The Evolution of Phacoemulsification

Struggling to achieve what we take for granted today.

BY I. HOWARD FINE, MD

This column is classic Howard Fine—complete in every way and written in a comprehensive, easy-to-follow style. I knew that Howard would tie together a lot of loose ends to bring readers of this column up to date on the ongoing evolution of cataract and refractive surgery.

Howard has many enviable characteristics: a keen, creative mind; a surprising love of motorcycling; profound modesty combined with wisdom and honesty; and an engaging, humble, yet persuasive manner. He is the vital link between the old guard of ophthalmology and the future generation of super surgeons.

—Herve M. Byron, MD, Section Editor

My engineering background has allowed me to help improve the technologies, techniques, and instrumentation used for cataract and lenticular refractive surgery. This experience has been one of the most exciting intellectual adventures anyone could have. In addition, the international friendships I have developed while teaching and traveling have been unbelievably rewarding (Figure 1).

With today's technology, young cataract surgeons effortlessly attack nuclei of all grades. They use clearly defined techniques for the safe and efficient emulsification of nuclei and are able to achieve excellent results in the immediate postoperative period. Few of them, however, know much about the recent history of cataract surgery or the names associated with the development of modern phaco techniques and technology. This article provides a brief review.

Figure 1. These international physicians traveled to Eugene in the mid-1990s to observe Dr. Fine at the Oregon Eye Surgery Center.

PIONEERS

Charles Kelman, MD, innovated phacoemulsification. He favored a one-handed procedure in the anterior chamber, because he believed it was most likely to be adopted by surgeons. Richard Kratz, MD, DSci, and James Little, MD, employed a second instrument and developed techniques for two-handed phacoemulsification. Dr. Kratz developed the technique that was most popular for about a decade: two-handed phacoemulsification in the plane of the pupil. This approach involved central sculpting of the nucleus and then prolapsing the superior equator of the lens into the anterior chamber. Robert Sinskey, MD, was the first to initiate one-handed phacoemulsification in the posterior chamber, a technique that involved sculpting a bowl out of the nucleus, aspirating the rim of the bowl, and emulsifying it.

William Maloney, MD, who completed a fellowship under Dr. Kratz, systematized the teaching of two-handed phacoemulsification in the pupillary plane with his "Three Steps to Phaco" courses. These offerings were responsible for convincing many of the early adopters of phacoemulsification to attempt the procedure.

The development of Healon (Pharmacia Corp.; now manufactured by Advanced Medical Optics, Inc., Santa Ana, CA) by Robert Stegmann, MD, and David Miller, MD, in the mid-1980s boosted phacoemulsification's popularity, and new viscoelastics were subsequently developed. Ophthalmic viscosurgical devices continue to be important tools for phacoemulsification. Many of their properties were exploited through the insights and teachings of Steve Arshinoff, MD.

EARLY CHALLENGES

The main barriers to performing phacoemulsification in the mid-1980s were hard nuclei and small pupils. Robert Osher, MD, was the first to share his excellent results with extracting hard nuclei in presentations at the annual ASCRS symposia.

For small pupils, most surgeons performed large, superior-sector iridectomies in order to gain access to the lens. Bradford Shingleton, MD, devised a technique of excising a crescent-shaped area of the superior pupil, thereby improving access to the lens but leaving a more cosmetically and physiologically functional pupil postoperatively than with previous methods. Iris hooks were perhaps first used by Dr. Reynolds to hold the pupil open during surgery. Later, Richard Mackool, MD, popularized the use of metal hooks, whereas other surgeons preferred nylon or Prolene hooks for the same purpose.

I developed a technique involving partial-thickness radial sphincterotomies, which ruptured fibrotic elements of the pupil and allowed me to stretch the residual muscular elements. In almost all cases, this method provided me with adequate access for phacoemulsification and resulted in physiologically functional, cosmetically appealing pupils postoperatively. A technique developed by Luther Fry, MD, for stretching the pupil in a single meridian was later altered and published by Kevin Miller, MD.

CAPSULORHEXIS

The can opener capsulotomy, developed and popularized by Drs. Little and Sinskey, was the standard for a long time, but it led to capsular tears out to the equator and haptics being prolapsed into the ciliary sulcus. In the early 1980s, Calvin Fercho, MD, began using tearing methods to create a relatively circular capsulotomy. Whether or not it was a complete capsulorhexis is the subject of great debate today, but he was probably the first to consider a circular-tear capsulotomy. Dr. Fercho is a forgotten hero. Thomas Neuhann, MD, later described the technique in more detail, and Howard Gimbel, MD, popularized it in the Americas.

ENDOLENTICULAR PHACO TECHNIQUES

The continuous curvilinear capsulorhexis dramatically altered phaco techniques, because the superior pole of the nucleus could no longer be prolapsed into the anterior chamber. As a result, surgeons developed a number of endolenticular phaco techniques. In 1973, Dr. Kelman demonstrated grooving the nucleus in the meridian of the incision and then cracking it. He brought each of the heminuclei up into the anterior chamber and emulsified them. He called this technique *divide and conquer*, and Dr. Gimbel later modified it by sculpting a bowl and cracking its rim. John Shepherd, MD, took this technique a step further with an in situ phaco fracture, in which he grooved the nucleus in perpendicular meridians, cracked it, and emulsified the four resulting quadrants. This technique later assumed the name *divide and conquer*.

I developed a method that involved hydrodelineation to divide a nucleus into an endonucleus and an epinucleus. Unbeknownst to me, this approach had been previously described by Michael Blumenthal, MD, for extracapsular cataract surgery. My technique was called *chip and flip*, and it involved sculpting the endonucleus to half its thickness (the chip) and elevating it into the anterior chamber with a second instrument for full emulsification. I then trimmed the epinucleus and flipped it for evacuation from the eye. Ultimately, Dr. Maloney, David Dillman, MD, and I published a technique called *crack and flip phacoemulsification*, which involved cracking the endonucleus within the protective epinuclear shell.

In 1993, Kinihiro Nagahara, MD, introduced chopping, which is now recognized as an extremely efficient way of disassembling the nucleus prior to emulsifying it. Although many surgeons performed prechopping with two hooks, Takayuki Akahoshi, MD, developed a forceps that facilitated prechopping and popularized the technique in Europe and Asia.

CORTICAL CLEAVING HYDRODISSECTION

During my work with Drs. Maloney and Dillman, I developed the technique of cortical cleaving hydrodissection. We ruptured the cortical/capsular connections during hydrodissection, thereby making cortical cleanup dramatically safer.

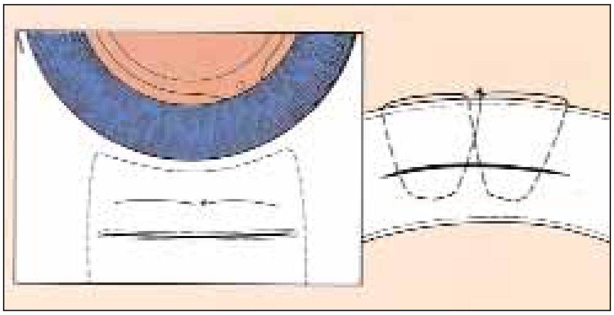

Figure 2. The infinity suture. (Reprinted with permission from Lee T. Nordan. Fine IH. The infinity suture. In: Nordan LT, Maxwell WA, Davison JA, eds. *The Surgical Rehabilitation of Vision*. London, United Kingdom: Gower Medical Publishing; 1992;20.1-20.4.)

FOLDABLE IOLs AND SUTURELESS INCISIONS

Foldable IOLs have a longer history than many ophthalmologists realize. In South Africa, Edward Epstein, MD, was using foldable IOLs at least 20 years prior to their introduction in the US. Thomas Mazzocco, MD, was perhaps the first to employ foldable, plate-haptic, silicone lenses in this country. This style of lens enabled phacoemulsification to achieve its real promise, rapid visual rehabilitation, because it dramatically reduced the amount of surgically induced astigmatism. I developed a number of forceps for folding and inserting IOLs through 4-mm incisions and later developed the bevel-down cartridge for injecting foldable IOLs.

In his “Three Steps to Phacoemulsification” courses, Dr. Maloney peformed scleral flap incisions as developed, taught, and popularized by Dr. Kratz and Louis Girard, MD. With foldable lenses, surgeons transitioned to what is now known as a *scleral tunnel incision*. Drs. Kratz, Girard, and Maloney all advocated entering through the clear cornea and leaving a so-called corneal shelf to avoid iris prolapse.

With brilliant insight, Dr. Shepherd began using a single, horizontal mattress suture placed tangential to the limbus to close scleral tunnel incisions. This suture lessened the vector forces on the cornea and dramatically reduced the amount of surgically induced astigmatism. Soon after his description of this type of single-stitch closure, I modified it for 6.5- to 7.0-mm incisions with my infinity suture (Figure 2). During the early years when foldable lenses were still in clinical trials and not available to most surgeons, the infinity suture allowed ophthalmologists to close large incisions with almost no induced astigmatism.

Michael McFarland, MD, was the first to recognize that a 4-mm scleral tunnel incision with a corneal shelf could seal itself. Subsequently, I came to believe that the scleral portion of the self-sealing scleral tunnel incision was not really necessary and developed what I called a *self-sealing corneal tunnel incision*. This technique later became known as the *clear corneal incision*, which I introduced at the ASCRS Symposium in 1992. (There was a history of clear corneal incisions prior to this time. Richard Troutman, MD, from the US, Dr. Stegmann in South Africa, Eric Arnott in England, and Kimiya Shimizu, MD, in Japan had all favored sutured clear corneal incisions.) One major advantage of operating through clear cornea was that the entire procedure could be performed through avascular tissue. As a result, patients on aspirin or other anticoagulants or those with blood dyscrasias became candidates for cataract surgery. I began to construct my clear corneal incisions in the temporal location, because it was farther from the visual axis and thus resulted in less flattening in that area than superiorly located incisions. Today, most surgeons operate temporally.

POWER MODULATIONS AND IMPROVEMENTS IN FLUIDICS

Power modulations have become important for phacoemulsification. Although pulse mode became available on many machines, Dr. Osher was the first to recommend reducing all of the parameters for slow-motion phacoemulsification, which he believed was much safer.

The MST Diplomax phacoemulsification machine (MicroSurgical Technology, Redmond, WA) was the first to offer a full menu of power modulations. I found burst mode to be especially efficacious for burying the phaco tip prior to chopping, because continuous phacoemulsification widens the tunnel and leads to an insecure "lollipopping" of the nucleus. I also found bevel-down phacoemulsification to be tremendously advantageous, because I could achieve vacuum rapidly, all of the energy was directed toward the lens, and I could mobilize nuclear material from the level of the capsulorhexis upward.

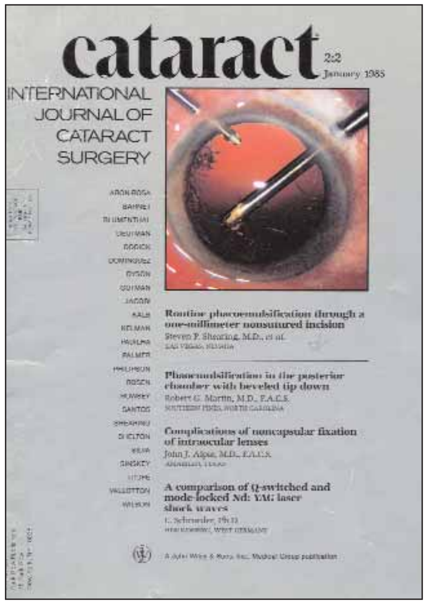

Figure 3. The cover of the *International Journal of Cataract Surgery*'s January 1985 edition demonstrated the early use by Steven Shearing, MD, of what would later be called *bimanual microincisional phacoemulsification*.

Phaco machinery has improved with better fluidic control, surge control, high-vacuum tubing, and other innovations in fluidics, including the dual-linear vacuum control on the Millennium phacoemulsification system (Bausch & Lomb, Rochester, NY). Barry Seibel, MD, was one of the first people to explain the phacodynamics of the phacoemulsification of cataracts in detail,[1] and the benefits of dual-linear vacuum have been taught widely by Graham Barrett, MD, and David Allen, BSc, FRCOphth.

Today, power modulations are primarily directed toward decreasing the energy delivered into the eye. Surgeons can disassemble nuclei by mechanical means (chopping) and extract them by high vacuum with mere nudges of ultrasound. My partners and I have been able to document that the best immediate postoperative visual acuities and clearest corneas are directly related to the lowest levels of phaco energy.[2]

Power modulations facilitated the recent change to bimanual microincisional phacoemulsification. This innovation was initially described in the early 1970s by J. P. Shock, MD, and Dr. Girard and was later discussed by Steven Shearing, MD (Figure 3); Tsutomu Hara, MD; Amar Agarawal, MD; Hiroshi Tsuneoka, MD; and Jorge Alió, MD, PhD. Power modulations led to a reduction in heat and allowed surgeons to use a sleeveless phaco needle through a 1.1-mm incision.

NEW TECHNOLOGY

In my own investigational studies, I have found that the AMO Signature phaco system (not available in the US; Advanced Medical Optics, Inc.) provides enhanced surgical control. It allows a coupling of occlusion-mode phacoemulsification (the ability to change parameters when going from an unoccluded to an occluded tip) with the vacuum surge control of Fusion Fluidics (Advanced Medical Optics, Inc.), which reduces vacuum prior to clearance of occlusion by reversing the pump in as little as 26 milliseconds. This machine also allows surgeons to use Venturi and peristaltic pumps for different portions of the same case.

Mikhail Boukhney developed torsional phacoemulsification for the Infiniti Vision System (Alcon Laboratories, Inc., Fort Worth, TX). This technology allows for ultrasonic oscillations of the system's bent phaco tip, which shears nuclear material and removes it without the repulsive force of translational phacoemulsification. This brilliant innovation moves away from high vacuum to a system of both lower energy and reduced vacuum.

REFRACTIVE LENS EXCHANGE

Surgeons are becoming increasingly accepting of refractive lens exchange, because of an enhanced ability to remove crystalline lenses efficiently and safely. The procedure was first described in the US by Paul Koch, MD, and Dr. Osher, who reported their results for clear lensectomies in high hyperopes at early ASCRS symposia. Joseph Colin, MD, later operated on a series of very high myopes, but a relatively high incidence of retinal detachment was noted by the 7th postoperative year due to his use of large-incision IOLs and a high rate of Nd:YAG laser posterior capsulotomies.[3]

By employing current techniques such as bimanual microincisional phacoemulsification or microincisional coaxial phacoemulsification (with an ability to maintain the anterior chamber and not "trampoline" the vitreous face) along with lenses that fill the capsular bag (such as dual-optic lenses and the Crystalens accommodating IOL [Eyeonics, Inc., Aliso Viejo, CA], which flexes posteriorly), ophthalmologists may see a reduction in the incidence of retinal detachment following lenticular surgery in high myopes.

CONCLUSION

We surgeons are now at the threshold of a tremendous shift in refractive surgery, away from the cornea and toward lenticular modalities, that allows us to address all refractive errors—hyperopia, myopia, astigmatism, and presbyopia. It is a great time to be practicing in our specialty. We have never had so much to offer patients. We stand on the shoulders of many who, in a relatively short period of time, have contributed to the techniques we take for granted today. ■

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