Converting Energy Into Innovation

The goal is the ongoing improvement of cataract surgery.

BY RICHARD J. MACKOOL, MD

In modern major league baseball, the relief pitcher has become as important as the starting pitcher. After the latter throws a predetermined number of pitches, the relief pitcher steps onto the mound with the aim of shutting down the opposition for the remainder of the game. For the phaco team, I would characterize Charles Kelman, MD, as the starting pitcher and Richard Mackool, MD, as the brilliant relief pitcher. Before Dick's intervention, the FDA was terribly close to halting the performance of the original phaco procedure due to dangerous side effects. By resolving the problems in the design of the first-generation phaco machines, he made the procedure safer and easier. His work eliminated the obstacles standing in the way of phacoemulsification's ultimate worldwide success. For those accomplishments, I believe that Dick deserves as much applause as my good friend Charlie.

—Herve M. Byron, MD, Section Editor

The template was already there, established by giants such as Charles Kelman, MD; Richard Kratz, MD; and Robert Sinskey, MD. Those of us who followed in their footsteps were charged with improving the pathway, rather than establishing one.

MY EARLY YEARS

I first became interested in engineering at the age of 14. My father and I took a 1953 Ford apart and put it back together. I learned about the miraculous conversion of energy, first from a liquid (gasoline) to gas and heat under the influence of electricity and then to kinetic energy that eventually resulted in a turning wheel. I was stunned by the wonderful series of transducers that converted one form of energy into another. I learned about the Venturi pump and the Bernoulli effect long before I knew the terms, because I saw them in action in that car's carburetor. I began to view the world as composed of shifting energy fields.

During my residency at the New York Eye and Ear Infirmary, I created the first vacuum corneal trephine in 1973 but later decided that it was not really necessary for the transplantation procedure. I became the director of resident training and completed a virtual corneal fellowship with the late, great Jorge Buxton, MD. In the early 1970s, most corneal transplants were performed on aphakic eyes. I began to perform mechanical open-sky vitrectomies as soon as the original vitrectors (Douvas, O'Malley) were designed. After Machemer et al reported the pars plana vitrectomy technique,[1] I began performing vitreoretinal procedures in 1975. I removed my first preretinal membrane for a macular pucker in 1976, unaware that Ronald Michels, MD, was doing likewise at the Wilmer Eye Institute in Baltimore. He published his cases before me.[2] Dr. Michels was a

"I first became interested in engineering at the age of 14. My father and I took a 1953 Ford apart and put it back together."

wonderful, immensely talented surgeon who died prematurely, and I am happy that he is recognized as the father of this procedure.

"The Ocusystem was ... the first machine to offer modulations of ultrasonic power."

THE OCUSYSTEM

I had a thriving corneal and vitreoretinal practice by the late 1970s, when I was approached by Anton Banko, a brilliant mechanical engineer who had been in charge of research and development at Cavitron. He and Dr. Kelman had co-designed the first phaco instrument, and Mr. Banko had then left Cavitron to establish his own business, Surgical Design Corporation. He had created a unique vitrectomy instrument and hoped that its fluidic advances would permit the safe removal of cataracts with vacuum levels as high as 500 mm Hg. I demonstrated that the instrument was ineffective and advised him that the profession really needed a special instrument that combined the capacity for phacoemulsification and vitrectomy in a single console. I invited my former resident and dear friend, Buol Heslin, MD, to join our efforts. The result of this collaboration was the Mackool/Heslin Ocusystem.[3] Introduced in 1980, the machine allowed surgeons to perform phacoemulsification and vitrectomy from an anterior or pars plana approach. The technology featured a host of other major fluidic and ultrasonic breakthroughs.

The first generation of phaco machines had a number of deficiencies. For example, the cataract incision had to leak like a sieve around the phaco tip in order to prevent wound burn. I was struck by the contrast with pars plana vitrectomy, in which the tight incisions and stable IOPs permitted precise manipulation. To seal the phaco incision, I designed a rigid (metallic) infusion sleeve that was concentric with the phaco tip. Because it was impossible for this tip to contact the vibrating needle, there was no friction between the two and no possibility of burning the incision. The surgeon could therefore elevate the infusion bottle without increasing flow through the eye. As a result, the incidence of postocclusion hypotony (surge) and shallow chambers decreased. Mr. Banko, Dr. Heslin, and I also took steps to decrease compliance in the aspiration portion of the system and added another first, fluid venting, that allowed us to use vacuum of 250 mm Hg or more—radically high levels at that time for phacoemulsification. These advances made the procedure much more efficient.

The Ocusystem was also the first machine to offer modulations of ultrasonic power. Not only could it automatically deliver pulses of ultrasound whenever the system detected occlusion at the phaco tip, but it also interrupted the tip's vibration whenever the machine sensed a break in occlusion.

ADVANCES IN INFUSION SLEEVES

In 1991, I was contacted by Storz. The surgical company's engineers had created a Venturi-based ultrasonic system (the Storz Premier), and they were having terrible problems controlling the aspiration flow rate. The machine was therefore dangerous, and the company asked if I could resolve the issue. I agreed and subsequently designed a flared phaco tip with a shaft that tapered both internally and externally, thereby restricting flow to levels that were easily manageable with a vacuum-based Venturi pump. At the same time, I found a better mechanism by which to seal the phaco incision.

A disadvantage of my design for a metallic infusion sleeve was the extreme tension it placed on the ocular tissues surrounding the incision. As a result, forward or reverse motion of the phaco tip would automatically move the globe in the same direction. The only way to avoid the problem was to maintain the globe's position forcibly with a second instrument such as a spatula

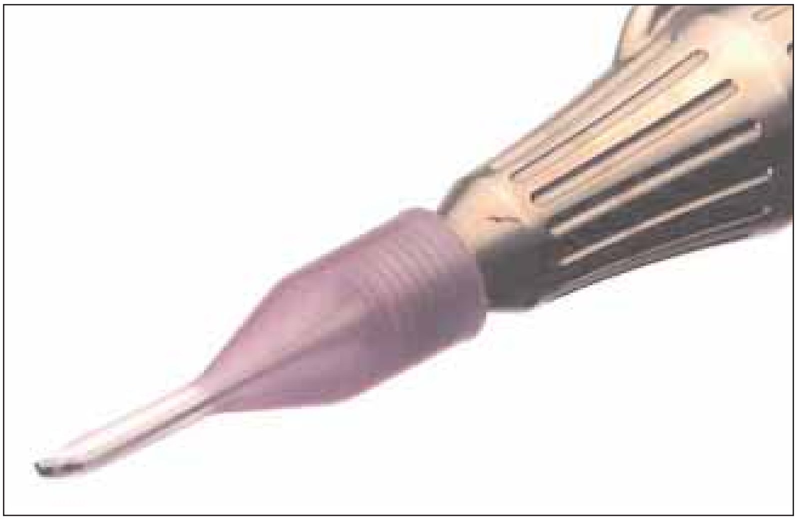

Figure 1. The angulated flared phaco tip.

placed through a sideport incision. I therefore placed two sleeves on the newly designed flared tip: (1) an inner sleeve made of a rigid polymer with a low coefficient of friction and (2) a standard silicone sleeve to surround the inner one. The rigid inner sleeve minimized the risk of wound burns, while the outer silicone sleeve deformed easily into an elliptical shape that did not greatly distort or place tension on the incision. The phaco tip was introduced as the MicroSeal phaco handpiece on the Storz Premier in 1992. The tip's small size allowed surgeons to perform phacoemulsification through a 2.5-mm incision.

> "I believe that the best IOL is one that can be safely replaced in the future by the next advance in IOL technology."

The dual-sleeved technology was added to the Legacy platform from Alcon Laboratories, Inc. (Fort Worth, TX), as the Mackool System in 1996. Shortly thereafter, the company asked me to help create its Infiniti Vision System, which was introduced in 2004. Alcon's engineers and I realized that one of the platform's features, the NeoSoniX oscillatory device, vibrated at a frequency that was far too low to fragment lenticular material efficiently. They then designed the remarkable torsional phaco system introduced in 2005 that features an ultrasonic oscillation rate of 32 KHz.

ADDITIONAL CONTRIBUTIONS

I have been fortunate to make other contributions to ophthalmic surgery during my career. They include the method of stromal hydration[4] in 1976, simultaneous phacoemulsification and vitreoretinal surgery in 1980,[5] the aphakic technique[6] to calculate IOL power in eyes with corneal or other abnormalities that preclude the accurate measurement of axial length in 1983, and the use of iris retractors to enlarge the pupil during cataract surgery in 1990.[7] I also assisted in the design of the first acrylic IOL[8] and inserted it in 1990, described infusion misdirection syndrome[9] during phacoemulsification in 1993, performed the first endocyclophotocoagulation procedure at the time of phacoemulsification in 1994, co-developed and inserted the first prismatic IOL[10] for age-related macular degeneration in 1996, invented the angulated flared phaco tip (Figure 1) in 2000, and developed the Cataract Support System[11,12] for phacoemulsification in the absence of adequate zonular support in 2002.

In 2006, I reported that removing lens epithelial cells from the inner surface of the anterior capsule[13] greatly facilitated future IOL exchange. The work is important, because I believe that the best IOL is one that can be safely replaced in the future by the next advance in IOL technology in order to provide patients with the most desirable visual function.

CONCLUSION

In 2005, my son R. J. was observing me as I performed viscodissection in an eye with a congenital posterior polar cataract, and he felt the step should be a part of cataract surgery in every eye. Two years later, we reported the results of our controlled study.[14] Viscodissection prior to phacoemulsification had reduced our rate of posterior capsular tears from 0.8% to 0.1%!

Our joint publication is now my favorite and most gratifying. It reminds me of working on that 1953 Ford with my dad. ■

Section Editor Herve M. Byron, MD, is Clinical Professor for the Department of Ophthalmology at the New York University School of Medicine in New York. Dr. Byron may be reached at (212) 249-8494; hervembyron@gmail.com.

Richard J. Mackool, MD, is the director of The Mackool Eye Institute and Laser Center in Astoria, New York. He is a consultant to Alcon Laboratories, Inc., and Impex, Inc. Dr. Mackool may be reached at (718) 728-3400 ext. 256; mackooleye@aol.com.

1. Machemer R, Buettner H, Norton EW, Parel JM. Vitrectomy: a pars plana approach. *Trans Am Acad Ophthalmol Otolaryngol.* 1971;75(4):813-820.
2. Kenyon KR, Michels RG. Ultrastructure of epiretinal membrane removed by pars plana vitreoretinal surgery. *Am J Ophthalmol.* 1977;83(6):815-823.
3. Mackool RJ, Heslin KB, Banko A. Combined phacoemulsification and close pars plana vitrectomy capability in a single computerized instrument. *J Am Intraocul Implant Soc.* 1980;6(4):377-378.
4. Mackool RJ. Stromal hydration [letter]. *Cataract & Refractive Surgery Today.* February 2007;7(2):13.
5. Mackool RJ. Pars plana vitrectomy and posterior chamber intraocular lens implantation in diabetic patients. *Ophthalmology.* 1989;96(11):1679-1680.
6. Mackool RJ, Ko W, Mackool R. Intraocular lens power calculation after laser in situ keratomileusis: aphakic refraction technique. *J Cataract Refract Surg.* 2006;32(3):435-437.
7. Mackool RJ. Small pupil enlargement during cataract extraction. A new method. *J Cataract Refract Surg.* 1992;18(5):523-526.
8. Mackool RJ. New foldable IOL designed to use smallest possible incision. *Ophthalmology Times.* July 1, 1988; pp 1,39.
9. Mackool RJ, Sirota M. Infusion misdirection syndrome. *J Cataract Refract Surg.* 1993;19(5):671-672.
10. Mackool RJ. Prismatic IOL for macular degeneration. *EyeWorld.* March 1998; pp 26-27.
11. Mackool RJ. Phaco technique with loose zonule—capsule support system. In: *Ophthalmic Hyperguide.* Thorofare, NJ: Slack, Inc.; April 2001.
12. Mackool RJ. Cataract support system stabilizes capsule in patients with weak zonule. *Ocular Surgery News.* April 1, 2003;21(7):44.
13. Mackool RJ, Mackool RJ Jr. Removal of lens epithelial cells to delay anterior capsule-intraocular lens adherence. *J Cataract Refract Surg.* 2006;32(10):1766-1767.
14. Mackool RJ, Nicolich S, Mackool R Jr. Effect of viscodissection on poterior capsule rupture during phacoemulsification. *J Cataract Refract Surg.* 2007;33(3):553.