The Science of Ophthalmology

The study of engineering informed one surgeon's approach to the eye.

BY PAUL H. ERNEST, MD

Paul Ernest, MD, is one of the most soft-spoken, understated, and innovative ophthalmologists I know. Whenever he speaks or writes, he carefully chooses every word to convey his latest contribution to the evolution of modern cataract and refractive surgical procedures. He fills the role of the unspoiled, upbeat ophthalmologist in spite of the mounting financial stress on us all. —Section Editor Herve M. Byron, MD

My father was an engineer at Ford Motor Company (Dearborn, MI) and encouraged me, his oldest son, to follow in his footsteps. I had been strong in math and science in high school, but mechanical engineering was not my interest. I chose to pursue science engineering at Northwestern University in Evanston, Illinois, as part of a cooperative program; I studied for 6 months of the year and then returned home to work at the Ford Motor Company for 6 months. This arrangement also helped me to pay my way through school, and it taught me a lot about setting up experiments and designing studies to test ideas.

As I entered my fourth year of college, I realized I was not excited about a career in engineering. After talking to my fraternity brothers, who were all in pre-med, I chose to pursue medicine. I broke the news to my father, who at first thought I was joking and then became concerned at my changing direction so late in my college career. Unfortunately, he passed away in 1986, before he could see how my early training in engineering influenced my work in ophthalmology.

WOUND CONSTRUCTION

I began ophthalmic practice in 1978. My interest in wound construction was piqued by the work of Norman Jaffe, MD, on preventing the sliding of the cataract incision, which produced against-the-rule astigmatism. In 1984, I developed a trapezoid incision for my intracapsular and extracapsular cataract extractions as a way of increasing vertical support of the wound and decreasing its sliding.[1]

John Sheppard, MD, introduced the idea of a horizontal closure for tunnel incisions in the late 1980s as a means of minimizing induced astigmatism. I used his technique but found it problematic. My results on the first postoperative day were excellent, but my patients called on the second day after surgery with a complaint of blurry vision due to microbleeding from the tunnel incision into the anterior chamber. In all but one case, the droplets of blood disappeared spontaneously in a few days. Richard Kratz, MD, and Louis Girard, MD, began creating a corneal shelf during cataract surgery. I followed their lead and found that a corneal shelf prevented both microbleeding and the formation of cystic blebs, which often developed inside cataract incisions and raised the risk of infection.

Michael McFarland, MD, introduced the concept of sutureless cataract surgery in 1990. He made the outer portion of the incision smaller than its internal part as a way of preventing leaks. I added the corneal component I was already using to his configuration. My incision was approximately 6.0 mm long, 3.0 mm wide at its outermost aspect and 4.5 mm long at its innermost part. The "oarlock" was terrible as I forced instrumentation through the incision. I was nevertheless convinced that a corneal component was essential to achieving a watertight sutureless cataract incision.

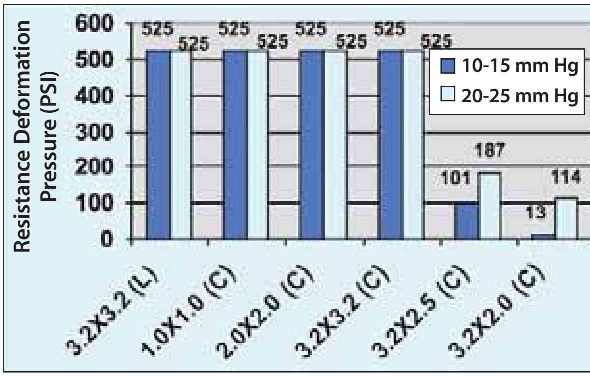

Figure 1. The author's research demonstrated that geometrically square incisions offered the most resistance to deformational pressure independent of their location. Rectangular incisions provided significantly lower resistance to deformational pressure and depended on the IOP.[4,5] (Note: The incisions' dimensions are given in millimeters.)

Because I was using foldable IOLs manufactured by Allergan, Inc. (Irvine, CA), I availed myself of the company's laboratories to perform studies in cadaveric eyes. I met with the graphics department, and we devised the three-step incision.[2,3] Next, I contacted my future partner, Kevin Lavery, MD, who was doing his fellowship at the Kresge Eye Institute in Detroit. In laboratories there, we inflated cadaveric eyes with fluid and used pressure gauges to determine how different cataract incisions withstood increases in IOP. The only ones that did not rupture or leak had an internal corneal lip. I presented our findings at the ASCRS meeting in 1991.[4]

Critics questioned the relevance of our findings for external pressure. In further studies, I found that square incisions with a 1.5-mm corneal component were the strongest (resisting external pressures of up to 525 psi) (Figure 1). I presented the results at the ASCRS meeting in 1992 and published them thereafter.[5] Additional vector analysis demonstrated that a square incision induced only 0.25 D of cylinder.[6]

At the same time that I was presenting these findings, however, other surgeons were promoting clear corneal incisions and gaining a lot of attention. Based on my research, I did not believe that these wounds could be stable. I conducted further studies in cadaveric and animal eyes and showed that the integrity of avascular, rectangular corneal incisions depended utterly on the IOP and that they leaked with low external pressure[7,8] (Figure 2). Clear corneal incisions improved when they became narrower and technology advanced (eg, the development of cartridge delivery systems).

To me, the fact that a cataract incision works is not more important than its *margin of safety*. My research showed that a wound must be stable (whether due to its architecture or the placement of a suture or glue) to allow fibroblasts to seal it. In addition, in order to seal properly, the ocular tissue must return to its original configuration after it has stretched during surgery. Unlike the cornea, the limbus and sclera have elastin, so incisions located there can stretch to accommodate instrumentation without becoming distorted. I performed feline studies at Wills Eye Hospital in Philadelphia with Richard Tipperman, MD, and Ralph Eagle, MD, along with Chris Kardasis, MD, at the Kresge Eye Institute. Our results showed that incisions made in vascular (eg, limbal) tissue heal in 7 days, whereas those created in avascular (eg, corneal) tissue heal in 30 to 60 days[9] (Figure 3). I therefore favor a square limbal incision. Moreover, it is for the reasons that I have outlined that I believe that clear corneal incisions have a lower *margin of safety*, which correlates with the rising number of incidents of endophthalmitis. My views on clear corneal incisions have, of course, generated controversy.

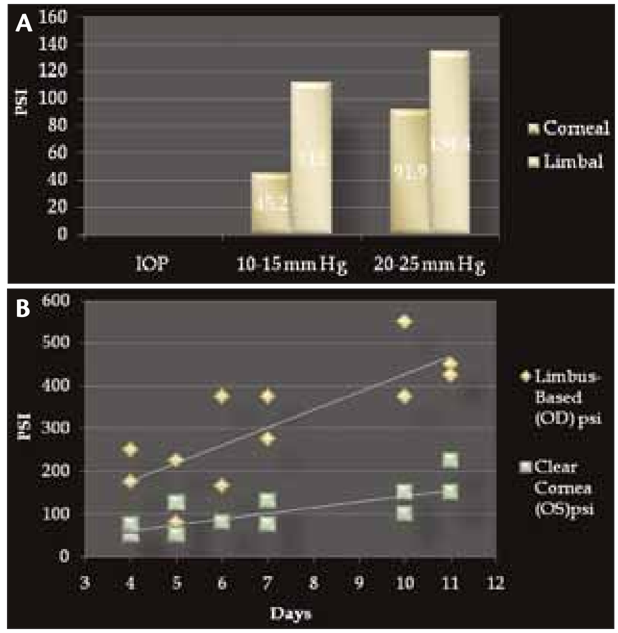

Figure 2. The same 3.00 X 1.75-mm corneal and limbal incisions in cadaveric (A) and feline (B) eyes. In a side-by-side comparison, the clear corneal incision's resistance to deformational pressure was the same in the cadaveric eye as on postoperative day 4 in the feline eye. These results implied that the endothelial pump did not stabilize the wound and that fibroblasts were not present to seal the incision. In contrast, on postoperative day 4, the limbal incision made in the feline eye offered more than two times greater resistance to deformational pressure than the same incision in a cadaveric eye due to fibroblastic activity.[6-8]

CATASTROPHIC WOUND BURNS

Like many other surgeons, I encountered catastrophic wound burns during cataract procedures between 1990 and 1995. The complication usually occurred in cases of dense cataract. Surgeons would refill the anterior chamber with a viscoelastic, reinsert the handpiece, move to foot position 3, and fry the incision. In rabbit models, Marcus Rhem, MD, and I found that simultaneously blocking irrigating flow and aspiration caused the temperature at the site of the incision to rise to approximately 250ºF in less than 2 seconds—so fast that no surgeon could react in time to prevent a burn. I presented these findings at the ASCRS meeting in 1997 but was unable to publish them for another 4 years for political reasons.[10] Ultimately, however, the studies helped in the defense of ophthalmologists who were sued after cases of severe wound burn.

Manufacturers and surgeons responded to the problem with a variety of measures. Companies created aspiration bypass systems as well as burst and pulse modes. Richard Mackool, MD, began to use two sleeves on the phaco needle to prevent thermal injury.

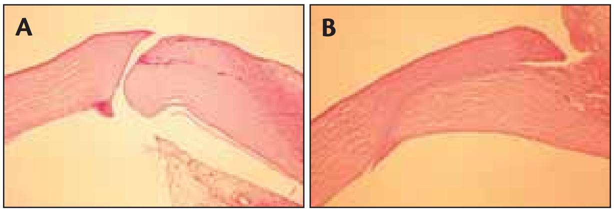

Figure 3. Seven days postoperatively, there is no sign of fibroblastic activity at the site of this corneal incision (A). In contrast, fibroblasts have completely sealed this limbal incision 7 days after surgery (B).[9]

DYSPHOTOPSIA

In 1995, I became interested in how Johnny Gayton, MD, and Joel Shugar, MD, piggybacked IOLs in order to improve patients' near vision by increasing their depth of focus. I began working with this technique as well and immediately found myself on a conference call with Drs. Gayton and Shugar and a researcher at the IOL's manufacturer regarding the formation of a membrane between the lenses that decreased patients' visual acuity. Unfortunately, it was impossible to separate and fold the IOLs for explantation. The complication was causing capsular ruptures and necessitating vitrectomies.

Although none of my 70 patients had developed the interlenticular membrane, I knew that they would in time. I used a YAG laser to remove the entire anterior lens capsule of every eye in which I had piggybacked IOLs. I theorized that, as the lens epithelial cells proliferated in the equator of the bag, they would migrate anteriorly rather than between the IOLs. I was right. More than that, I made two interesting discoveries.

First, patients with piggyback IOLs were experiencing a hyperopic shift due to the compression of the acrylic lenses upon contraction of the capsular bag. I found that the YAG treatment restored my patients' ability to read, provided they had perfect macular function.

Second, I noticed that none of my patients experienced any photic phenomena despite the exposed polished edges of their IOLs. I recalled this observation in 2005 when one of my partners consulted me about a patient with 20/15 visual acuity but severe photic phenomena after cataract surgery. I advised him to implant a second IOL in the sulcus, on top of the first lens. This measure eliminated the problem.[11] Since then, I have found that a secondary lens implanted in the sulcus effectively neutralizes negative dysphotopsias 100% of the time. The technique is not always effective in cases of positive dysphotopsias, however, for unknown reasons.

AGE-RELATED MACULAR DEGENERATION

The current focus of my research—on which I am collaborating with my vitreoretinal associate, Carmelina Gordon, MD—is the visual rehabilitation of patients with age-related macular degeneration (AMD). Those with significant central scotomata struggle with available low-vision aids, which magnify objects but narrow the field of vision. This telescopic effect means that they will see two letters at a time and must remember each pairing as their eyes move until they can piece together the word. Reading becomes a tiring and frustrating experience.

Richard Mackool, MD, had the idea to implant the AcrySof Restor IOL (Alcon Laboratories, Inc., Fort Worth, TX) in the eyes of patients with AMD, because the lens provides a wide field of vision. Expanding on this concept, Johnny Gayton, MD, began targeting a postoperative refraction of -2.00 D, which creates an add power of 5.20 D and a working distance of approximately 10 inches. I started using the IOL in September 2006 for eyes with AMD as well. The results are often amazing in these legally blind patients, and the only downside has been that the technique may not work. Dr. Mackool, Dr. Gayton, and I are compiling our data and hope to publish our results soon. Because so many patients with AMD are pseudophakic, however, my hope is that manufacturers will develop and market multipiece IOLs in powers ranging from plano to +3.00 D and that Medicare will cover the cost of the surgery. ■

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