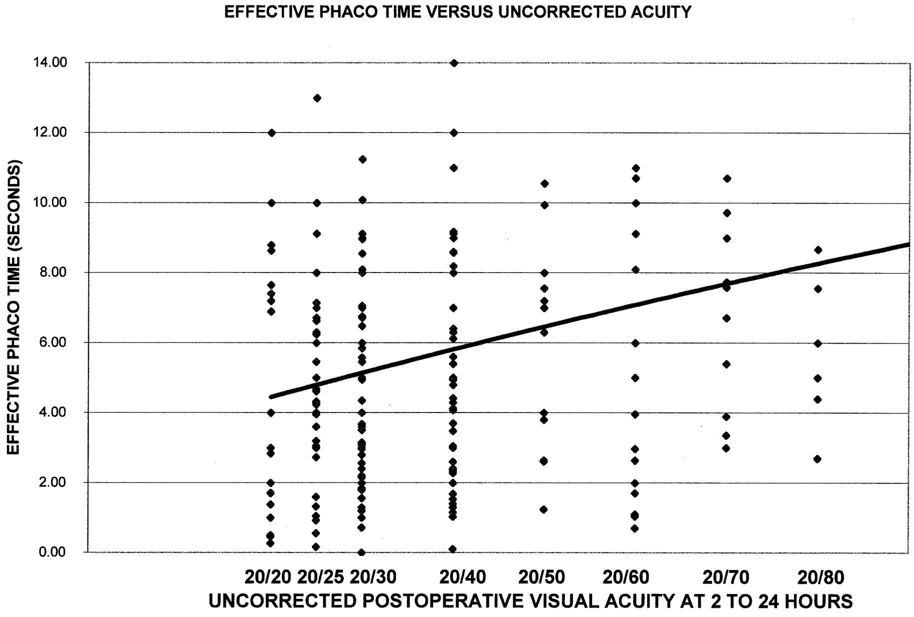

Figure 16. (Fine) Relationship of effective phaco time to postoperative UCVA demonstrated by polynomial trendline.

by chopping rather than grooving and cracking, vacuum extraction of nuclear material rather than emulsification and aspiration, power modulations, and low levels of average phaco powers, we achieved minimal disturbance of intraocular structures and maximized the rapidity and levels of visual rehabilitation.

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